Assessing the Potential for Energy Savings with China's ES&L program

2011 Second Training Workshop on Energy Efficiency Standards and Labeling

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Nina Zheng and Nan Zhou
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, California, USA

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Presentation Outline

- Introduction to LBNL and China Energy Group
- Significance of China's Appliance Efficiency Standards & Labeling (ES&L) Programs
- Importance of Impact Evaluations
- Overview of Modeling Study:
  - Methodology: 1 study, 2 evaluations, 3 scenarios
  - Comparison of energy savings and emissions reduction results
- Overall Findings and Conclusions

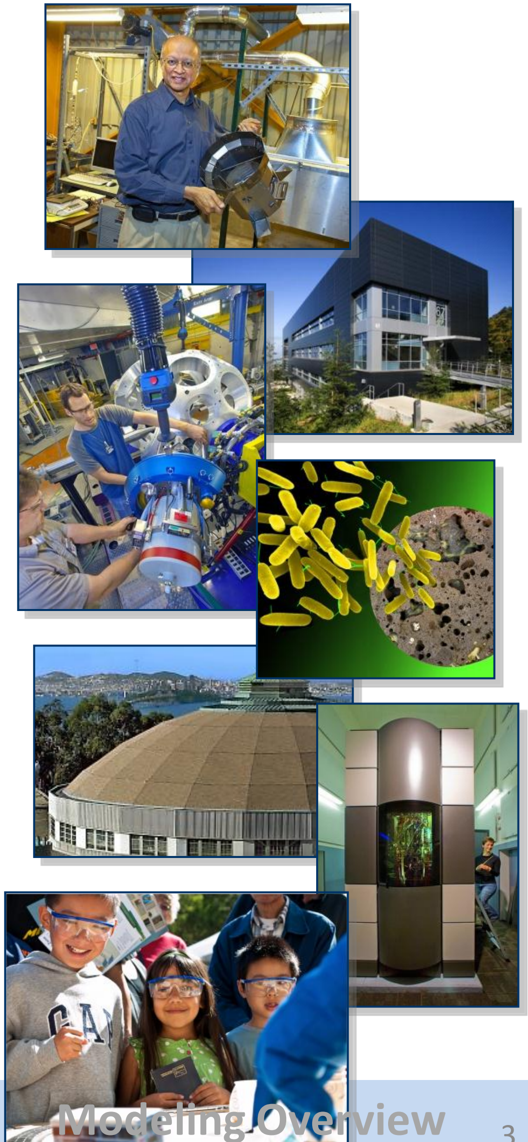
Lawrence Berkeley National Laboratory

Managed by the University of California for the United States Department of Energy

Lawrence Berkeley National Laboratory

Mission:

- Solve the most pressing and profound scientific problems facing humankind
  - Basic science for a secure energy future
  - Understand living systems to improve the environment and energy supply
  - Understand matter and energy in the universe
- Build and safely operate world-class scientific facilities
- Train the next generation of scientists and engineers



LBNL Research Areas and Facilities

Research Areas

- ***Biological Systems Science***
- ***Chemical and Molecular Science and Engineering***
- ***Subsurface and Environmental Science***
- ***Technologies for Energy Efficiency***
- ***System Analysis for Energy Applications***
- ***Photon Science***
- ***Computational Science***
- ***Particle- and Astro-Physics***
- ***Climate Science***

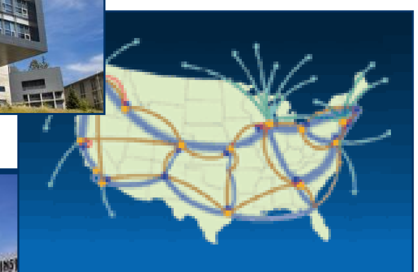
Advanced Light Source

National Energy Research Scientific Computing Center

88-Inch Cyclotron

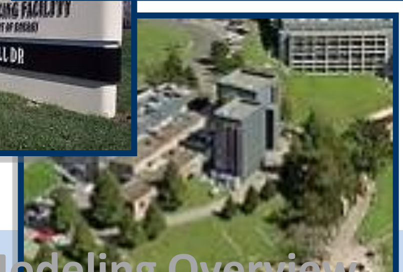
Molecular Foundry

Energy Sciences Network (ESnet)



Joint Genome Institute

National Center for Electron Microscopy



Lawrence Berkeley National Laboratory's China Energy Group

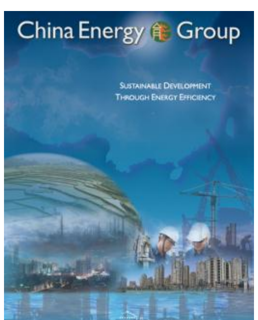
Founded in 1988

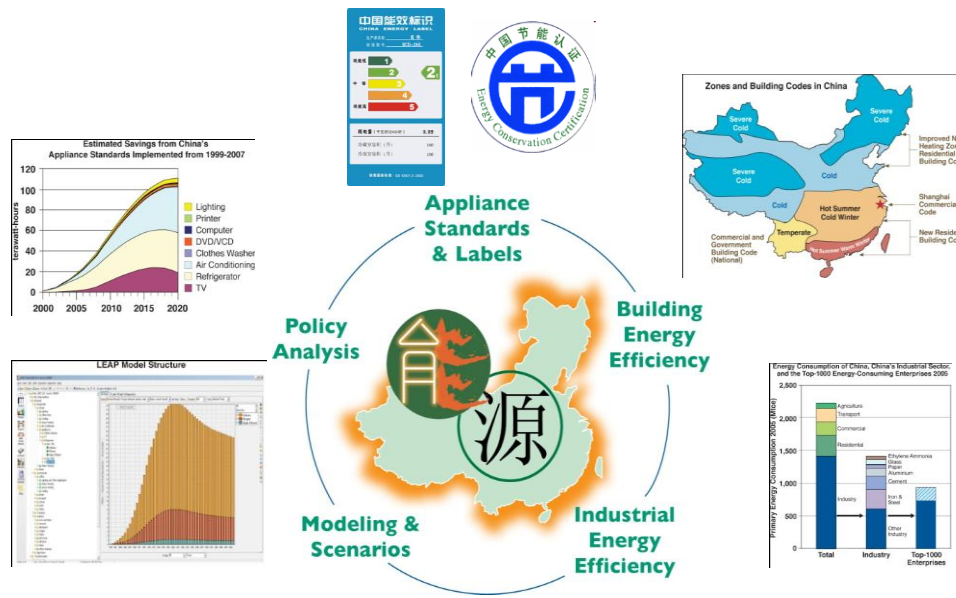
Mission: China Energy Group works collaboratively with groups in China and elsewhere to:

- **Understand the dynamics of energy use in China**
- **Enhance capabilities of Chinese institutions to promote energy efficiency**
- **Create links between Chinese and international institutions**
- **Promote energy efficiency in China**

Focus on End-Use Energy Efficiency

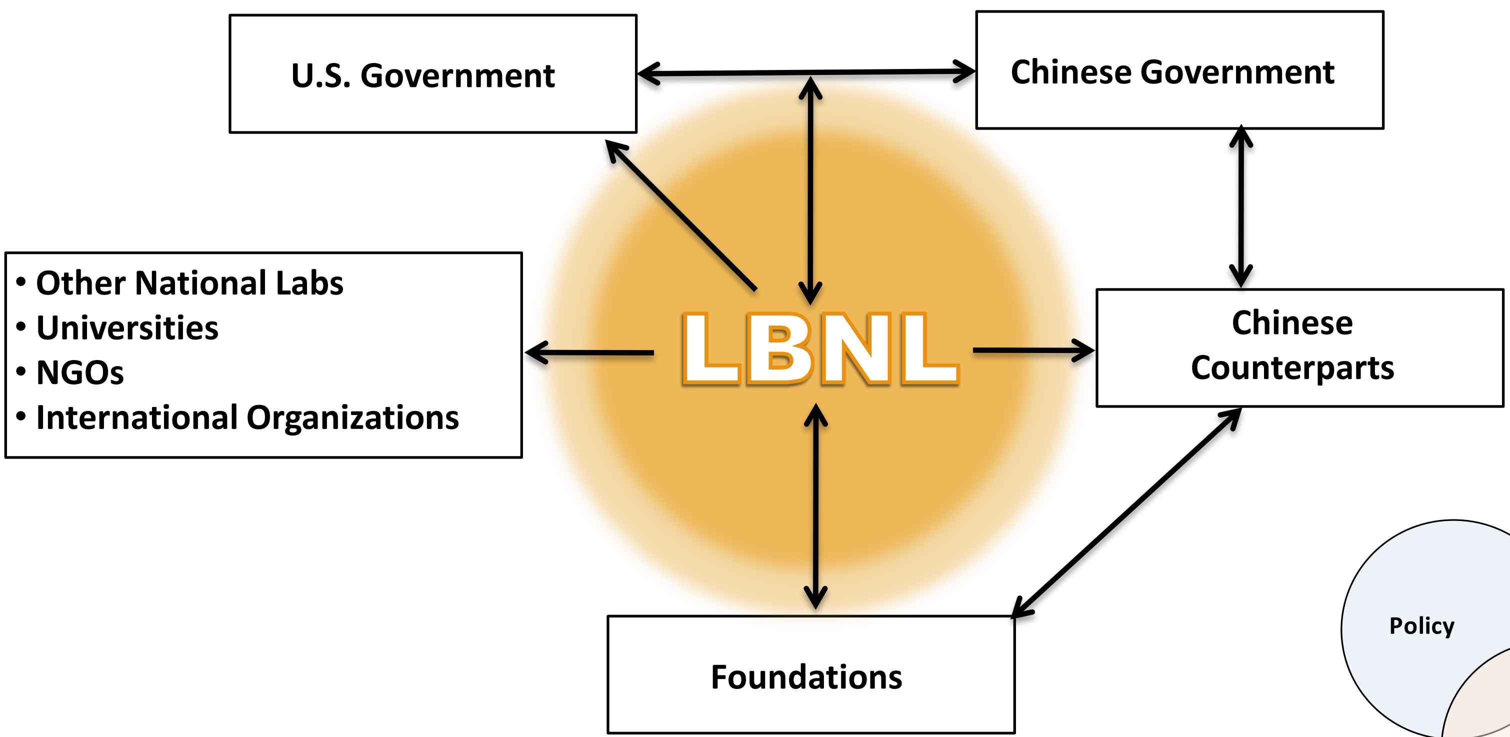
- **~ 40 Current Projects in China**
- **Collaborations with ~50 Institutions in China**

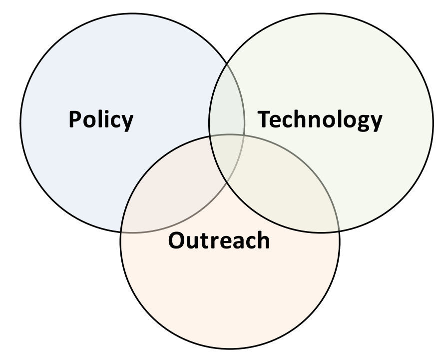




China Energy Group's Work

Collaboration Approach



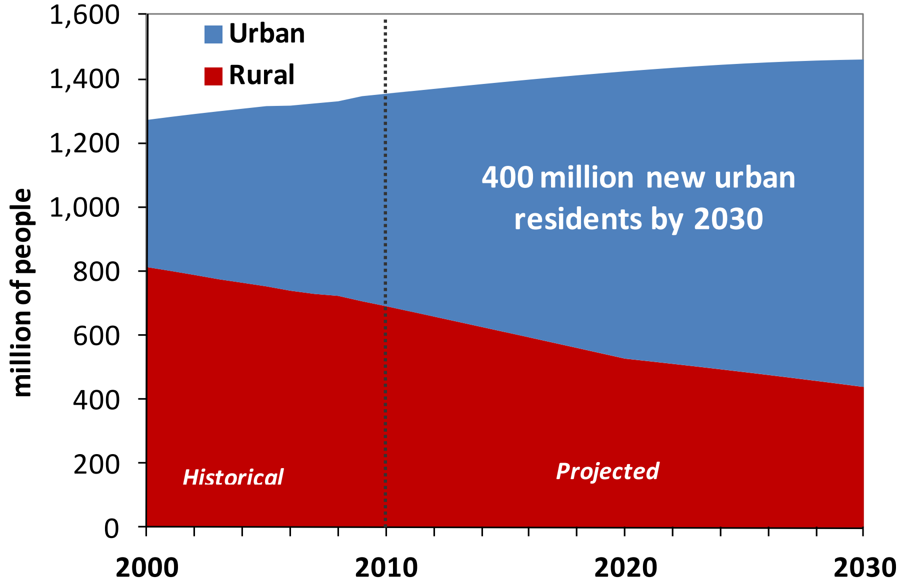


Our Group's History of Working with China on Appliance Efficiency

- Training and Implementation: 1998-2003
  - Training in Dept. of Energy analysis toolkit (technical analysis, energy impact, economic impact, consumer impact)
  - Development of initial standards for major products
  - Transfer of Energy Star modeling techniques
  - Development of first set of labeled products
- Expanding the Scope: 2003-2007
  - Introduction of mandatory energy information label
  - Development of "reach" (tiered) standards
  - Linkage of voluntary label to government procurement
  - International harmonization
- Institutional Strengthening: 2008-Present
  - Regional compliance check-testing
  - Laboratory round-robin testing
  - New products for standards regulation

