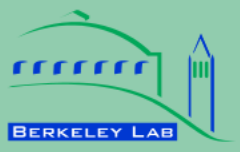

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Business Case for Energy Efficiency in Support of Climate Change Mitigation, Economic and Societal Benefits in China

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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.

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 relative to the base case as calculated in this way is often referred to as "economic savings potential".

Chinese energy demand has grown dramatically over the last few decades. While heavy industry still plays a dominant role in greenhouse gas emissions, demand from residential and commercial buildings has also seen rapid growth in percentage terms. In the residential sector this growth is driven by internal migration from the countryside to cities. Meanwhile, income in both urban and rural subsectors allows ownership of major appliances. While residences are still relatively small by U.S. or European standards, nearly all households own a refrigerator, a television and an air conditioner. In the future, ownership rates are not expected to grow as much as in other developing countries, because they are already close to saturation. However, the gradual turnover of equipment in the world's largest consumer market provides a huge opportunity for greenhouse gas mitigation. In addition to residences, commercial floor space has expanded rapidly in recent years, and construction continues at a rapid pace. Growth in this sector means that commercial lighting and HVAC will play an increasingly important role in energy demand in China.

The outlook for efficiency improvement in China is encouraging, since the Chinese national and local governments have implemented significant policies to contain energy intensity and announced their intention to continue and accelerate these. In particular, the Chinese appliance standards program, first established in 1989, was significantly strengthened and modernized after the passage of the Energy Conservation Law of 1997. Since then, the program has expanded to encompass over 30 equipment types (including motor vehicles). The current study suggests that, in spite of these efforts, there is significant savings to be captured through wide adoption of technologies already available on the Chinese market. Potential impacts of this adoption include:

<u>Energy savings:</u>

- 490 billion kWh per year in 2020
- 1010 billion kWh per year in 2030
- A total of 10,000 billion kWh cumulatively through 2030

Cumulative greenhouse gas emissions mitigation:

- 7730 million metric tons of CO_2 through 2030
- 26 million metric tons of SO_2 through 2030
- 33 million metric tons of NO through 2030
- 1650 metric tons of mercury through 2030

Financial impacts to consumers through 2030:

- Equipment investment of 350 billion USD
- Energy bill savings of 1200 billion USD
- Net savings of 846 billion USD

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. Early in 2011, the Chinese government announced a plan to reduce carbon dioxide emissions intensity (per unit GDP) by 16% by 2015 as part of the 12th five year plan. These targets are consistent with longer term goals to reduce emissions intensity 40-45% relative to 2005 levels by 2020. The efforts of the 12th FYP focus on short-term gains to meet the four-year targets, and concentrate mainly in industry. Implementation of cost-effective technologies for all new equipment in the buildings sector thus is largely complementary to the 12th FYP goals, and would provide a mechanism to sustain intensity reductions in the medium and long term. 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:

Residential End Uses

Incandescent Lamps
Refrigerators
Residential AC (Including Heat Pumps)
Washing Machines
Fluorescent Ballasts
Electric Water Heaters
Standby Power
Induction Ranges
Gas Ranges
Gas Water Heaters
Gas Boilers

Commercial and Industrial End Uses

Commercial Room AC
Commercial Lighting
Commercial Gas Boilers (Space Heating)
Commercial Gas Water Heaters
Industrial Motors
Distribution Transformers

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

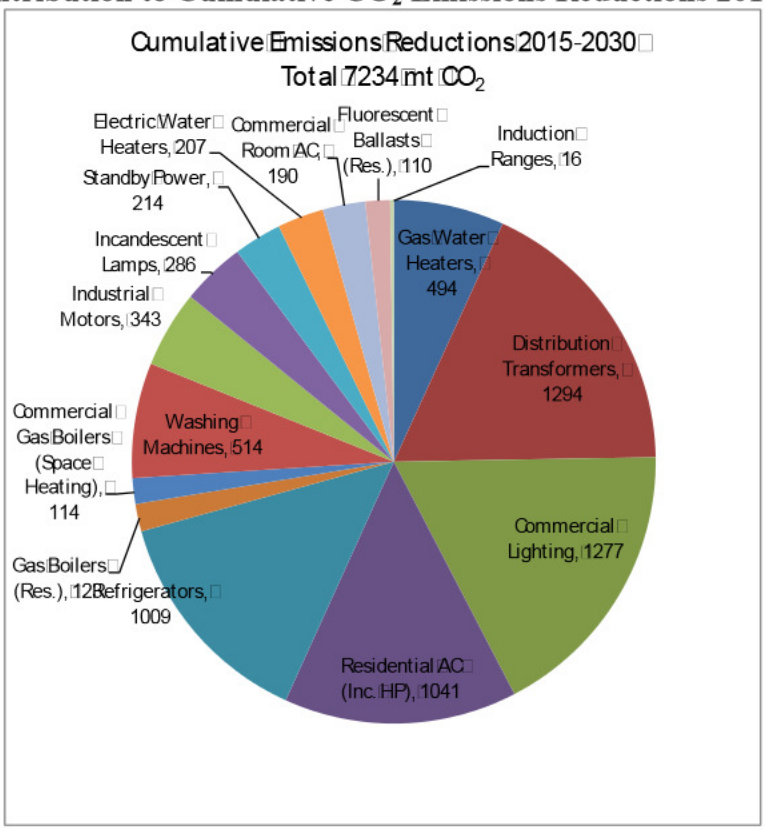
Table ES-1 – Energy Savings and Pollutant Mitigation by Appliance Group

Appliance Group	Final Energy Savings			Emissions Mitigation					
	In 2020	In 2030	Through 2030	In 2020	In 2030	Through 2030			
	TWh			mt CO2		mt CO_2	mt SO_2	mt NO	t Hg
Gas Water Heaters	118	255	2448	24	52	494	6.2	8.1	403.9
Distribution Transformers	57	148	1273	60	146	1294	3.2	4.2	210.1
Commercial Lighting	63	121	1249	66	119	1277	3.2	4.1	206.1
Residential AC (Inc. HP)	57	90	1020	60	89	1041	2.6	3.4	168.3
Refrigerators	49	100	991	51	98	1009	2.5	3.3	163.5
Gas Boilers (Res.)	26	75	607	5	15	123	1.5	2.0	100.1
Commercial Gas Boilers (Space Heating)	32	49	567	7	10	114	1.4	1.9	93.5
Washing Machines	25	50	505	27	49	514	1.3	1.7	83.3
Industrial Motors	14	40	338	15	40	343	0.9	1.1	55.8
Incandescent Lamps	10	38	282	11	38	286	0.7	0.9	46.5
Standby Power	12	20	210	12	19	214	0.5	0.7	34.6
Electric Water Heaters	12	17	203	12	17	207	0.5	0.7	33.5
Commercial Room AC	11	14	185	11	14	190	0.5	0.6	30.5
Fluorescent Ballasts (Res.)	7	9	108	7	9	110	0.3	0.4	17.7
Induction Ranges	1	2	16	1	2	16	0.0	0.1	2.6
Total	494	1028	10001	368	717	7234	26	33	1650

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 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, emission reduction potential is well distributed among end uses and sectors. The largest potential exists for commercial lighting, residential air conditioning and distribution transformers, each of which could provide over 100 TWh of electricity demand reduction in 2030 and over 1000 mt CO_2 over the forecast period. Savings in commercial lighting is possible due to the prevalence of magnetic ballasts for fluorescent lamps, which can be replaced with electronic ballasts. Air conditioning savings includes reduction of heating energy from reversible models (heat pumps). Finally, distribution transformers 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. Much of the remaining mitigation potential comes from major appliances such as refrigerators and washing machines. Significant savings can be gained from replacement of gas and electric water heaters with solar water heating systems, which already have a significant market share in China.