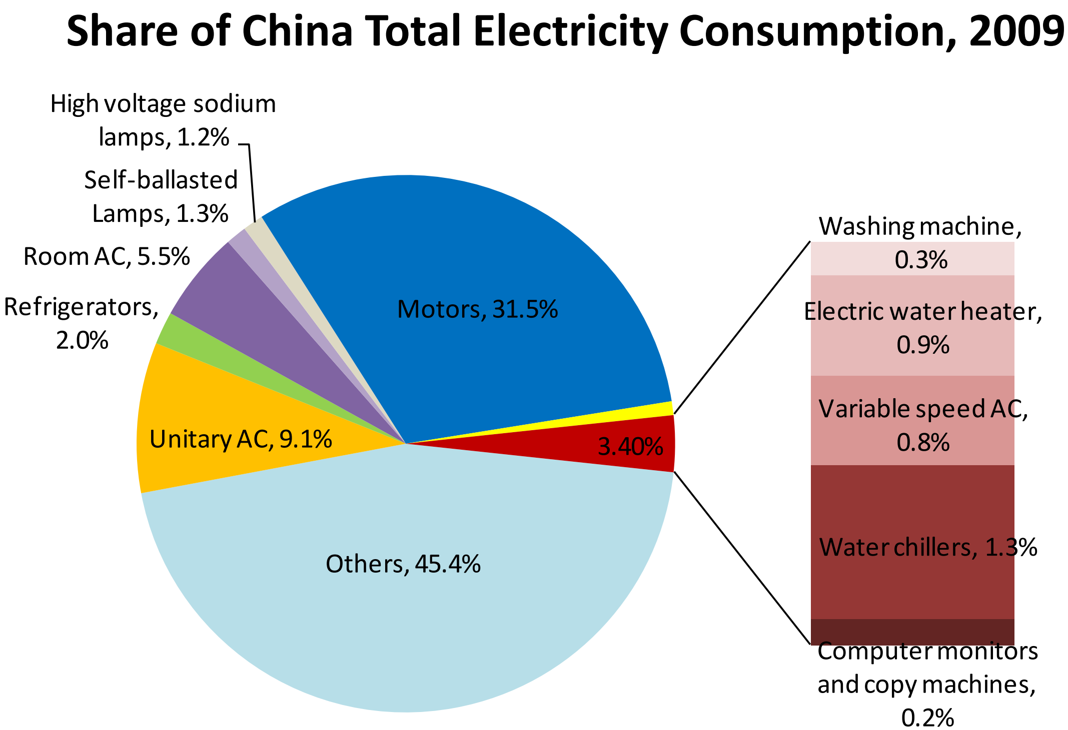
Why China?

- China is the world's leading energy consumer and annual CO_2 emitter, with growth expected to continue in coming years
  - Urbanization driving energy demand with over 300 million *new* urban consumers since 1990
  - Coal is the dominant energy source, and responsible for majority of electricity generation



Why ES&L in China?

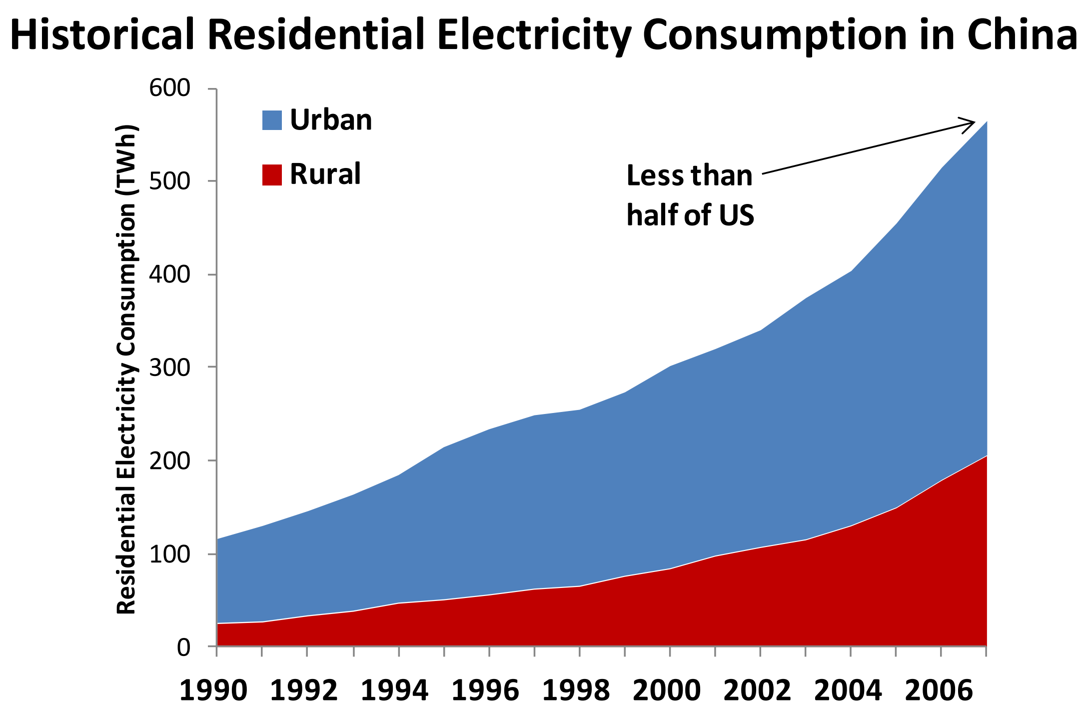
Household appliances consume increasingly large shares of China's total electricity, while other commercial and industrial products consume significant electricity



Source: CNIS 2010 White Paper

Why Appliance Efficiency?

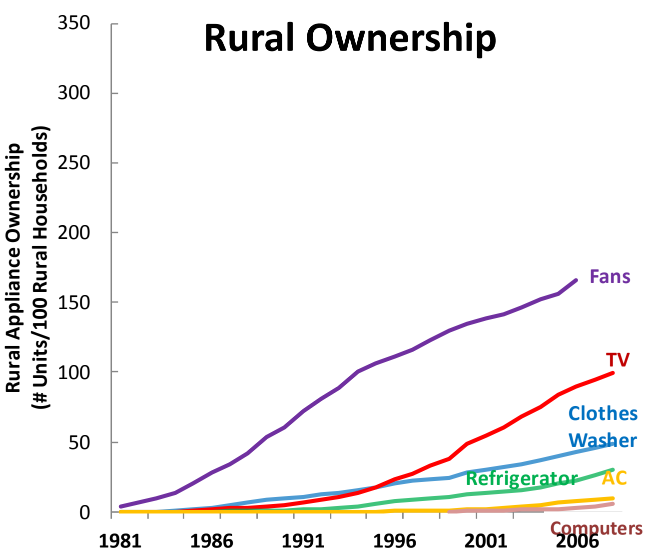
- Total residential electricity use in China growing at annual average of over 13% since 1990s
- Urbanization will further drive appliance ownership and usage

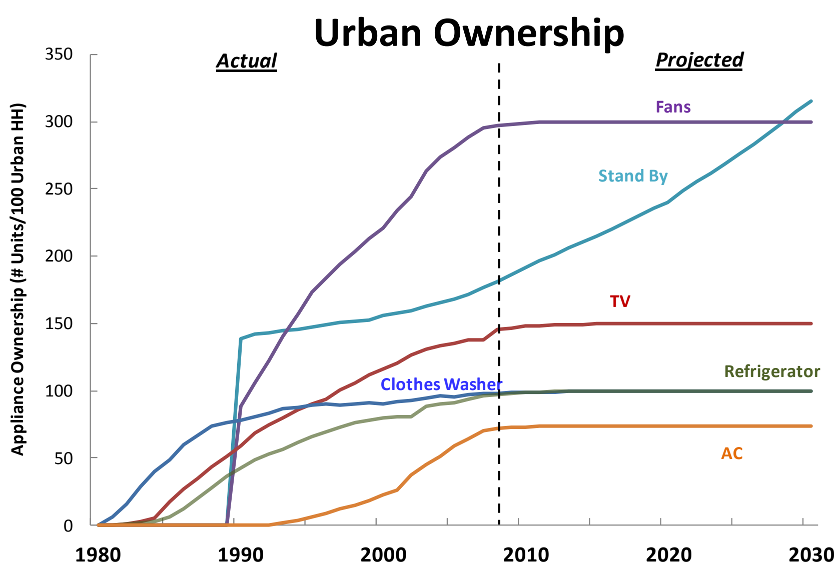


Source: National Bureau of Statistics, various years

Linkages between Urbanization and Appliance Ownership

- Rising disposable income driving appliance ownership and usage in Chinese cities, with greater demand for thermal comfort and energy services
- Rural ownership trends lag 15 years behind urban ownership, suggesting that more new appliances will be purchased and used by new urban households
- Recent government subsidies making appliances more affordable for rural households





China’s Appliance Efficiency Programs

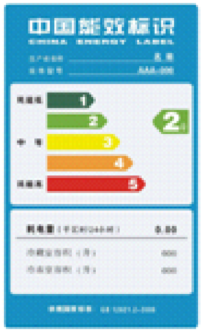
Regulatory Standards & Labeling (S&L) Programs:

1999: Voluntary energy efficient product certification

1989: Minimum Energy Performance Standards (MEPS) limit energy use for equipment
Now: covers 30+ products

Now: covers 40+ products

2005: Mandatory China energy information label.
Now: covers 20+ products



Financial Incentives:

- manufacturer subsidy program for efficient lighting
- 2009-2010 rebate for efficient (Grade 1 & 2) air conditioners

Focus on Mandatory Minimum Energy Performance Standards

Minimum Efficiency Standards

	1989	1990	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Domestic refrigerators/freezers		◆				◆				◆						◆	
Room air conditioners		◆					◆					◆					◆
Clothes washers		◆								◆							
Electric irons		◆															
Automatic rice cookers		◆															
Televisions		◆											◆				
Radio receivers and recorders		◆															
Electric fans		◆															
Fluorescent lamp ballasts							◆										
Small electric motors									◆					○			
Compact fluorescent lamps										◆							
Single-cap fluorescent lamps										◆							
Linear fluorescent lamps										◆							
Air Compressor										◆							
AC Electric Ventilating Fans										◆						○	
HPS lamps											◆						
HPS lamp ballasts											◆						
Chiller											◆						
Fans												◆					
Pumps												◆					
Commercial packaged AC												◆					
MH lamps													◆				
MH lamp ballasts													◆				
Instantaneous gas water Heaters														◆			
External power supplies														◆			
Small-medium sized three-phase asynchronous motors														◆			
Variable speed air conditioners															◆		
Multi-connected air condition (heat pump) unit															◆		
Electric storage water heaters															◆		
Household induction cooktop															◆		
Computer monitors															◆		
Copy machines															◆		
Printers																○	
Computers																○	
Servers																○	
Heat-Pump Water Heaters																○	
Range Hoods																○	
Grid Lighting																○	

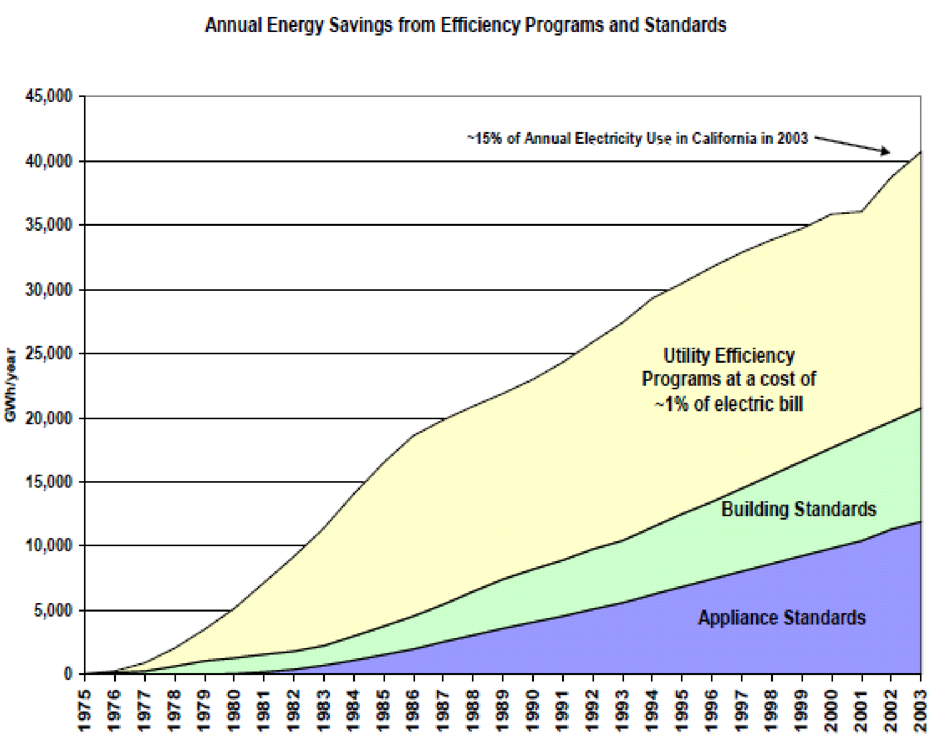
Pace of development accelerated with launch of "2010 Target" to reduce economic energy intensity by 20%

Importance of Evaluating Impact of Appliance S&L programs

Why S&L impact evaluations?

- Quantify energy and economic impacts of policies and programs
- Serve as basis for justifying program funding
- Assess the effectiveness of existing program design or implementation, identify weaknesses to be addressed

Example: California-mandated Impact Evaluation



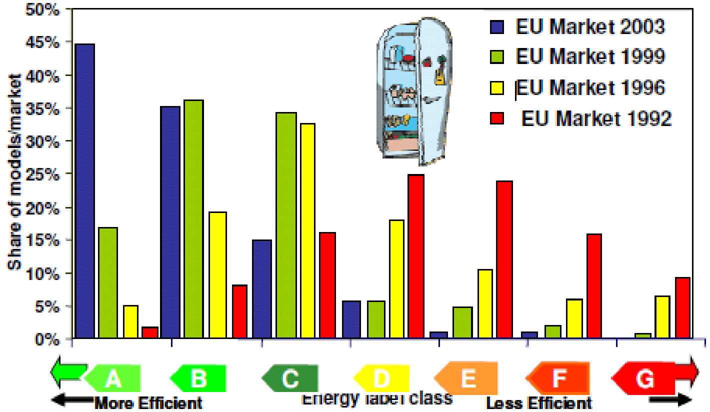
Source: Rosenfeld, California Energy Commission, 2008.

Potential Impact Evaluation of Appliances Efficiency Standards

- Help identify products with most energy savings potential for policy prioritization
- Quantify the impact of existing and future standard stringency and pace of revisions
- Evaluate and compare the impact of different efficiency levels of standard stringency
- Identify the potential for additional savings from reaching current world best practice MEPS or efficiency level

Other Impact Evaluations Not Covered

- Retrospective impact evaluation can also be done
  - Evaluates the energy savings and market transformation impact of existing policies
- Labeling Program Impact Evaluation: more difficult to assess
  - May require qualitative research to determine consumer decision-making behavior
  - Impacts occur over longer period time, more subtle than standards
  - Market data needs significant for evaluating market transformation
  - LBNL has done preliminary evaluation of China Energy Label for refrigerators, with estimates of 16 TWh annual savings possible by 2020



Source: Lebot, Benoit, "European Union: Cumulative experience from a mixture of voluntary & mandatory policy approaches" IEA Workshop on Energy Efficiency Standards and Labelling, Bangalore, Oct 2004

Study Focus: Potential Impacts of China's MEPS

- Focus specifically on residential and commercial products with standards that are:
  - Already in effect
  - Currently under development
  - Proposed for development in 2010
- Use stock turnover and scenario analysis to analyze potential energy savings and emission reduction from 2010 to 2030 from China's MEPS program
- Costs not considered because energy savings assumed to offset incremental cost of efficient appliances
- This study in numbers:

  1 Study

  2 Impact Evaluations and Bottom-up End-Use Models

  3 Scenarios of Efficiency

Overview of Two Impact Evaluations

	Evaluation 1	Evaluation 2
Purpose of Analysis	Evaluate the total savings potential of China's MEPS for all products	Evaluate the efficiency gap between existing MEPS and world best practice efficiency
Model Methodology	Simple stock turnover analysis	Stock turnover analysis with retirement function within larger bottom-up end-use model
Product Coverage	37 Products (Residential, Commercial, Industrial)	Subset of 11 Products (Residential only)
Evaluation Scenarios	Frozen Efficiency: baseline for measuring savings	Frozen Efficiency: baseline for measuring savings
	Continuous Improvement Scenario (CIS) at current pace of MEPS Revisions	Continuous Improvement Scenario (CIS) at current pace of MEPS Revisions
		Best Practice Scenario (BPS) of one-time improvement to current world best practice

Comparison of Products Coverage

Cooking Products: microwave, rice cookers,rangehoods

Office Equipment: computers, monitors, servers, fax, copiers, printers, external power supply

Additional Lighting: double-capped fluorescent, LED, grid lighting, high intensity discharge lamps

Commercial Products: vending machines, chillers, unitary AC

Industrial Products: air compressors, transformers, motors

Clothes Washer, TV, Refrigerator, Fans, AC , Fluorescent Ballast, Standby Power Use, Water Heaters , Stove

Best Practice Scenario evaluated products

Data Needs and Sources

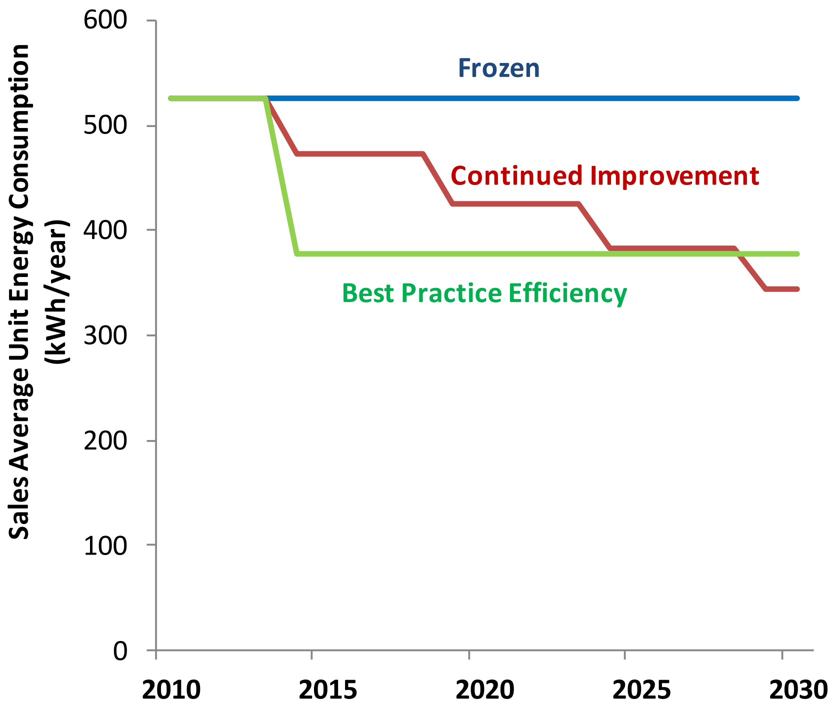
Annual production, sales, ownership rates	• National statistics • Market studies, media reports and websites	Long-term and ongoing collaboration with CNIS
Average efficiency, average kWh/year, current international best practice	• Various Chinese and international reports • International standards and testing information • Survey and metering data	
Usage Patterns (e.g., air conditioners)	• Econometric analysis based on historical international experience • Survey results	

Three Scenarios of Efficiency Analysis

Scenarios used to assess different pace of efficiency improvements through strengthening mandatory standards:

1. ***Frozen Efficiency Scenario:*** energy use (kWh/year) frozen at average level of first standard
2. ***Continued Improvement Scenario (CIS):*** MEPS revisions at likely pace of every 4-5 years with likely efficiency improvement of 5-10% given technical limitations
3. ***Best Practice Scenario (BPS)*** for selected 11 products: all new sales reach current international best practice in 2014

Example of Refrigerator

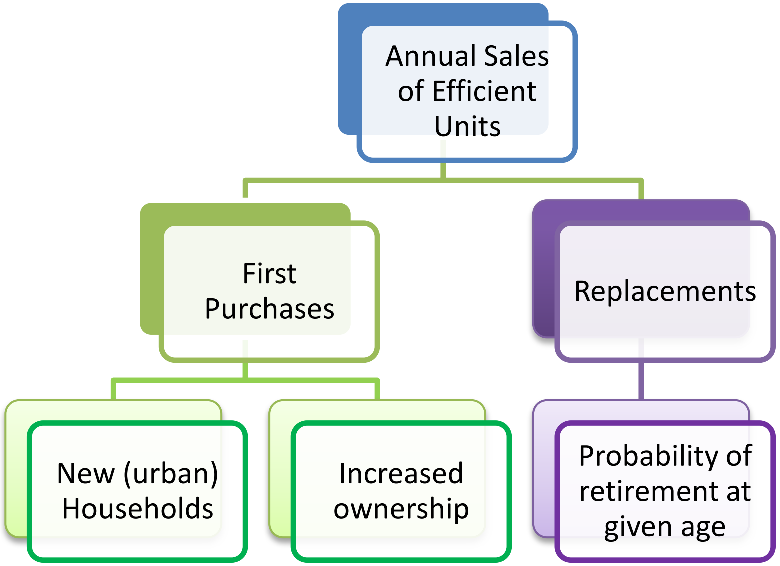


Comparison of Efficiency Assumptions

Product	CIS Scenario Assumption			BPS Scenario Assumptions	
	Standard Dates	Baseline Unit Energy Consumption	Efficiency Improvement per standard	Standard Date	One-time Efficiency Improvement
AC	2012 (compressor standard), 2014, 2019, 2024, 2029	396 kWh/yr	10%	2014	Baseline of 2.6 EER increases to 4 EER
Electric motors	2010	21, 816 kWh/yr	4.5%	2014	Average Efficiency of 87.9% increases to 92.4%
Refrigerators	2009, 2014, 2019, 2024, 2029	525 kWh/yr	10%	2014	Efficiency improves 38%
Heat Pump Water Heater	2011, 2016, 2021, 2026 and 2031	2065 kWh/yr	10%	2014	Not analyzed
TV	2009, 2014, 2019, 2024, 2029	132 kWh/yr	10%	2014	35% improvement
External Power Supply	2012	80 kWh/yr	28%	2014	Not analyzed
Standby	2020	64 kWh/yr	50%	2014	5W baseline lowered to 1W
Transformers	2011	8342 kWh/yr	25%	2014	Not analyzed
Computers/ Servers	2011	Desktop: 201 kWh/yr Laptop: 50 kWh/yr Servers: 2854 kWh/yr	Desktops: 17% Laptops: 10% Servers: 28.3%	2014	Not analyzed
Clothes washers	2010, 2015, 2020, 2025, 2030	135 kWh/yr	10%	2014	47% Improvement
Electric Water Heaters	2013, 2018, 2023, 2028	617 kWh/yr	5%	2014	76% Efficiency Baseline improves to 88%

Stock Turnover Analysis

Stock turnover analysis help understand the rate that products (of different efficiency) enter households and subsequent impact on energy use