Table ES-2 – Cumulative Financial Impacts of Efficiency Improvement

Appliance Group	Cumulative Financial Impacts				
	Cost	Savings	Net Savings	NPV @ 3% DR	NPV @ 7% DR
	Billions USD				
Commercial Lighting	25.0	242	217	145	88.0
Distribution Transformers	7.7	220	212	137	79.7
Refrigerators	45.6	144	98.5	64.3	37.8
Gas Water Heaters	52.1	116	63.8	41.5	24.4
Residential AC (Inc. HP)	96.6	148	51.8	34.2	20.4
Industrial Motors	11.0	58.4	47.4	30.5	17.6
Incandescent Lamps	4.6	41.0	36.4	23.2	13.2
Standby Power	1.9	30.5	28.6	18.9	11.3
Washing Machines	47.9	73.4	25.5	16.7	9.8
Commercial Gas Boilers (Space Heating)	11.8	31.7	19.9	13.4	8.3
Commercial Room AC	21.4	35.9	14.5	9.9	6.2
Electric Water Heaters	12.4	29.6	17.1	11.3	6.8
Gas Boilers (Res.)	16.1	28.7	12.6	8.1	4.7
Fluorescent Ballasts (Res.)	6.4	15.6	9.2	6.1	3.7
Induction Ranges	0.7	2.3	1.6	1.0	0.6
Total	354	1200	846	554	328

The analysis shows that cost-effective efficiency improvement could yield very significant financial benefits to Chinese 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 354 billion USD over the next 20 years, but these investments will return over more than three times as much over the same period, for a net savings of 850 billion dollars, or of order of six hundred dollars per capita. The present value of net savings is 554 billion USD assuming a discount rate of 3%, and 328 billion USD with a 7% discount rate.

Of the appliance groups studied, residential room air conditioners require the largest investment at 97 billion USD, but provide a payoff of 148 billion USD. Refrigerators generate similar savings, but with only half of the investment. Phasing out incandescent lamps is extremely cost effective compared to other appliance groups, with a payoff of nearly 10 times as high as the required investment. Finally, distribution transformers are by far the best investment, with a savings of almost 10 times the investment of 25 billion USD.

1. Introduction

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

- A Lawrence Berkeley National Laboratory (LBNL) report, *Impacts of China's Current Appliance Standards and Labeling Program to 2020*, estimated cumulative savings of 1143 TWh (9% of cumulative residential electricity use) from 2000 to 2020 for China's standards and labeling programs for eleven key energy-consuming products (Fridley 2007)
- Another 2010 LBNL study estimated cumulative 2009-2030 electricity savings of 9503 TWh under a scenario of regularly scheduled appliance standards revisions and cumulative savings of 5450 TWh for a subset of products that achieves international best practice (Zhou 2010a).
- The China National Institute of Standardization (CNIS)'s 2010 White Paper estimated 198.7 TWh of annual electricity savings in 2030, or about 6.3% of total annual electricity consumption from China's appliances and equipment standards and labeling programs covering a subset of key products subject to standards (CNIS 2010)

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. Early in 2011, the Chinese government announced a plan to reduce carbon dioxide emissions intensity (per unit GDP) by 16% by 2015 as part of the 12th five year plan. These targets are consistent with longer term goals to reduce emissions intensity 40-45% relative to 2005 levels by 2020. The efforts of the 12th FYP focus on short-term gains to meet the four-year targets, and concentrate mainly in industry. Implementation of cost-effective technologies for all new equipment in the buildings sector thus is largely complementary to the 12th FYP goals, and would provide a mechanism to sustain intensity reductions in the medium and long term. 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. Policies and Programs to Encourage Efficiency

Chinese energy demand has grown dramatically over the last few decades. While heavy industry still plays a dominant role in greenhouse gas emissions, demand from residential and commercial buildings has also seen rapid growth in percentage terms. In the residential sector this growth is driven by internal migration from the countryside to cities. Meanwhile, household income in both subsectors allows ownership of major appliances. While residences are still relatively small by U.S. or European standards, nearly all households own a refrigerator, a television and an air conditioner. In the future, ownership rates are not expected to grow as much as in other developing countries, because they are already close to saturation. However, the gradual turnover of equipment in the world's largest consumer market provides a huge opportunity for greenhouse gas mitigation. In addition to residences, commercial floor space has expanded rapidly in recent years, and construction continues at a rapid pace. Growth in this sector means that commercial lighting and HVAC will play an increasingly important role in energy demand in China.

The outlook for efficiency improvement in China is encouraging, since the Chinese national and local governments have implemented significant policies to contain energy intensity and announced their intention to continue and accelerate these. In particular, the Chinese appliance standards program, first established in 1989, was significantly strengthened and modernized after the passage of the Energy Conservation Law of 1997. Since then, the program has expanded to encompass over 30 equipment types (including motor vehicles). The current study suggests that, in spite of these efforts, there is significant savings to be captured through wide adoption of technologies already available on the Chinese market.

Efficiency Standards

China first enacted minimum energy performance standards in 1989 for eight residential products including refrigerators, clothes washers, air-conditioners, fans, rice cookers, televisions, radio receivers and recorders, and electric irons. However, the energy efficiency requirement at the time was rather low and the monitoring and enforcement was almost inexistent. Since, China has beneficiated from the assistance of international experts, notably the Collaborative Labeling and Appliance Standards Program (CLASP), to develop the necessary infrastructure capacity to develop and implement product standards (Zhou, 2008). In 1997, China promulgated the Energy Conservation Law which highlighted the importance of end-use energy efficiency and standards and label programs. As a result, energy efficiency standards were revised and extended to more products including fluorescent lamp ballasts, compact and linear fluorescent lamps. More recently, the Eleventh Five Year Plan (2006 to 2010) sets an ambitious energy efficiency objective of reducing energy consumption per unit of GDP by 20% by 2010. Standard and labeling programs are major piece of the plan to achieve the energy efficiency target. The close collaboration with international experts has propelled a very comprehensive and robust China's appliance standards and labeling program.

The National Development and Reform Commission (NDRC) is the main government institution responsible to develop and manage energy efficiency policy in China. AQSIQ (State Administration of Quality, Supervision, Inspection, and Quarantine) is responsible for

developing the MEPS with administrative support from the Standardization Administration of China (SAC), and technical support from the China National Institute of Standardization (CNIS). (Fridley, 2007)

Further, China launched a voluntary label program in 1999, designed to identify and promote energy-efficient products. The program was managed by the China Standards Certification Center (CSC) under CNIS, but management of the label was transferred to the China Quality Certification Center (CQC) in 2008. It now covers over 50 products from over 300 participating manufacturers including: home appliances; consumer electronics; office equipment; lighting; and selected industrial equipment (Zhou, 2008).

In 2005, China launched a mandatory comparative energy information label for air conditioners, refrigerators, and clothes washers. The label includes five categories of efficiency, from 1 (more efficient) to 5 (less efficient). The program is managed by CNIS and was further extended in June 2008 to include gas water heaters, water chilling packages, three-phase induction motors, high-pressure sodium lamps and self-ballasted lamps (IEA, 2009). It now covers 26 products, and the label in some cases, such as consumer electronics, gas water heaters, and air conditioners, has been simplified to three categories from five.

Financial Incentives

China's NDRC and the Ministry of Finance currently provide subsidies to companies whose products reach a defined energy efficiency level. In April 2008, China launched the Financial Subsidies Fund for Promoting High Efficient Lighting Products Green Lights program to increase the use of energy-efficient light bulbs. The program is the first financial subsidy type of program used in China to promote the penetration of energy efficient products. Subsidies were offered to suppliers to provide a 30 percent discount on wholesale purchases and a 50 percent discount on retail sales. A total of 210 million subsidized CFLs were sold to consumers between 2008 and 2009, which had resulted in an estimated savings of 8.8 billion kWh of electricity each year, a reduction of 8.8 million tonnes of carbon dioxide per year. China planned to subsidize the price to the public of 150 million compact fluorescent light bulbs in 2010. (China Daily, 2010).

In May 2010, the Chinese government extended the incentive program to other products by allocating over 400 billion RMB (60 billion USD) annually to promote domestic demands for energy efficient products that include ACs, refrigerators, washers, TV, motors, and computer displays. For example, the central government offers subsidies of 500-850 RMB per unit for grade 1 AC products and 300-650 RMB per unit for grade 2 AC products. Local governments provide additional subsidy of 150 RMB for grade 1 AC units and 100 RMB for grade 2 units. (Wang, 2010)

ESCOs

In April 2010, the State Council, China's central government, issued a measure called "Opinions on Accelerating the Promotion of Energy Performance Contracting to Boost the Energy Service Industry," which provides new financial and tax incentives for energy service companies carrying out energy-performance contracting.