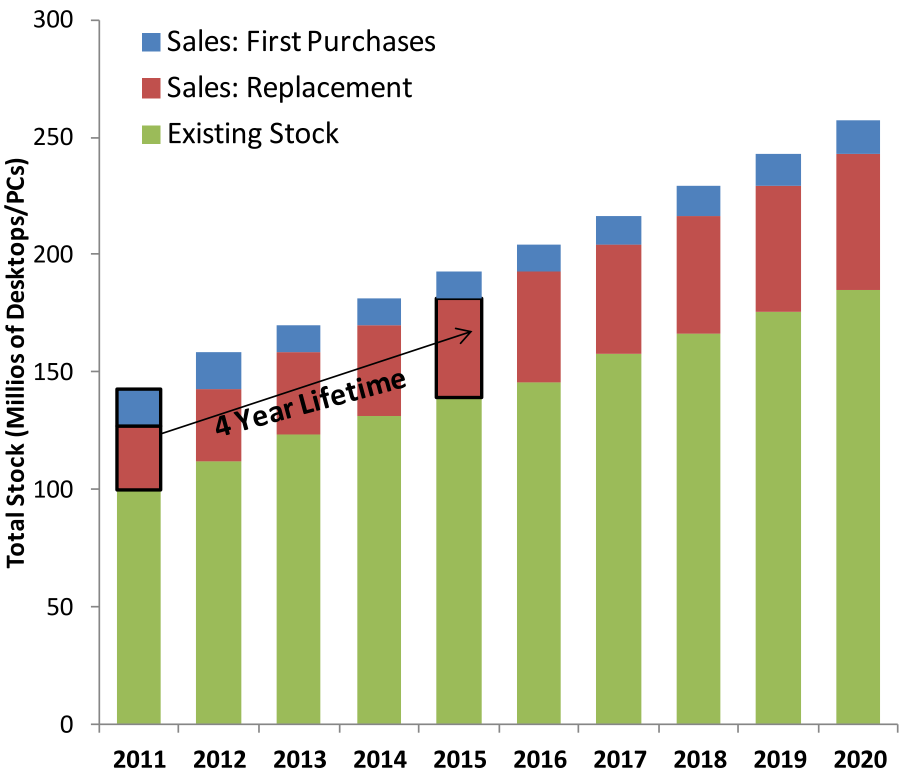
Calculated as Δ stock over time; with ownership as a function of income

Modeled using retirement function

Evaluation 1: Total Savings Potential

- Simple turnover spreadsheet analysis due to product specificity and limited data: 26 products
- Historical and projected sales and stock data provided by CNIS or collected from literature review
- Standard unit efficiency gain (average savings per year from standard)
- Given year's sales all retired at end of lifetime

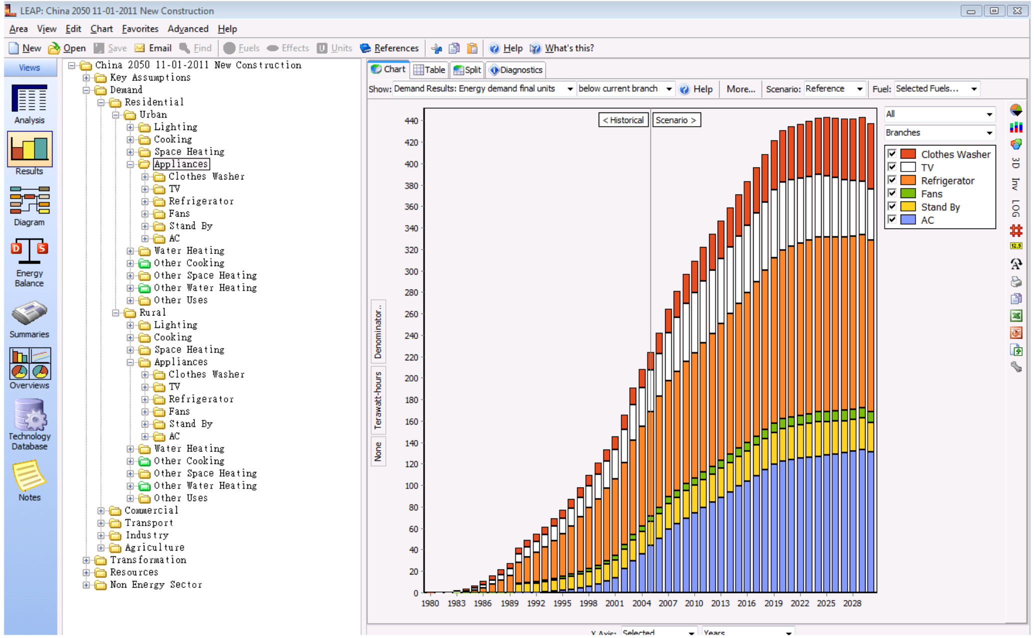
Example: Desktop Simple Stock Turnover Analysis



Evaluation 2: Best Practice Gap Analysis

- More detailed data and complex stock turnover analysis possible for 11 major residential products
- Modeled using customized bottom-up, technology-specific Long range Energy Alternatives Planning (LEAP) model
- Ownership and some usage linked directly to macroeconomic parameters such as urbanization, household income growth, floorspace

LEAP *Tools for Sustainable Energy Analysis*



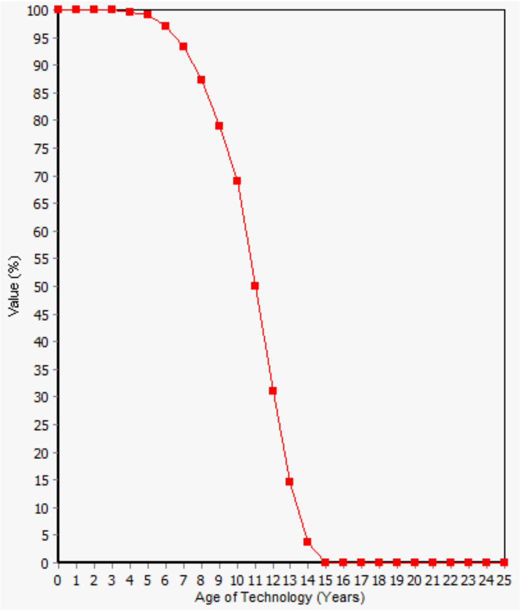
Detailed Product Sales and Energy Use Forecast

- Detailed macroeconomic drivers of first purchases: economic activity, population and household size, urbanization, dwelling area – aligned with China's targets and plans
- Diffusion model to examine relationship between macroeconomic drivers and appliance ownership, based on international trends
- Differentiation between urban and rural household ownership rates
- Regression model to examine changes in size and usage due to macroeconomic drivers such as income

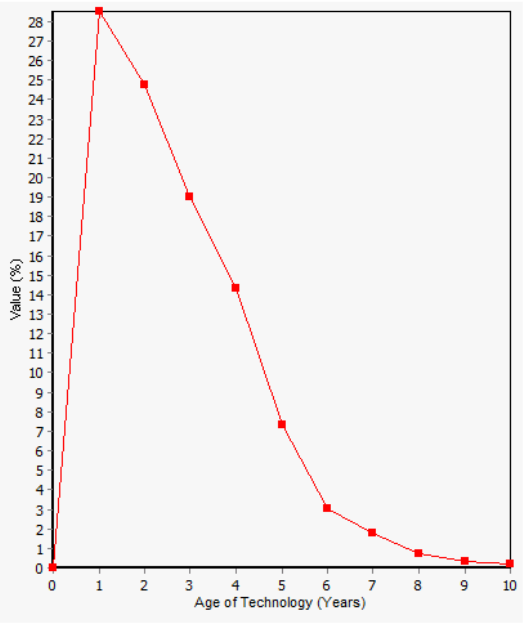
Retirement Function

- Retirement function with different probability of retirement for product's given age based on actual experiences
- Specific retirement function enables age profile for total stock

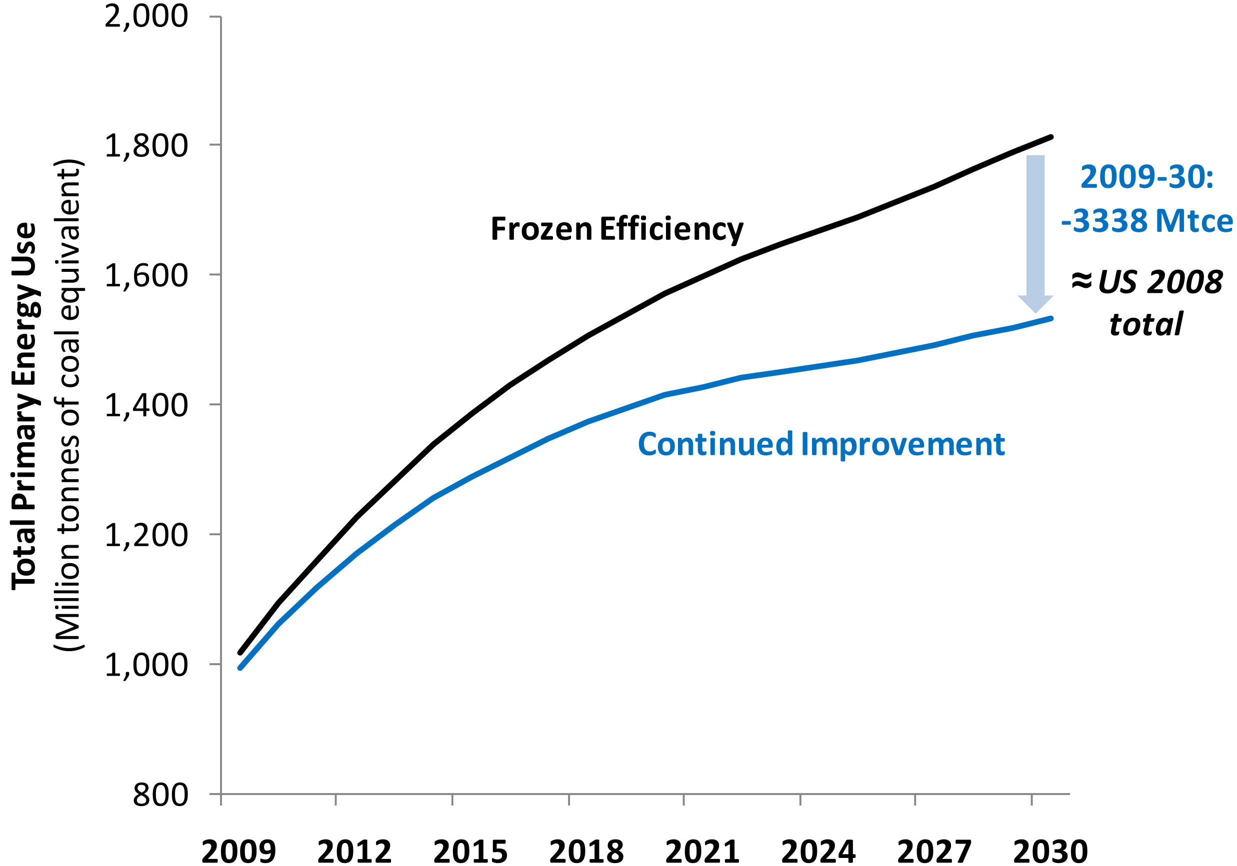
Retirement Function of Refrigerators



Stock Age Profile of Refrigerators

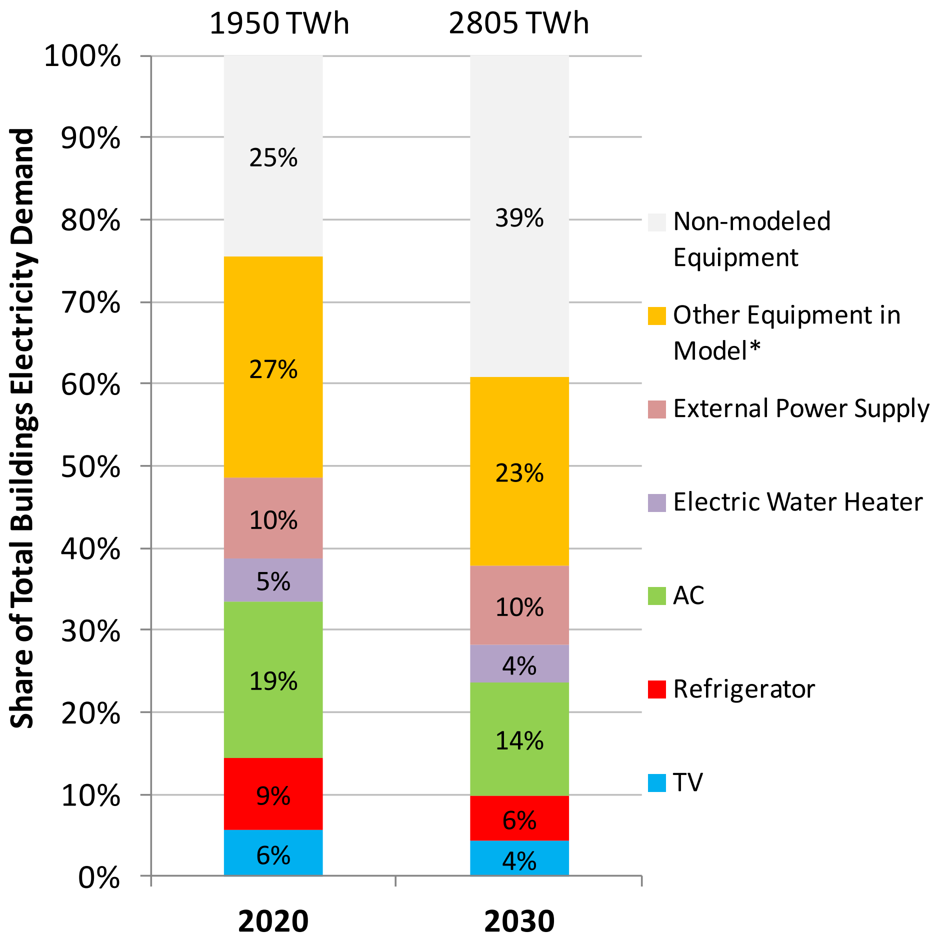


Evaluation 1: Energy Savings Potential of All 37 Products

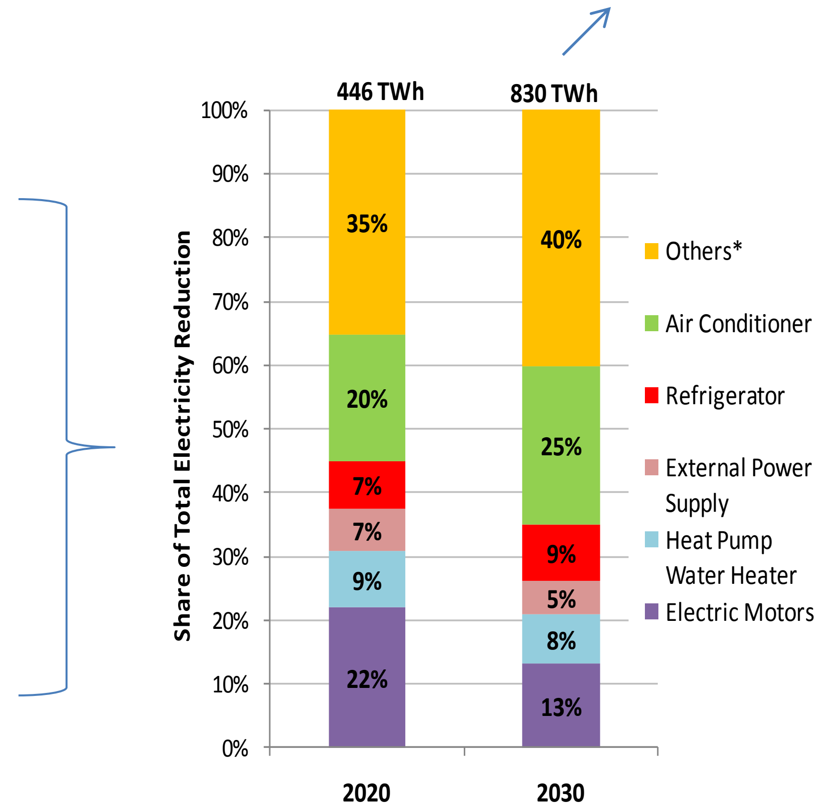


Note: Y-axis not set at zero. 1 million tonnes of coal equivalent = 29.27 million GJ. Electricity converted to primary (source) coal equivalent using 0.404 kilograms of coal equivalent per kWh.

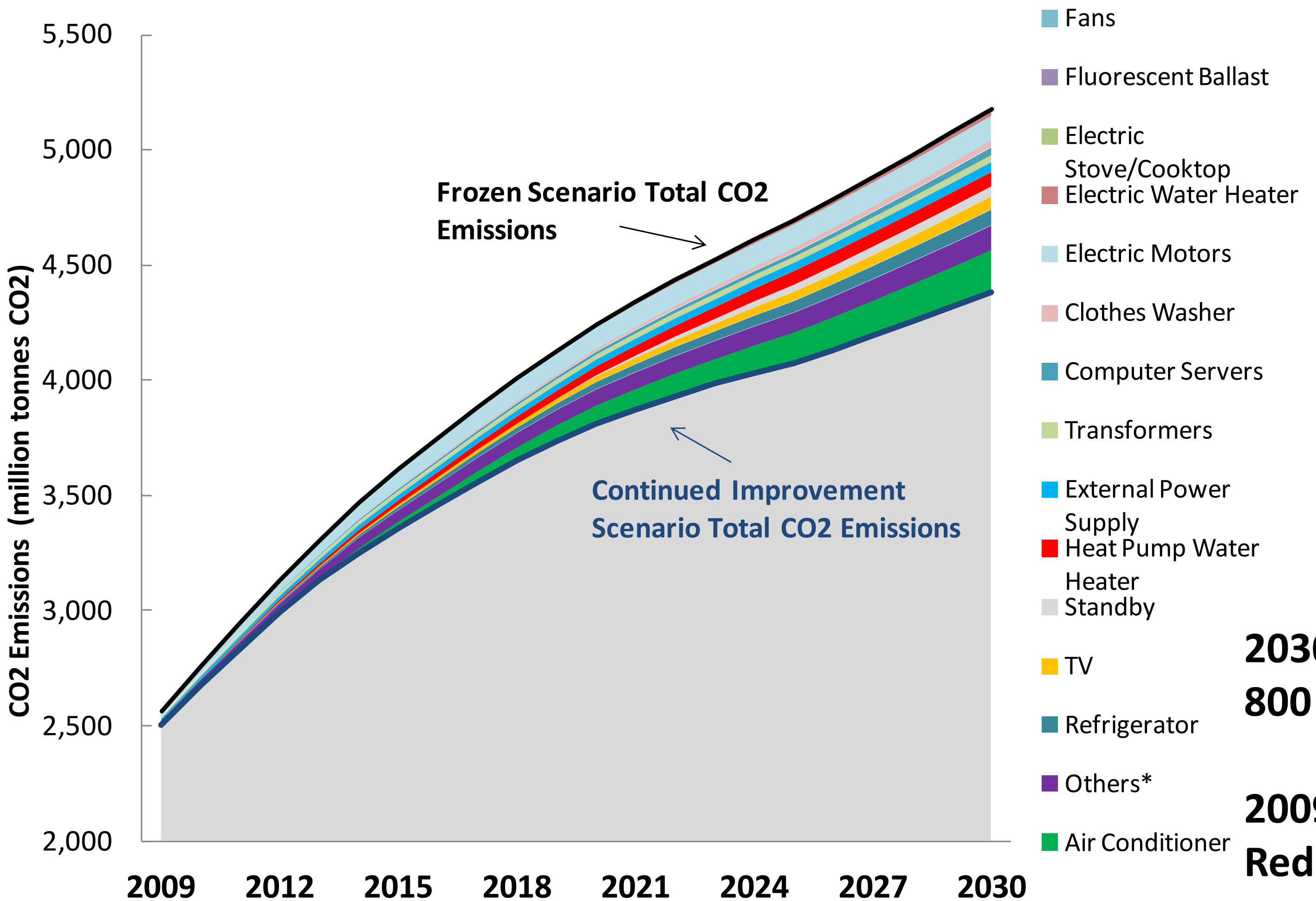
Total Potential Electricity Savings from Continued Efficiency Improvement for All Products



Reduction = 30% of total building electricity demand; 12% of total electricity demand