Utility Programs

Historically, China's DSM experience has largely focused on load management rather than energy efficiency, in part to address a massive power shortage. No mechanisms were set up to encourage utilities to design and implement energy efficiency programs. Recently, a few pilot projects developed with international collaboration in Jiangsu, Hubei, Shanghai, and Guangzhou have been generating significant electricity savings that has caught the attention of the Chinese top leadership (EF, 2006; Moskovitz, 2005). On November 2010, the China's central government enacted national energy efficiency regulations that require China's power grid companies to achieve energy savings equivalent to at least 0.3% in sales volume and 0.3% in maximum load compared with their previous year (Finamore, 2010). The new regulation came into effect on January 1, 2011. Possible sources of funding include: a rate surcharge applicable to all, rate surcharge differentiated by customer categories, and government budget allocations (Finamore, 2010). These new regulations have largely been inspired by the Energy Efficiency Resource Standards passed in many US States and notably in California. Responsibility for DSM implementation is placed on the shoulders of power grid companies by requiring these companies to invest in energy efficiency programs for their customers. Ongoing research and international collaboration are analyzing the implementation process for adopting effective DSM policies (Hu et al., 2005).

The experience in Chinese provinces already gives insight of the future development outcomes of the new regulations. In China, the term "DSM" generally relates to load management. Instead of DSM, the term Efficiency Power Plant (EPP) has been more wildly used in provinces to describe a virtual power plant that delivers "negawatts" through a portfolio of demand side management or energy efficiency projects.

An example of such an approach is the large-scale industrial EPP pilot in China's Jiangsu Province, developed under a California-Jiangsu partnership on energy efficiency improvements. In 2004, Natural Resources Defense Council (NRDC), along with the Energy Foundation (EF) and the Regulatory Assistance Project (RAP) worked with China's national government and Jiangsu Province to help launch China's first large-scale DSM pilot program in Jiangsu. Furthermore an agreement on DSM cooperation was signed between the California Public Utilities Commission, the California Energy Commission, and the Jiangsu Economic and Trade Commission in 2005. The joint work has helped Jiangsu build a large-scale industrial EPP program equivalent to a 300MW power plant during the period from 2005 to 2007. The implemented energy efficiency measures have helped Jiangsu reduce 580 megawatts of peak load, save 2 TWh of electricity annually, and reduce CO2 emissions by 1.88 million tons (Shen et, 2009). These initial efforts laid the foundation for demonstrating in China the value of establishing large-scale DSM programs to meet environmental and energy goals.

In Hebei, the local government collects, on an annual basis, 0.01RMB/kWh from a surcharge called urban construction fee that is levied on every customer's electric utility bill and utilizes the money for supporting EPP programs.

Shandong has implemented an energy quota system covering 20 industries and 52 products

manufactured in the province. The provincial government has set energy use (electricity and other fuels) quota levels. Consumers who exceed the quota level pay a substantial surcharge, as much as 400% of the energy price. The surcharge is paid to the Shandong Energy Conservation Supervision Center and is deposited in a special fund to be used for energy efficiency. (Moskovitz et al., 2007)

There is a growing trend in China to use financial incentives to foster the market penetration of energy efficient products. The national government already implemented subsidies to manufacturers of energy efficient appliances and a few provincial governments have developed their own target for utility to promote energy efficiency at the end use level. The new regulations that set an obligation for all utility companies promise to bring significant energy savings over the next years.

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[1].

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 USD per unit energy, can be compared to prevailing energy prices to assess

[1] 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.

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 et al. 2011)
- (Fridley 2008) estimates potential savings of 1.2 TWh in 2012 and 16 TWh by 2020 for energy labels on refrigerators in China.
- (Cheung 2008) describe the growth of China's energy efficiency industry, projecting spending of USD 300 billion over five years.
- (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.
- (Zhou 2010) provides an overview of China's policies on energy efficiency.

India

- (Delio 2009) estimates potential savings from energy efficiency across all sectors in India to be 183 TWh in five years.
- (De la Rue du Can 2009) provides both retrospective and prospective views of energy use in the residential and transport sectors of India.

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 energy.
- 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[2]. 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.

The application of BUENAS to Chinese building end uses was implemented in collaboration with LBNL's China Energy Group and follows a somewhat different methodology than other regions in the 'global' version of the model. First of all, while urbanization is a driver variable in the global model, in the China model the sector division is more distinct, with separate assumptions and econometric parameters for urban and rural sectors. Second, since electricity access is basically universal in China, electrification is not an activity driver. Therefore, household income is the main driver of appliance ownership. The relationship between income growth and appliance ownership is determined for each sector using appliance ownership rates provided by the China's National Bureau of Statistics in its annual *China Statistical Yearbook*. The resulting version of BUENAS not only supports the current study, but constitutes a component in LBNLs "China Energy 2050" model. Further description of the modeling of the Chinese residential sector can be found in (Letschert 2009)

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.

[2] 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.

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 *China 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. In the residential sector, all of the original end uses were covered for China except for fans and electric ovens. Due to the prevalence of air conditioners in China, residential fans do not account for a significant savings opportunity. Electric ovens were replaced by electric induction ranges and gas ranges, which are much more common in Chinese households. Residential space heating included both electric heat pumps and gas boilers. Electric room heaters were not covered. Also, much of residential heating in Chinese homes is district heat – while this end use may afford cost-effective savings, these savings are difficult to analyze in terms of direct consumer equipment costs and energy cost savings. Finally, televisions are not covered here. While efficiency improvements are certainly possible in television displays, this is 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 cannot be adequately forecast in order to provide definitive cost-effective improvement potential.

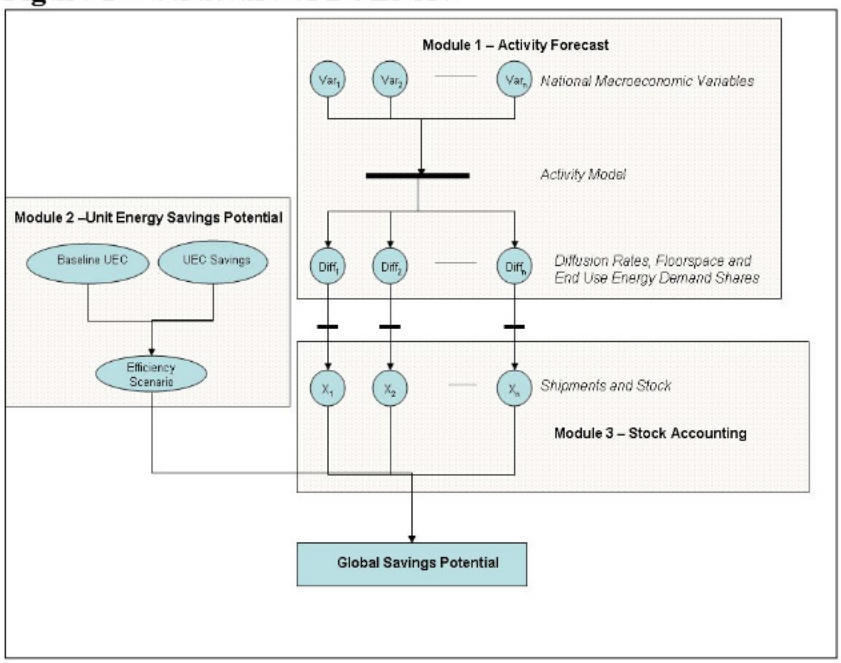
In the commercial sector, both central and room air conditioners were considered for cost-effective improvement, but a cost-effective target for central air conditioners was not found in the data, partially due to the less transparent nature of pricing for this type of equipment relative to residential equipment. This end use deserves further study than was in the scope of the current project. Fluorescent ballast efficiency improvement was considered for lighting, as were gas boilers for space heating, and gas water heaters. Distribution transformers were added for this sector, but ventilation, refrigeration and office products were not considered due to lack of data.