CO_2 Emissions Reduction Potential of MEPS for All Products

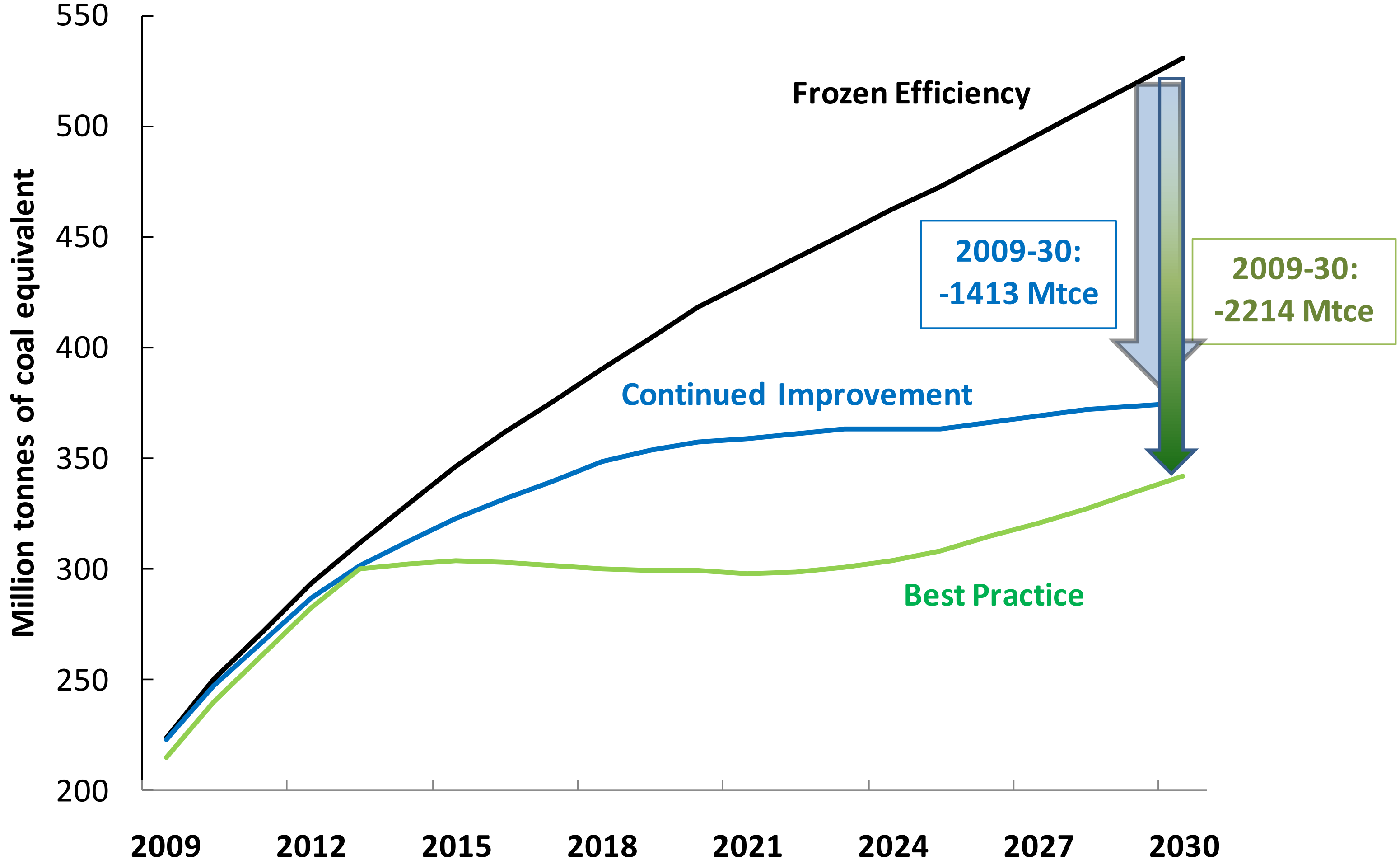


2030 Annual Reduction: 800 Mt CO_2

2009 – 2030 Cumulative Reduction: 9160 Mt CO_2

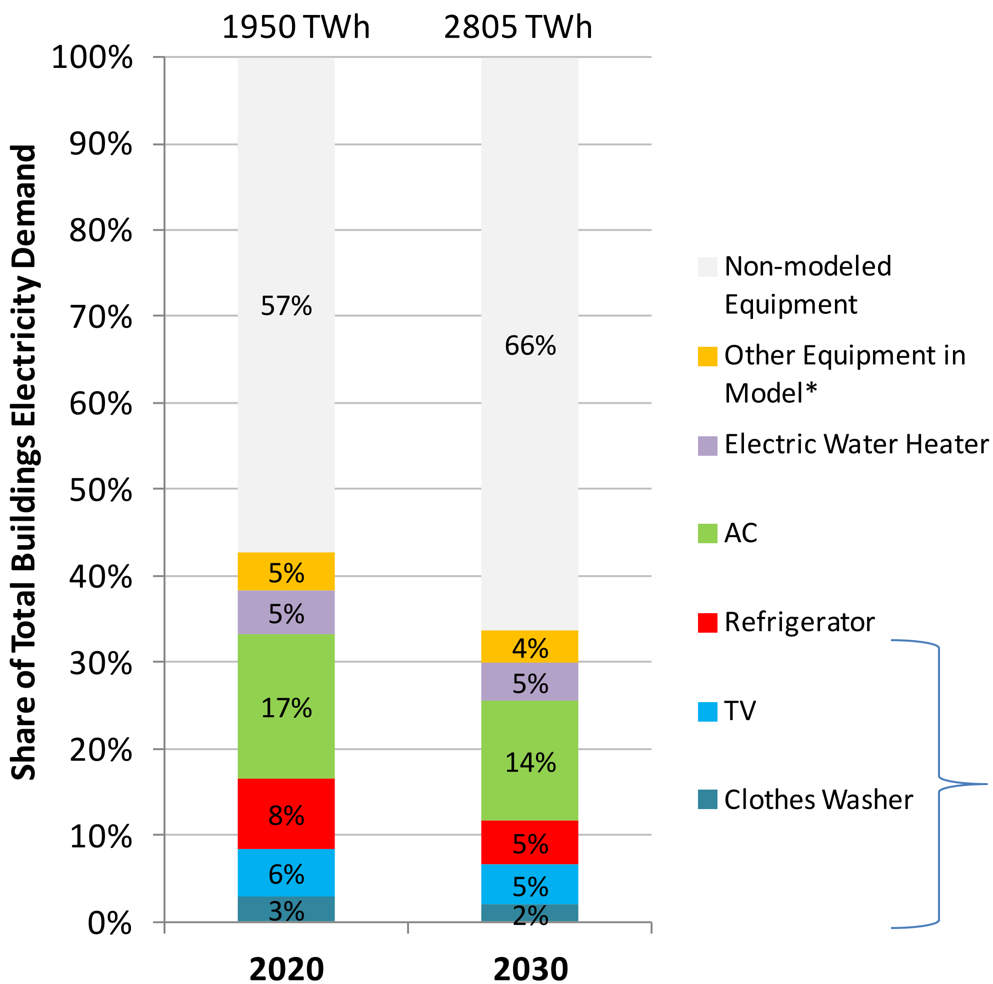
Note: Y-axis not set to zero. constant emission intensity per kWh generated is assumed for 2009-2030.

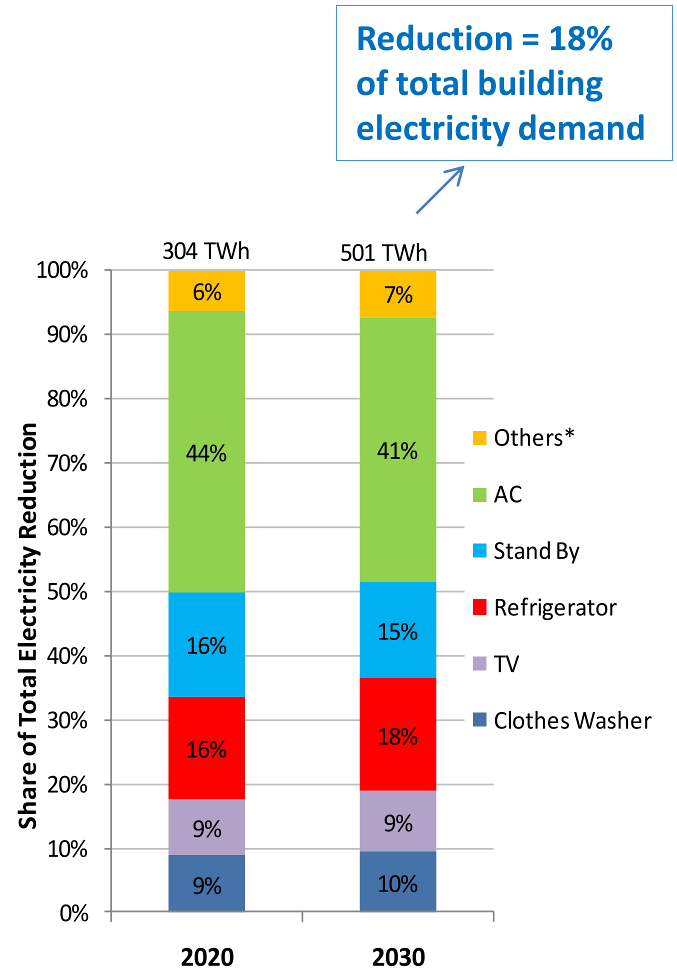
Evaluation 2: Efficiency Gap from Current World Best Practice



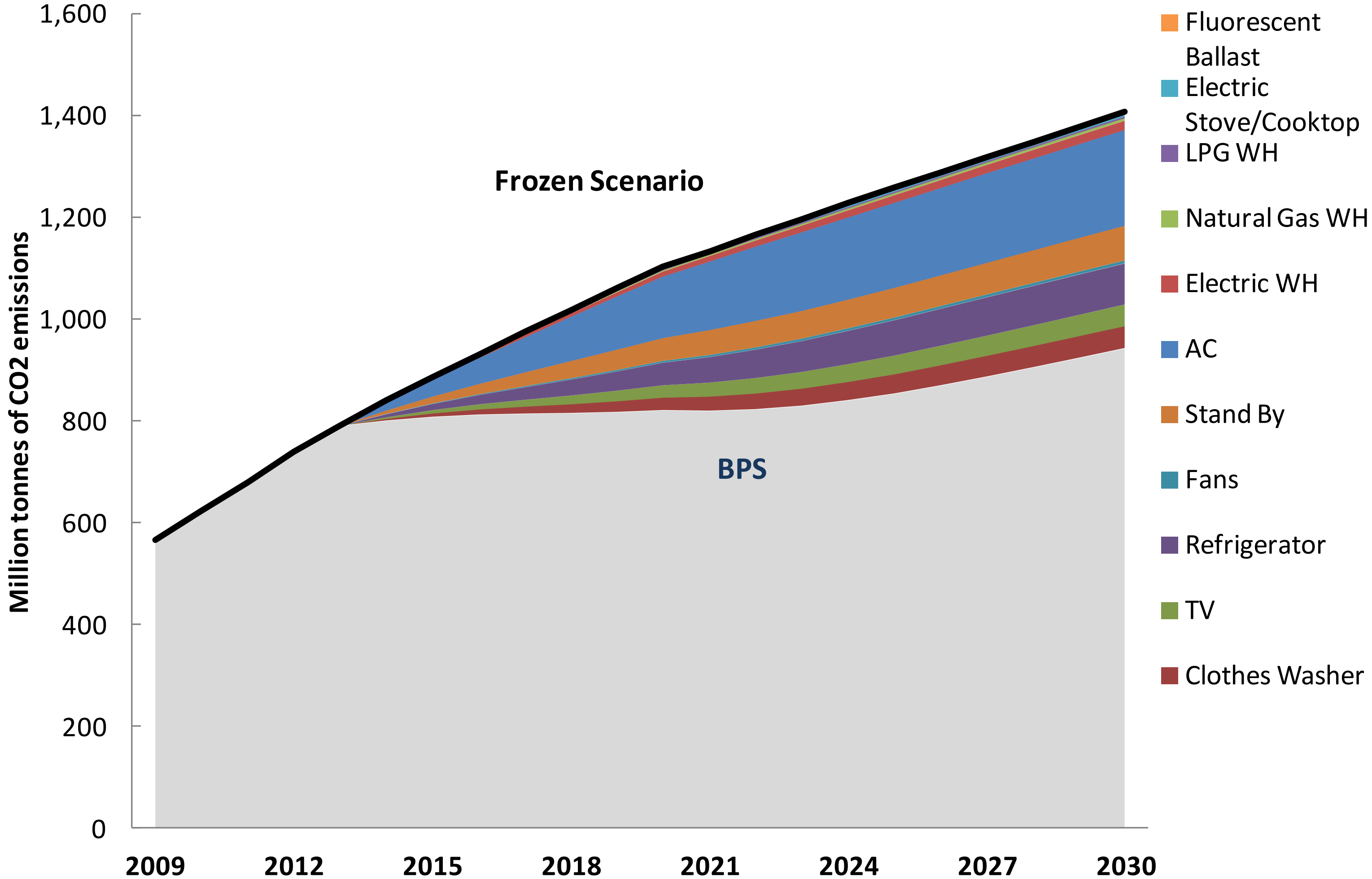
Note: Y-axis not set at zero.

Total Potential Electricity Savings from Best Practice Efficiency of 11 Selected Products



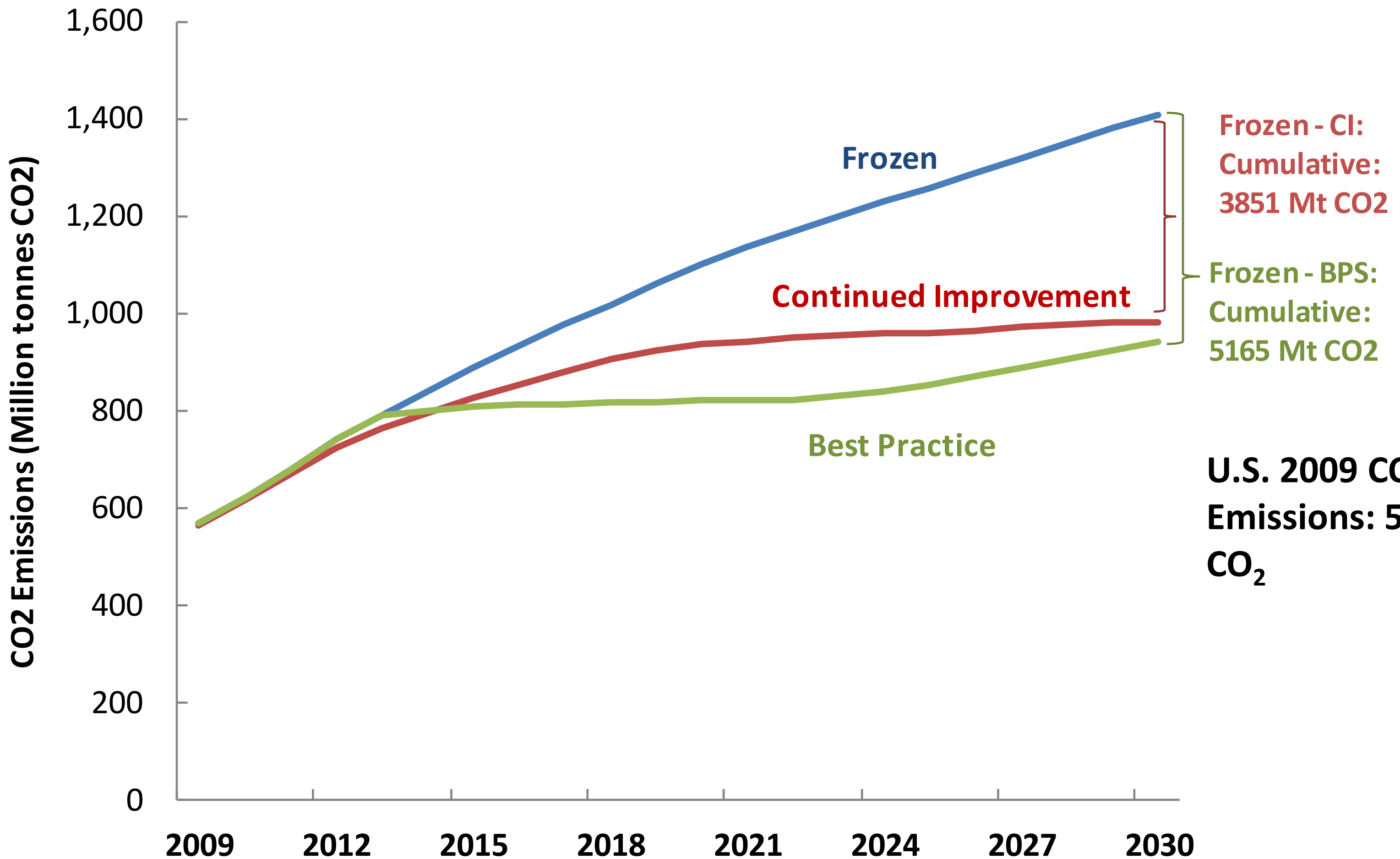


CO_2 Emissions Reduction Potential of Best Practice Efficiency for 11 Selected Products



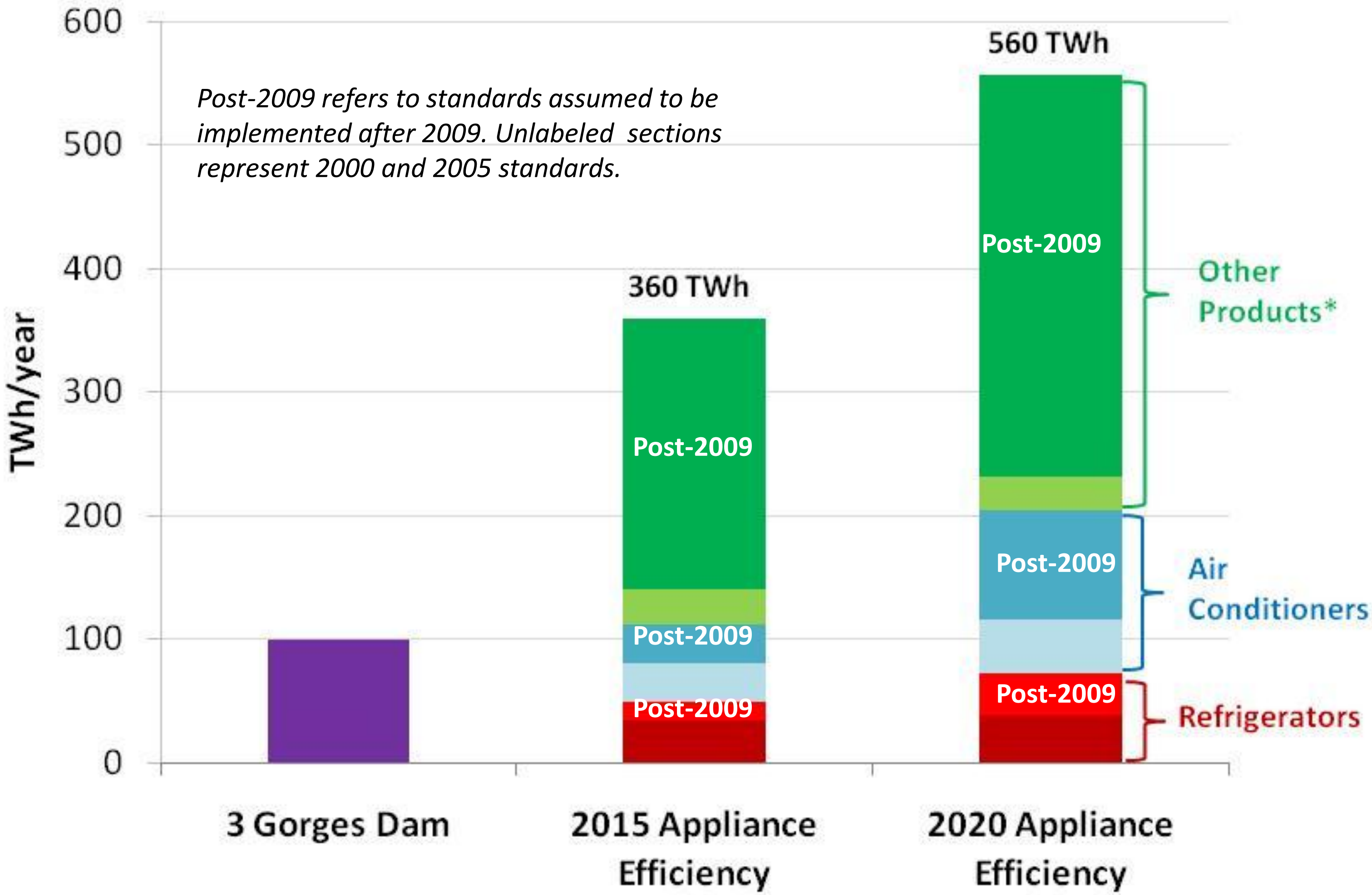
Note: constant emission intensity per kWh generated is assumed for 2009-2030.

Comparison of CO_2 Emission Reduction for 11 Selected Products under 3 Scenarios



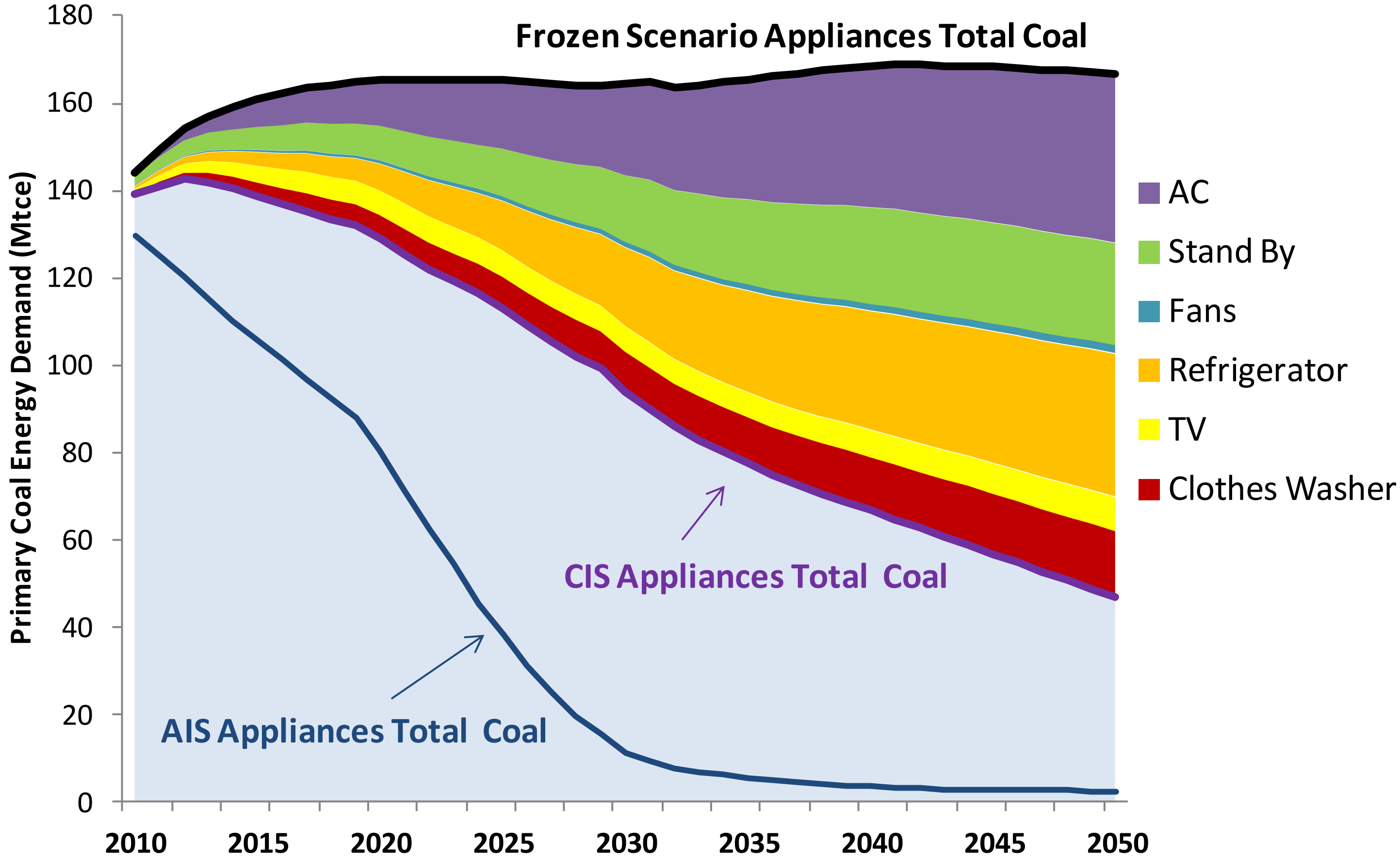
U.S. 2009 CO_2 Emissions: 5405 Mt CO_2

Annual generation from China's Three Gorges Dam compared to annual *savings* in 2015 and 2020, from 20 years of sales of equipment subject to China's energy efficiency standards



*Other 34 products

Contextualizing Potential Savings in terms of Coal: 2790 Mtce cumulatively to 2050 possible



Note: Both CIS and AIS scenarios in this study assumes significant decarbonization of China's power sector after 2010, with high renewables and nuclear generation.

Key Findings

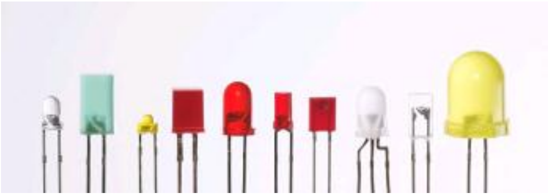
- Continuous improvement of current standards can achieve cumulative reduction of 9503 TWh by 2030 (~ 2009 OECD electricity generation) and 16% lower annual CO_2 emissions than frozen efficiency
- If selected products can reach international best practice efficiency, cumulative reduction of 5450 TWh and 35% lower annual CO_2 emissions are possible
- Equipment efficiency standards in place (excluding motors, transformers and air compressors) can save 6947 TWh cumulatively by 2030, or 14% of cumulative consumption of building electricity to 2030

Conclusions

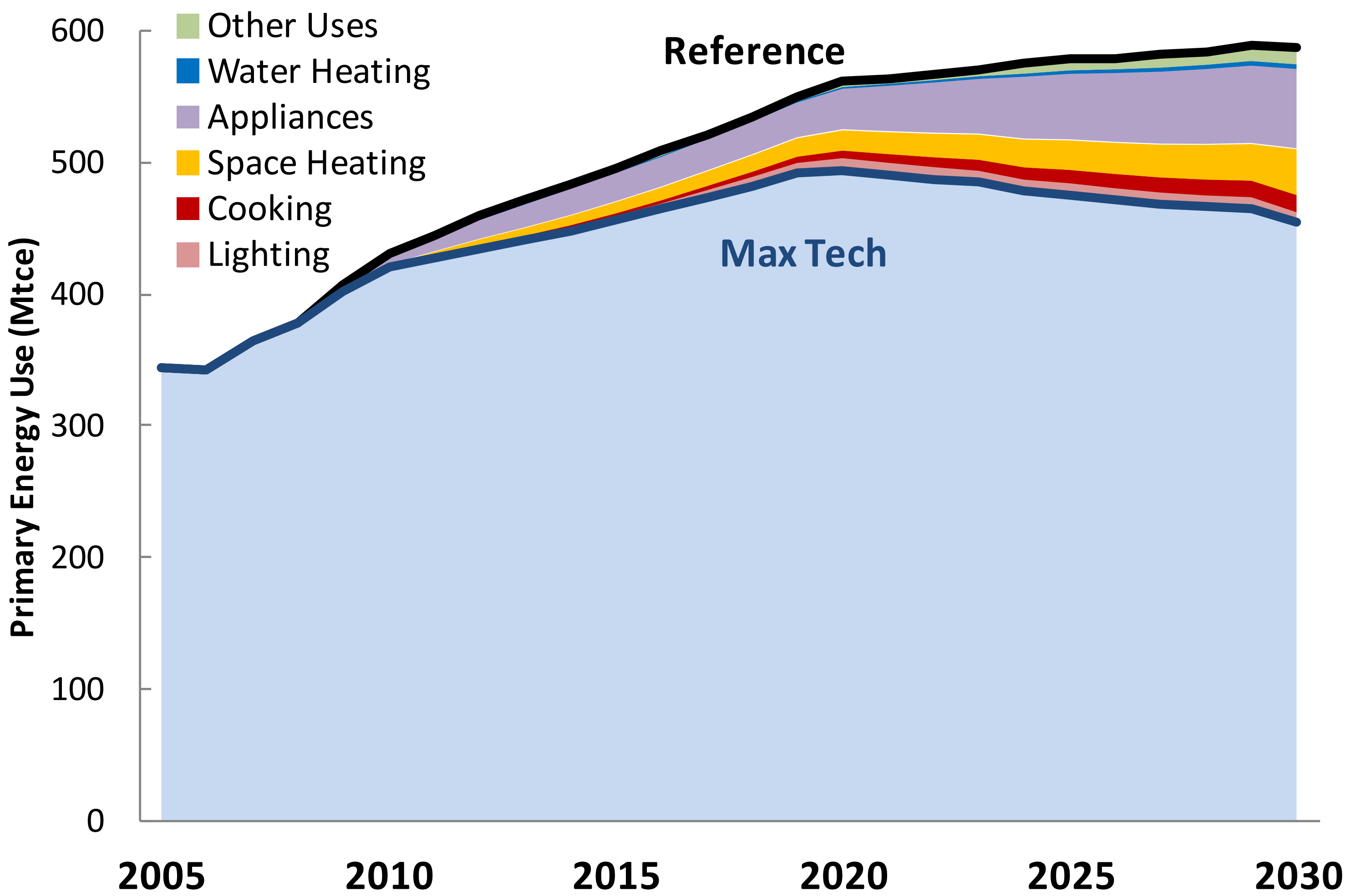
- **Simple stock turnover analysis** can provide **quick assessment of potential impact** of mandatory appliance efficiency standards, especially in absence of detailed data
- **Detailed bottom-up modeling and stock turnover analysis** provide insight on **complex linkages** between economic activity and residential energy consumption
- Efficiency standards help **decelerate growth** in China's residential energy demand, but **total demand still rises** with urbanization
- **Similar magnitudes** of potential savings between **large one-time improvement and more frequent incremental improvements** – pace depends on specific country's standard-setting process
- **Continued efficiency improvements** with regularly scheduled standards revisions can **achieve significant energy saving potential** but **require continuous strengthening of ES&L program**