The BUENAS model uses the Long Range Energy Alternatives Planning (LEAP) platform[3] 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

[3] More information about the LEAP platform may be found at http://www.energycommunity.org

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[4]. Figure 1 shows the analytical structure of BUENAS.

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 Chinese households in a given year.

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

[4] 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.

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 3 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 China are taken from LBNLs China Energy 2050 model (Zhou 2011). This model forecasts the growth in China's commercial building sector according to expected increases in tertiary sector employment and per-employee floor space. 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. 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

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

$$\frac{I \cdot q}{S} \qquad \textbf{Eq. 1}$$

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:

$$\square \square \frac{\square}{\square\square\square\square\square\square\square\square} \qquad \textbf{Eq. 2}$$

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[5].

3.1. Equipment Data

The evaluation of cost-effectiveness of Chinese efficiency technologies for this study relied heavily on current retail price data taken from retail websites in China. Identification of efficiency for most products studied was facilitated by the mandatory Energy Label program, covering 26 product types, since most models were identified with a specific 1 to 5 efficiency level, where the "5" level typically is the minimum allowed efficiency and "1" is the most efficient level. Efficiency levels were combined with usage estimates from the Chinese National Institute of Standards (CNIS) and other sources to establish estimates of annual unit energy consumption. The result of this data collection is a database of prices and consumption level allowing evaluation of costs and benefits of substituting one model for another. Assumptions of baseline energy consumption, high efficiency levels and price data sources are shown in Table 1.

Incandescent Lamps

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. China has announced a phase-out of incandescent bulbs by 2018 according to NDRC. [6]

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 characterized by successful implementation and enforcement of the policy, rather than the establishment of it. We assume that the typical incandescent lamp in China is 60W and is operated for 2.3 hours per day on average, for an annual energy consumption of 53.4 kWh. An equivalent CFLs is assumed to use only 15W, or 12.6 kWh per year. We assume that a CFL lasts for 5 years, compared to only 1 year for incandescent.

Refrigerators

According to data from CNIS, refrigerators capacity has been growing in capacity over time, significantly increasing their energy consumption in Chinese households. At the same time,

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

[6] China National Development and Reform Commission "a phase-out of incandescent bulbs road map" . (http://www.eeo.com.cn/Politics/beijing_news/2010/06/25/173754.shtml).

Chinese minimum efficiency performance standards and labels have contributed to a reduction of consumption than would otherwise have been the case. We assume that the baseline refrigerator corresponds to the China Energy Label Level 5, and that the market average refrigerator consumes 1.5 kWh per day, or 547.5 kWh per year. We assume that a refrigerator lasts 15 years.

Room Air Conditioners and Heat Pumps

Room air conditioners are the dominant technology for residential space cooling in China, with the most common configuration being split units. Room air conditioners, including reversible mode units (heat pumps) are used in both residential and commercial applications. In China, heat pumps enjoy a large market share, which we assume to be about 70% of the market. A revised minimum efficiency standard that went into effect in July 2010 reduced the label categories to three, with Level 3 being the mandatory minimum;; therefore we take this level as the baseline, and consider Level 1 as the high-efficiency level
In order to calculate cooling and heating energy, we assume that the typical RAC unit is 1.125 kW and that it operates 4 hours per day every day during a 3 month cooling period. In commercial applications, we assume that the air conditioner is used for 8 hours per day in the same cooling season. The resulting annual baseline energy consumption estimates are 385 kWh per year for residential cooling and 770 kWh per year for commercial cooling.

Where the same unit is used for heating (residential sector only), we make the following regional assumptions:

- Northern Region: 20% of heat pump market - 6 hours per day for two weeks (shoulder period of heating season when district heating is turned off).
- Transition Region: 80% of the heat pump market - 6 hours per day for 3 months.

These assumptions result in a weighted average baseline consumption of 891 kWh per year for heating and cooling. The average lifetime of Room Air Conditioners is assumed to be 12 years.

Washing Machines

Two types of washing machines are popular in China - vertical axis washing machines and horizontal axis (front load) washing machines. The proportion of front-loading machines is increasing very quickly. From 2006 to 2010, the sales share of this product class increased from 12.7% to 58.4%[7]. Therefore we assume that this will be the dominant technology in 2015. We assume that the baseline washing machine corresponds to the China Energy Label Level 5, and that washing machine consumes 0.464 kWh per day, or 169.38 kWh per year. The average lifetime of washing machines is assumed to be 12 years.

Fluorescent Ballasts

We assume that fluorescent tube lights account for 20% of the lighting fixtures in residences and 75% of lighting energy in the commercial sector in China. The baseline fluorescent ballast is estimated at 38.6W with a high-efficiency option using 33.6W. We assume fluorescent ballasts

[7] http://life.yesky.com/113/11596113.shtml

consume 56.38 kWh per year and assume commercial fluorescent ballasts consume 112.76 kWh per year. The lifetimes of fluorescent ballasts are assumed to be 15 years

Water Heaters

Both electric and gas water heaters are used widely in Chinese homes, and solar water heaters are becoming popular. The capacity of typical electric and gas water heaters are about 11 liters per minute. We assume that the baseline electric water heater corresponds to the China Energy Label Level 5, and that electric water heater consumes 1.69 kWh per day, or 617 kWh per year. We assume that the baseline gas water heater corresponds to the China Energy Label Level 3, and that gas water heater consumes 0.0137 GJ per day, or 4.97 GJ per year. The lifetimes are both are assumed to be 15 years. We consider replacement of water heaters by high efficiency units using the same fuel, but also replacement with solar water heating. Solar water heaters in China include a small electric back-up heater, which we assume to be used to heat water 30% of the time.

Standby Power

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. The Chinese government has not moved to bring standby power into a single regulatory framework for all products, but it does include the reduction of standby power as part of individual rulemakings 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. We assume that the average product using standby power lasts 8 years.

Electric Induction Ranges

Electric induction ranges are very popular in China. This technology uses an inductive core and high frequency current to produce heat, and has a much higher efficiency than traditional electric stoves. The key technology of higher efficiency products is the reduction of magnet leakage. We assume that the baseline electric induction range corresponds to the China Energy Label Level 5, and that electric induction range consumes 1.19 kWh per day, or 437.33 kWh per year. The lifetime of induction ranges is assumed to be 15 years.

Residential Boilers

An increasing number of Chinese homes use boilers for space heating. Residential boilers typically use natural gas for fuel, with diesel used less often. Residential boilers space heating equipment are subject to the same national standard as gas water heaters. We assume that the

baseline gas residential boiler corresponds to the China Energy Label Level 3, and that gas residential boiler consumes 14.73 GJ per year[8] and has a lifetime is 17 years.

Commercial Boilers

Historically, Chinese commercial boilers used coal but increasingly, they are fired with natural gas, with a small fraction using diesel or methanol. We assume that the baseline commercial boiler corresponds to the China Energy Label Level 3. We estimate annual energy consumption assuming that 70kW unit operates for 4 hours per day for 6 months, resulting in gas consumption of 181.4 GJ per year. We assume a lifetime of 20 years for commercial boilers.

Industrial Motors

We assume that the baseline industrial motor corresponds to the China Energy Label Level 3. Annual energy consumption for motors is based on an assumption of 3000 hours per year. With this assumption, the baseline 10 HP industrial motor consumes 22500 kWh per year, 50 HP motors consume 112500 kWh per year and 100HP industrial motors consume 225000 kWh per year. The distribution of motor capacities in China is assumed to be in a 10:5:1 ratio for 10 HP, 50HP and 100 HP, respectively. The lifetime for all motors is assumed to be 12 years.

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. There is a national standard to regulate distribution transformers in China, with "minimum allowable values of energy efficiency and the evaluating values of energy conservation for three-phase distribution transformers" published in 2006. The typical baseline efficiency of distribution transformers is 95% (at 80% load). While there is not a Chinese labeling system for distribution transformers, an industry-recognized standard for high-efficiency transformers exists at 98.1% to 99.0% (at 80% load), depending on transformer capacity. Using these efficiency values, we calculate electricity losses from 5 size categories of transformers assuming that transformers are loaded 25% of the time. Distribution transformer lifetime is assumed to be 30 years.

[8] LBNL estimate – *China Energy 2050 Model*

Table 1 – Summary of Appliance Definitions and Retail Price Source

Appliance	Baseline Definition	High Efficiency Definition	Retail Price Source	Number of Observations
Incandescent Lamps	60 Watt Incandescent Lamp	15 Watt CFL	Haolives.com	282
Refrigerators	China Energy Label - Level 3	China Energy Label - Level 1	price.ea3w.com	830
Residential AC (Stable Speed)	China Energy Label - Level 5	China Energy Label - Level 2	detail.zol.com.cn	3800
Residential AC (Variable Speed)	China Energy Label - Level 5	China Energy Label - Level 2	detail.zol.com.cn	731
LCD TV	China Energy Label - Level 3	China Energy Label - Level 1	price.ea3w.com	480
PDP TV	China Energy Label - Level 3	China Energy Label - Level 1	price.ea3w.com	332
Washing Machines (Vertical)	China Energy Label - Level 5	China Energy Label - Level 1	price.ea3w.com	60
Washing Machines (Front Loading)	China Energy Label - Level 5	China Energy Label - Level 1	price.ea3w.com	60
Fluorescent Ballasts (Res.)	Magnetic	Electronic	Zhigou.com	10
Electric Water Heaters	China Energy Label - Level 5	China Energy Label - Level 1	price.ea3w.com	492
Induction Ranges	China Energy Label - Level 5	China Energy Label - Level 1	price.ea3w.com	88
Gas Water Heaters	China Energy Label - Level 3	China Energy Label - Level 1	price.ea3w.com	38
Gas Boilers (Residential)	China Energy Label - Level 3	China Energy Label - Level 1	163.com	45
Commercial Lighting	Magnetic	Electronic	Zhigou.com	10
Commercial Gas Boilers (Space Heating)	China Energy Label - Level 3	China Energy Label - Level 1	detail.china.alibaba.com	428
Commercial Room AC	China Energy Label - Level 5	China Energy Label - Level 2	detail.china.alibaba.com	3800
Industrial Motors	China Energy Label - Level 3	China Energy Label - Level 1	detail.china.alibaba.com	239
Distribution Transformers	95% Efficiency	98.1% - 99% Efficiency	detail.china.alibaba.com	305

3.2. 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 the Appendix, unless otherwise specified[9]. 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 Rates – In order to evaluate cost-effectiveness to consumers, the analysis takes into account the real cost of financing for Chinese consumers. As a reference, we considered interest rates offered by the People's Bank of China as representative of consumer financing costs. Interest rates for consumers at the time of the study were 5.6%[10]. Discount rates for the commercial and industrial sector were assumed to be somewhat higher, at 6.6% and 7.7% respectively.

[9] 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.

[10] http://www.global-rates.com/interest-rates/central-banks/central-bank-china/pbc-interest-rate.aspx

Energy Prices – Current consumer electricity and natural gas prices do not fully reflect the cost of production and include cross-subsidization between tariff groups. For example, residential electricity prices range by region from about 0.35 RMB/kWh (0.05 USD/kWh) to 1.1 RMB (.17 USD/kWh)[11]. Current rates in Beijing are 0.48 RMB/kWh (0.073 USD/kWh) for residential customers 0.64 RMB/kWh (0.097 USD/kWh) for commercial customers and 0.57 RMB/kWh (0.086 USD/kWh) for small industrial consumers[12]. Aggressive moves by the Chinese government to raise consumer electricity prices are expected to continue, though with timing sensitive to the state of consumer price inflation. We therefore assume that by 2015 electricity rates for all consumer types will double. Electricity price assumptions are shown in Table 2.

Table 2 – 2015 Electricity Price Assumptions

Sector	2010 RMB/kWh	2010 USD/kWh	2015 RMB/kWh	2015 USD/kWh
Residential	0.48	0.073	0.96	0.15
Commercial	0.64	0.097	1.28	0.19
Small Industry	0.57	0.086	1.14	0.17

Similarly, natural gas prices have shown a rapid increase in recent years. In fact, price trends indicate a doubling of retail natural gas prices, from 700 RMB per m^3 in 2001 to 1400 RMB per m^3 in 2009[13]. We assume that natural gas prices will increase an additional 50% by 2015. We apply industrial natural gas prices to the commercial sector. Assumptions for natural gas prices are shown in Table 3.

Table 3– 2015 Natural Gas Price Assumptions

City	Residential Use	Industry Use
Beijing	2.05	2.35
Shanghai	2.5	3.3
Tianjin	2.2	2.4
Chongqing	1.4	1.67
Nanjing	2.2	2.35
Hangzhou	2.4	2.5
Chengdu	1.43	1.66
Wuhan	2.3	2.43
Urumqi	1.36	1.85
Guangzhou	3.45	3.95
Shenzhen	3.5	4.8
Average		
RMB/m^3	2.25	2.66
USD/1000m^3	341	403
USD/MJ	0.009	0.010
USD/GJ	8.8	10.4
2015 Prices	13.2	15.5

Source: China Natural Gas Report 2009 - C12009720CN

[11] Exchange rate of 6.6 RMB per dollar as of October 2010.

[12] http://www.bj.sgcc.com.cn/Contents/Channel_52/2009/1123/58255/content_58255.htm

[13] http://wenku.baidu.com/view/41c0e93610661ed9ad51f3ea.html

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 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.

To illustrate the construction of the efficiency scenario, we consider the example of room air conditioners. The top portion of Table 4 shows *UEC*, *Price* and cost of conserved energy (*CCE)* for each design option for room air conditioners. Room air conditioners (RAC) are used in both residential and commercial settings. In the residential sector, about 70% of the RAC market in China are heat pumps (reversible mode) and are therefore used for both heating and cooling. In the commercial sector, we assume that heating is generally supplied from other sources (such as district heat or boilers), and therefore RAC is used for cooling only in this sector. The revised efficiency standard that went into effect in July 2010 set Level 3 as the mandatory minimum; therefore we take this level as the baseline, and consider Level 1 as the high-efficiency level. In order to calculate cooling and heating energy, we assume that the typical RAC unit is 1.125 kW and that it operates 4 hours per day every day during a 3 month cooling period. In commercial applications, we assume that the air conditioner is used for 8 hours per day in the same cooling season. The resulting annual baseline energy consumption estimates are 385 kWh per year for residential cooling and 770 kWh per year for commercial cooling.

Where the same unit is used for heating (residential sector only), we make the following regional assumptions:

- Northern Region: 20% of heat pump market - 6 hours per day for two weeks (shoulder period of heating season when district heating is turned off).
- Transition Region: 80% of the heat pump market - 6 hours per day for 3 months.

These assumptions result in a weighted average baseline consumption of 891 kWh per year for heating and cooling.

Cost of conserved energy is calculated from Equations 1 and 2 using UEC, retail price, and the assumptions of product lifetime and appropriate discount rates. The result is a cost of conserved energy of 0.44 USD for residential cooling only, 0.095 USD for residential heating plus cooling and 0.116 USD for commercial cooling. The result is that the current Level1 is not a cost effective substitution to the current Level 3 baseline for consumers using cooling only, but it is cost-effective for heat pump users. In order to evaluate the total cost effective savings potential from this end use, we take the weighted average, assuming an improvement from 891 kWh to 669 kWh for heat pump (HP) users, and no improvement for AC-only users. The weighted average improvement is from 739 kWh to 584 kWh, an improvement of 21%. In the commercial sector, since the hours of operation are twice as high, replacement of Level 3 room air conditioners with Level 1 units is found to be cost effective, with a cost of conserved energy of

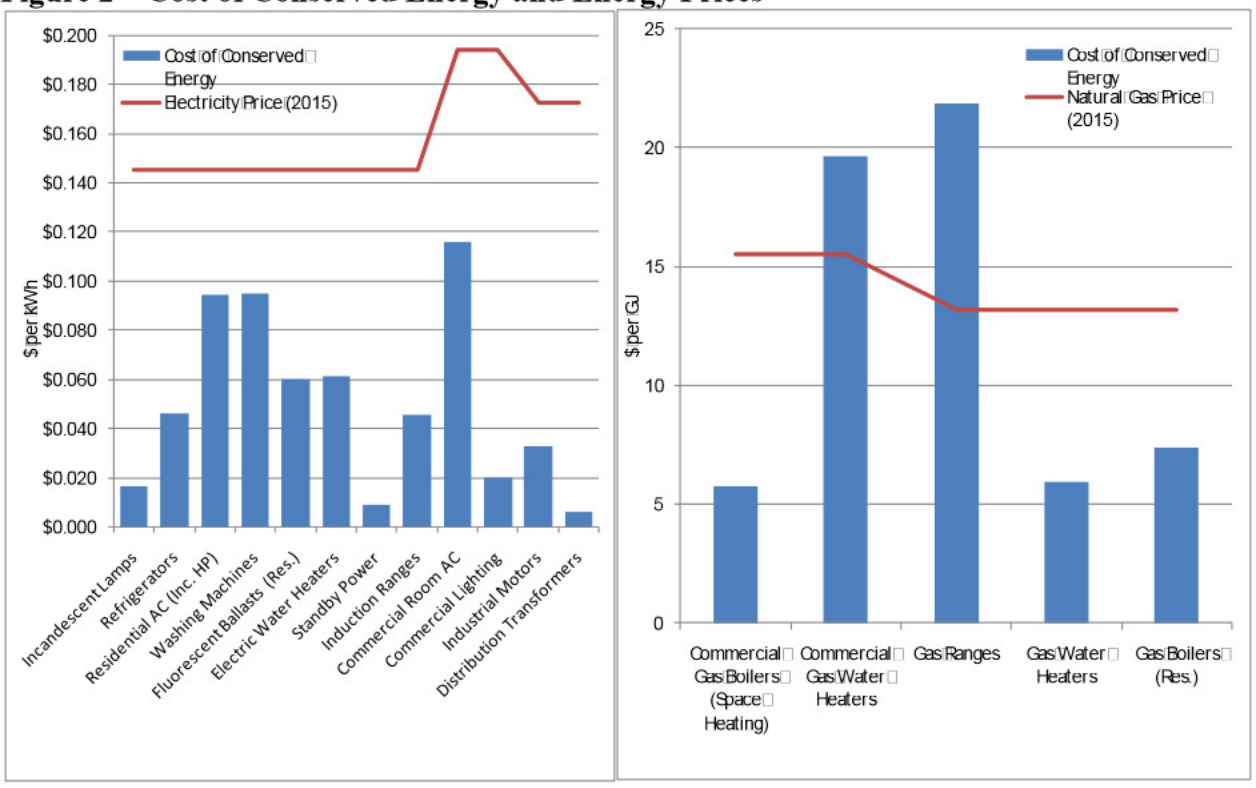
0.116 USD. The corresponding energy consumption reduction from 770 kWh to 578 kWh constitutes a 25% improvement.

Table 4 – Cost of Conserved Energy Calculation for Room Air Conditioners

	Room AC								
Class	Residential AC (Cooling)			Residential HP (Cooling + Heating)			Commercial RAC		
Market share	30%			70%			100%		
Lifetime (years)	12			12			12		
Q	0.116			0.116			0.123		
Level	UEC (kWh)	Price ($)	CCE	UEC (kWh)	Price ($)	CCE	UEC (kWh)	Price ($)	CCE
Baseline (Level 3)	385	367		891	367		770	367	
High Efficiency (Level 1)	289	548	0.44	669	548	0.095	578	548	0.116
In-Class Target UEC	385			669			578		
Target End-Use UEC	584						578		
End-Use Baseline UEC	739						770		
Target End-Use CCE	0.095						0.116		

The Appendix tables show the calculation of CCE for each product class, and calculate 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 2.

Figure 2 – 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 2. We call this the *Business Case UEC*. Baseline UEC, *Business Case* UEC, Percent Improvement and Cost of Conserved Energy are presented in Table 5.

Table 5 – Unit Level Efficiency Improvement and Cost of Conserved Energy

Equipment	Baseline UEC	Business Case UEC	Percent Improvement	Cost of Conserved Energy
Electric Equipment	kWh	kWh	%	USD/kWh
Standby Power*	17.2	3.4	80%	0.009
Incandescent Lamps	50	13	75%	0.016
Industrial Motors	63281	61964	2.1%	0.020
Distribution Transformers	11176	2639	76%	0.006
Induction Ranges	437	398	9%	0.045
Refrigerators	548	292	47%	0.046
Fluorescent Ballasts (Res.)	56	49	13%	0.060
Electric Water Heaters	617	185	70%	0.061
Commercial Lighting	113	98	13%	0.020
Residential AC (Inc. HP)	739	584	21%	0.095
Washing Machines	169	92	46%	0.095
Commercial Room AC	770	578	25%	0.116
Fuel Equipment	GJ	GJ	%	USD/GJ
Commercial Gas Boilers (Space Heating)	181	159	13%	5.79
Gas Water Heaters	4.97	1.49	70%	5.92
Gas Boilers (Res.)	14.7	12.9	13%	7.37

* Per device using standby power (5W per device)

Table 5 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.

4. National Level Energy Savings Opportunities

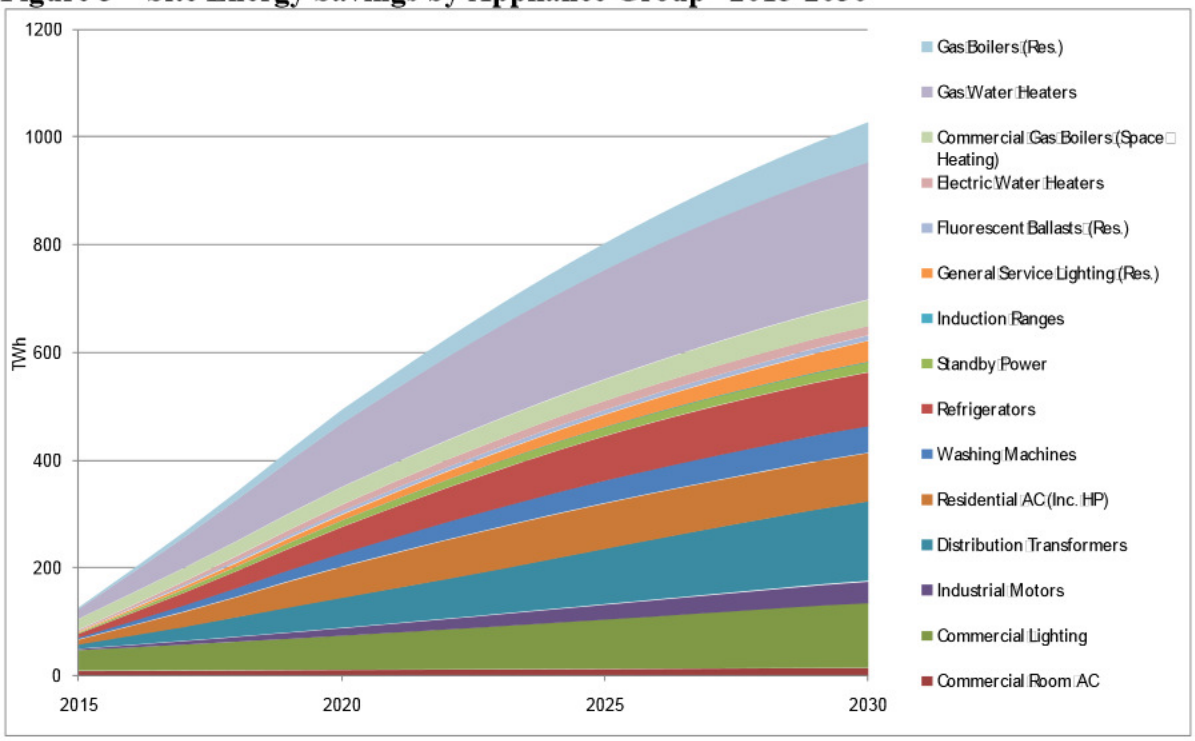
Because of the modular structure of the BUENAS model (see Figure 1), once the inputs are established it is a relatively straightforward process to construct the two energy demand scenarios and compare them to calculate savings potential. The full details of the calculation of energy demand are provided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

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[14], 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[15]. 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 3 shows the evolution of site energy savings by appliance group. From 2015 onward, energy savings grows for all products as high efficiency products begin to penetrate the stock in the *Business Case*.

Figure 3 – Site Energy Savings by Appliance Group– 2015-2030



Site energy savings results are summarized in Table 6. Total savings for all appliance groups totals 1028 TWh in the year 2030. Cumulative savings through 2030 total 10,000 TWh.

[14] 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.

[15] 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 taken from (Zhou 2011) is 0.98 kg CO_2/kWh in 2015, decreasing to 0.96 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 6. Total mitigation in the *Business Case* is found to be 717 mt CO_2 in 2030 and 7234 mt CO_2 over the entire forecast. Figure 4 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 [16], NO[17] and mercury (Hg)[18].

Table 6 – 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 CO2		mt CO_2	mt SO_2	mt NO	t Hg
Gas Water Heaters	118	255	2448	24	52	494	6.2	8.1	403.9
Distribution Transformers	57	148	1273	60	146	1294	3.2	4.2	210.1
Commercial Lighting	63	121	1249	66	119	1277	3.2	4.1	206.1
Residential AC (Inc. HP)	57	90	1020	60	89	1041	2.6	3.4	168.3
Refrigerators	49	100	991	51	98	1009	2.5	3.3	163.5
Gas Boilers (Res.)	26	75	607	5	15	123	1.5	2.0	100.1
Commercial Gas Boilers (Space Heating)	32	49	567	7	10	114	1.4	1.9	93.5
Washing Machines	25	50	505	27	49	514	1.3	1.7	83.3
Industrial Motors	14	40	338	15	40	343	0.9	1.1	55.8
Incandescent Lamps	10	38	282	11	38	286	0.7	0.9	46.5
Standby Power	12	20	210	12	19	214	0.5	0.7	34.6
Electric Water Heaters	12	17	203	12	17	207	0.5	0.7	33.5
Commercial Room AC	11	14	185	11	14	190	0.5	0.6	30.5
Fluorescent Ballasts (Res.)	1	9	108	1	9	110	0.3	0.4	17.7
Induction Ranges	1	2	16	1	2	16	0.0	0.1	2.6
Total	494	1028	10001	368	717	7234	26	33	1650

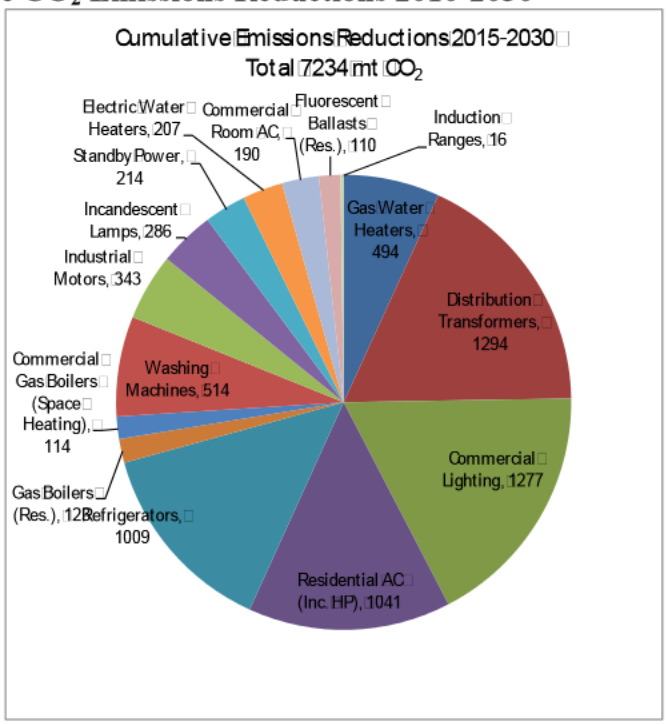
Several conclusions can be drawn from Table 6 and Figure 4. First, emission reduction potential is well distributed among end uses and sectors. The largest potential exists for commercial lighting, residential air conditioning and distribution transformers, each of which could provide over 100 TWh of electricity demand reduction in 2030 and about 1300 mt CO_2 over the forecast period. Savings in commercial lighting is possible due to the prevalence of magnetic ballasts for fluorescent lamps, which can be replaced with electronic ballasts. Air conditioning savings includes reduction of heating energy from reversible models (heat pumps). Finally, distribution transformers show significant savings even taking into account the recent standards rulemaking because of the scale of distribution losses at the national level, even though total efficiency improvement is small on a percentage basis. Much of the remaining mitigation potential comes from major appliances such as refrigerators and washing machines. Significant savings can be gained from replacement of gas and electric water heaters with solar water heating systems, which already have a significant market share in China.

[16] SO_2 Emissions rate of 2.55 g/kWh estimated from www.dianli.com

[17] NO Emissions rate of 3.3 g/kWh from (Zhou 2011)

[18] Mercury emissions rate of 0.165 mg/kWh from (Feng 2010)

Figure 4 – 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 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:

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:

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:

Substituting Equation 1, and cancelling terms, yields:

$$\square_{\square}\square\square\square\square\ \square\ \square\ \square_{\square}\square\square\square\square\ \square\square\square$$

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:

$$\square\square\square\ \square\ \ \square\ \ \frac{\square\square\square\square}{\square 1\ \square\ \square\square\square^{\square\square\square\square\square\square}}$$

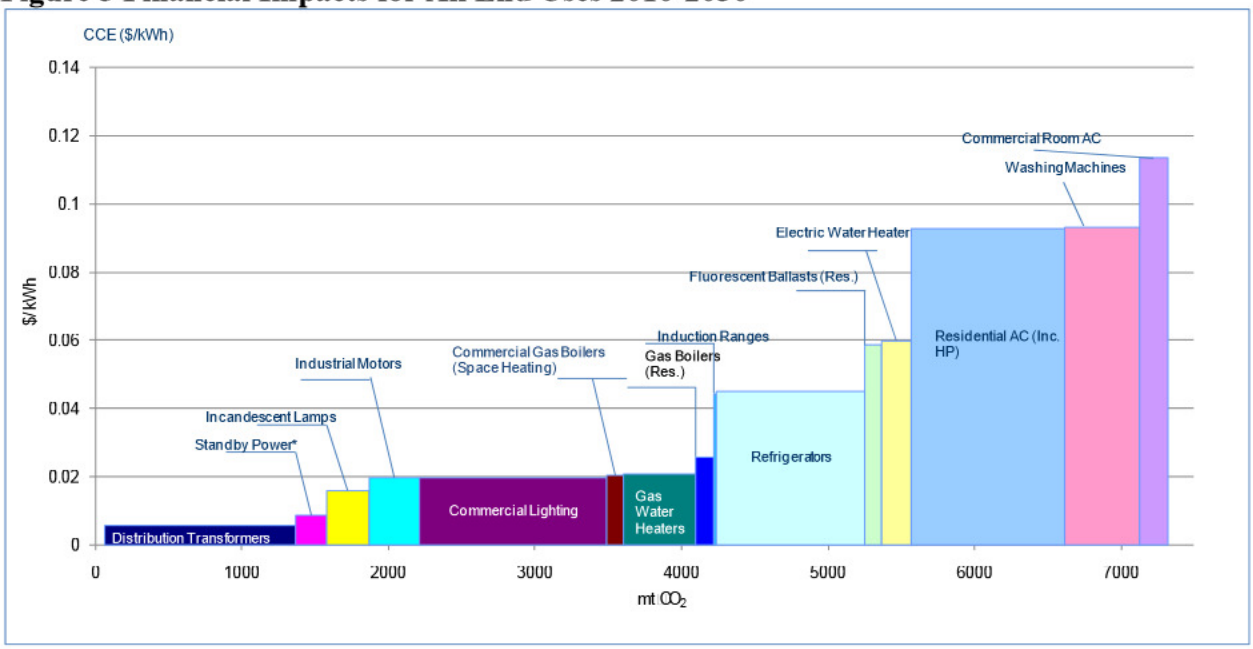
In this equation, *DR* is a "societal" discount rate that parameterizes the preference for immediate returns on public investments. We consider two scenarios in which the societal discount rate is taken to be 3% or 7%. Cumulative equipment costs, energy bill savings, net savings and *NPV* are shown in 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 354 billion USD over the next 20 years, but these investments will return over three times as much over the same period, for a net savings of 846 billion USD, or of order of six hunred USD per capita. The net present value is 554 billion USD assuming a discount rate of 3%, and 328 billion with a 7% discount rate. Of the appliance groups studied, residential air conditioners require the largest investment at 97 billion USD, but also have the one of the highest payoffs at 148 billion USD. The highest payoffs are found in the commercial sector, with 212 billion USD for distribution transformers and 217 billion for commercial lighting, which is driven by implementation of electromagnetic ballasts. Both of these technologies are highly cost effective, with net savings of over 200 billion USD.

Table 7 – Cumulative Financial Impacts of Efficiency Improvement

Appliance Group	Cumulative Financial Impacts				
	Cost	Savings	Net Savings	NPV @ 3% DR	NPV @ 7% DR
	Billions USD				
Commercial Lighting	25.0	242	217	145	88.0
Distribution Transformers	7.7	220	212	137	79.7
Refrigerators	45.6	144	98.5	64.3	37.8
Gas Water Heaters	52.1	116	63.8	41.5	24.4
Residential AC (Inc. HP)	96.6	148	51.8	34.2	20.4
Industrial Motors	11.0	58.4	47.4	30.5	17.6
Incandescent Lamps	4.6	41.0	36.4	23.2	13.2
Standby Power	1.9	30.5	28.6	18.9	11.3
Washing Machines	47.9	73.4	25.5	16.7	9.8
Commercial Gas Boilers (Space Heating)	11.8	31.7	19.9	13.4	8.3
Commercial Room AC	21.4	35.9	14.5	9.9	6.2
Electric Water Heaters	12.4	29.6	17.1	11.3	6.8
Gas Boilers (Res.)	16.1	28.7	12.6	8.1	4.7
Fluorescent Ballasts (Res.)	6.4	15.6	9.2	6.1	3.7
Induction Ranges	0.7	2.3	1.6	1.0	0.6
Total	354	1200	846	554	328

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 7234 mt CO_2, as shown in Table 6. 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.

Figure 5 Financial Impacts 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 USD per ton of carbon dioxide yields an additional 205 billion USD of savings, while a 100 USD per ton price yields 822 billion additional USD, nearly doubling the total.

The negative impacts of emissions of SO_2 and NO from power plants are well-known (see, for example, EPA 2010), 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.

5. Conclusions

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

Energy savings:

- 490 billion kWh per year in 2020
- 1015 billion kWh per year in 2030
- A total of 10,000 billion kWh cumulatively through 2030

Cumulative greenhouse gas emissions mitigation:

- 7730 million metric tons of CO_2 through 2030
- 26 million metric tons of SO_2 through 2030
- 33 million metric tons of NO through 2030
- 1650 metric tons of mercury through 2030

Financial impacts to consumers through 2030:

- Equipment investment of 350 billion USD
- Energy bill savings of 1200 billion USD
- Net savings of 846 billion USD

The "business case" analysis shows that the Chinese market already has access to efficiency technologies that could provide Chinese consumers with a financial benefit and make a dent in the growth of Chinese emissions if widely adopted. Most of the equipment studied has been the subject of at least one efficiency standard, but opportunities for improvement are not exhausted. To some extent, therefore, the savings potential estimated by this study can be captured through expansion and aggressive pursuit of existing Chinese government policies. 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 be 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. Likewise, 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.

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".

Finally, we believe this study to be among the few to attempt to evaluate the "economic" potential of efficiency improvement in China in a transparent way. In addition to demonstrating significant savings potential, we hope that it demonstrates a clear and consistent methodology for creation and expansion of alternative energy scenarios in China. 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 – 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 = 5.6%
Commercial Consumer Discount Rate = 6.6%
Industrial Consumer Discount Rate = 7.6%
Residential Electricity Price (2015) = $0.15 $/kWh
Commercial Electricity Price (2015) = $0.19 $/kWh
Commercial Electricity Price (2015) = $0.17 $/kWh
Residential Natural Gas Price (2015) $13.16 $/GJ
Commercial Natural Gas Price (2015) $15.53 $/GJ

Table A.1 – Efficiency-Cost Relationship for Room Air Conditioners and Heat Pumps

Class	***Room AC***								
	Residential AC (Cooling)			Residential HP (Cooling + Heating)			Commercial RAC		
Market share	30%			70%			100%		
Lifetime (years)	12			12			12		
Q	0.116			0.116			0.123		
Level	UEC (kWh)	Price ($)	CCE	UEC (kWh)	Price ($)	CCE	UEC (kWh)	Price ($)	CCE
Baseline (Level 3)	385	367		891	367		770	367	
High Efficiency (Level 1)	289	548	0.44	669	548	0.095	578	548	0.116
In-Class Target UEC	385			669			578		
Target End-Use UEC	584						578		
End-Use Baseline UEC	739						770		
Target End-Use CCE	0.095						0.116		

Table A.2.– Efficiency-Cost Relationship for Water Heaters

Class	***Water Heaters***					
	Waterheaters (Electric)			Waterheaters (Gas)		
Market share	100%			100%		
Lifetime (years)	15			15		
Q	0.100			0.100		
Level	UEC (kWh)	Price	CCE	UEC (GJ)	Price	CCE
Baseline	617	176		5.0	235	
1	370	367	0.077	4.1	470	28.362
2	185	441	0.061	1.5	441	5.915
Target End-Use UEC	185			1		
End-Use Baseline UEC	617			5		
Target End-Use CCE	0.061			5.92		

Table A.3. – Efficiency-Cost Relationship for Other Appliance Groups

Equipment	Lifetime	Q	Baseline UEC	Target UEC	Baseline Price	Target Price	Target CCE
Electric Equipment	years	years	kWh	kWh	$	$	$/kWh
Refrigerator	15	0.100	548	292	323	441	0.046
Laundry (Washing Machine)	15	0.100	169	91.9	220	294	0.095
Cooking Products (Electric Induction Stoves)	15	0.100	437	398	34	51	0.045
Lamps (Incandescent)	5	0.235	50.4	12.6	1.47	4.11	0.016
End-Uses with more than one product class							
Fluorescent Lamp Ballast : Residential	15	0.100	56.4	49.0	0*	4.41	0.060
Fluorescent Lamp Ballast : Commercial	15	0.100	112.8	98.1	0*	4.41	0.030
Commercial Air Conditioning	12	0.123	48000	35692	17621	26432	0.088
Market Share of Residential = 50% Commercial = 50%				Baseline UEC	73.540	84.57	0.060
10 HP (62.5%)	10	0.146	22500	22032	176	294	0.037
50 HP (31.25%)	10	0.146	112500	110159	881	1322	0.027
100 HP (6.25%)	10	0.146	225000	220318	1028	2349	0.041
Distribution Transformers							
25 kVA (6%)	30	0.085	2738	1051	1028	1367	0.017
60 kVA (25%)	30	0.085	6570	1822	1175	1562	0.007
100 kVA (44%)	30	0.085	10950	2628	1909	2539	0.006
160 kVA (3%)	30	0.085	19710	3854	2496	3320	0.004
200 kVA (14%)	30	0.085	21900	4555	2937	3906	0.005
Fuel Equipment	years	years	GJ	GJ	$	$	$/GJ
Commercial Gas Boiler	20	0.091	181	2496	159	3935	5.79
Gas Boilers	17	0.092	14.7	734	13	881	7.37