Other Related Appliances Potential Impact Evaluation Work: Max Tech Savings Potential

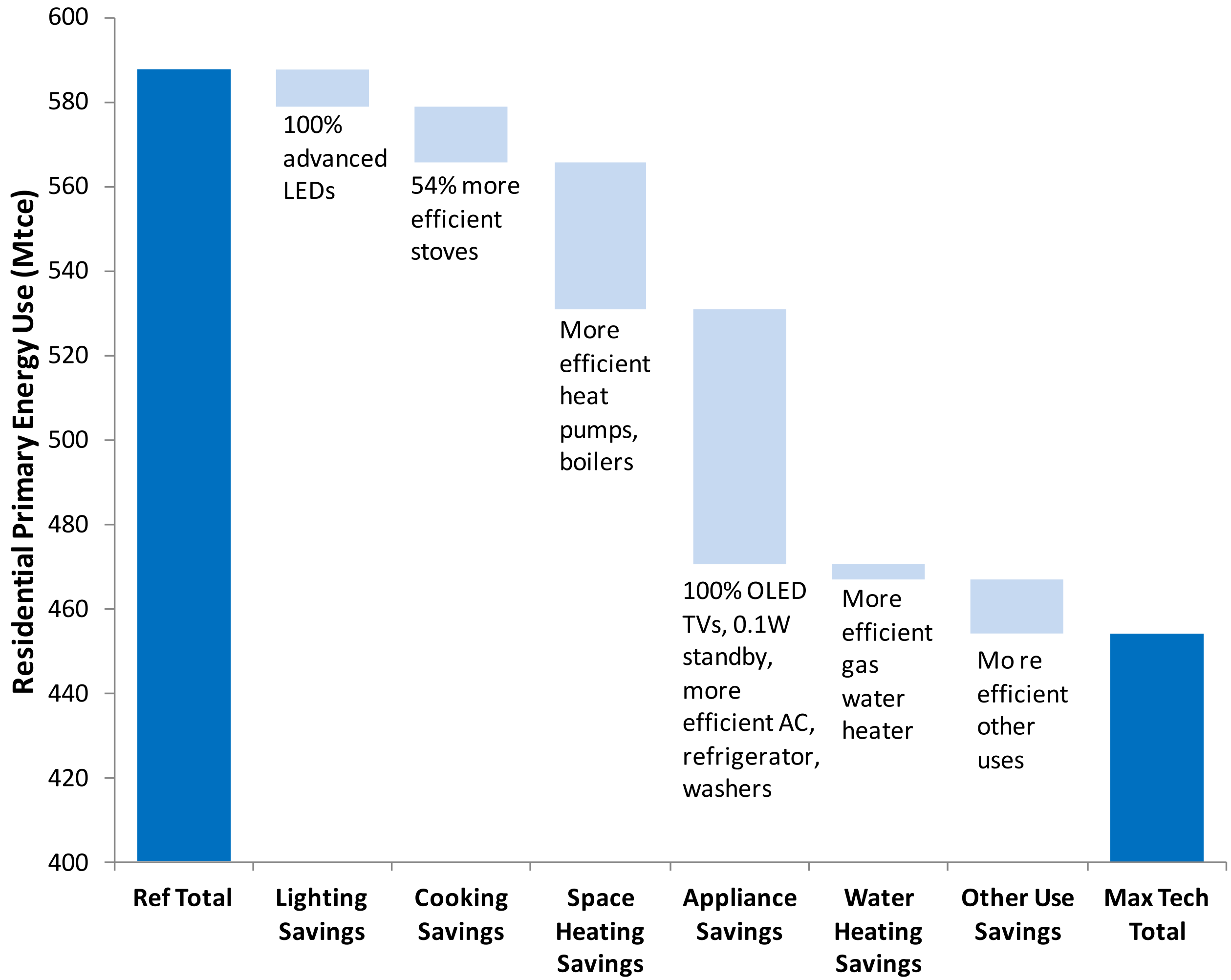
- Evaluation of potential savings from achieving best available technology (BAT) that is not necessarily commercially available yet for all residential end-uses between 2010 to 2030
- Researched the maximum technical feasibility levels of efficiency for each technology type worldwide, including: Organic Light-Emitting Diodes (OLED) TVs, advanced LED lights, heat pump water heaters
- "Max Tech" scenario modeled in LEAP model, assuming BAT levels reached by 2030, with aggressive shifts in technology shares and efficiency improvements



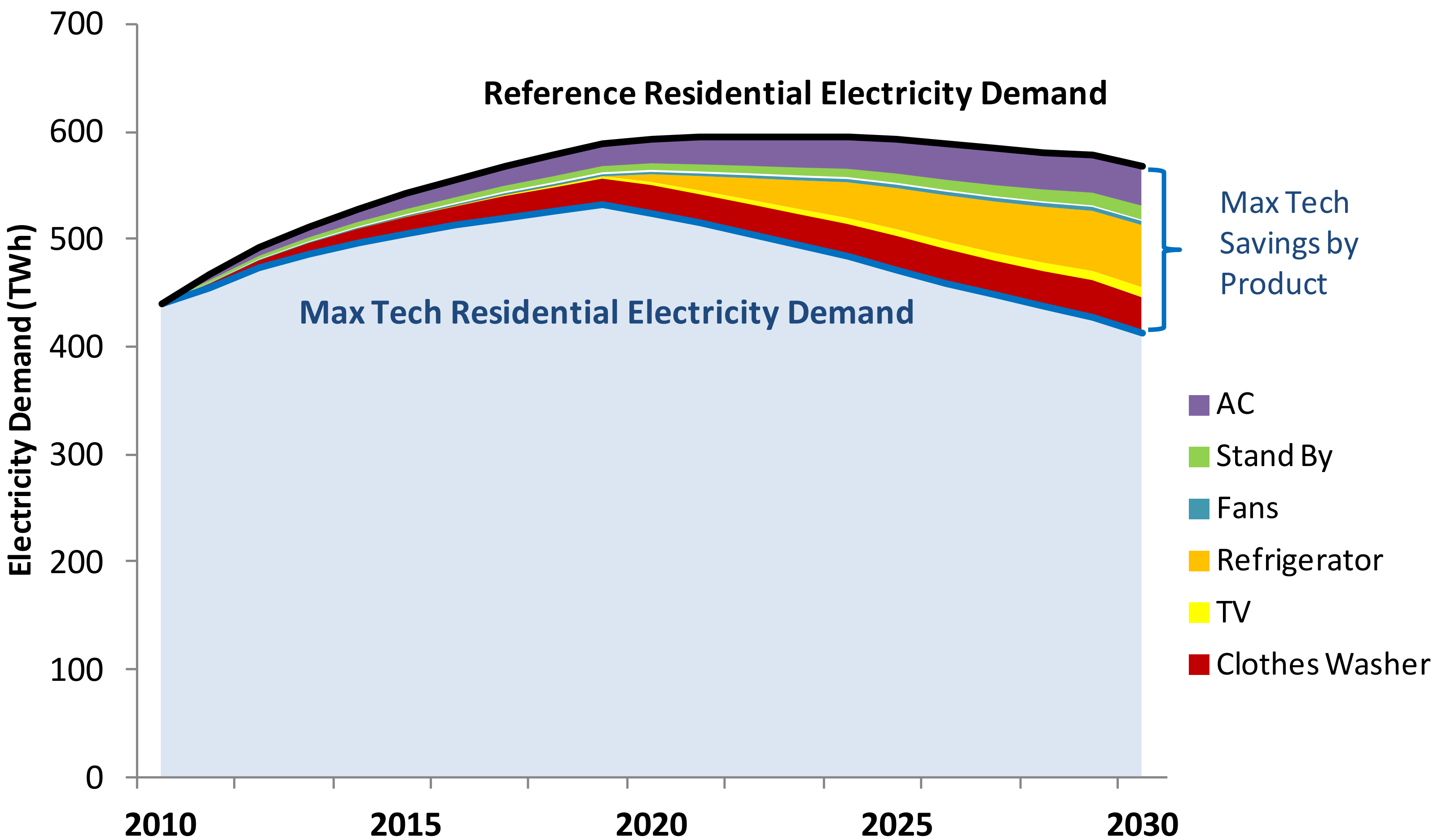
Study Results: Most of Max Tech Savings Potential in Residential Sector from Appliances



Appliances Contribute 45% of 2030 Residential Energy Savings from Max Tech



Achieving Max Tech Efficiency Could Reduce Residential Electricity Demand by 27% in 2030



Cumulative electricity savings from Max Tech efficiency: 1610 TWh

Areas of Further Work Needed

- Impact and market transformation evaluation of China's mandatory Energy Label program, subsidy programs
- Evaluation of changes in size due to consumer preferences and impact on energy consumption
- Cost-effectiveness analysis, especially for emerging very high-efficiency products

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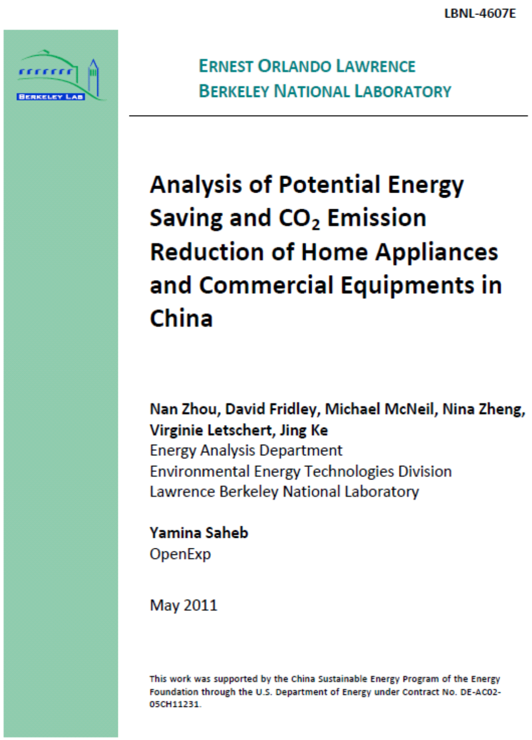
Full Study:



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Analysis of Potential Energy Saving and CO_2 Emission Reduction of Home Appliances and Commercial Equipments in China

Nan Zhou, David Fridley, Michael McNeil, Nina Zheng, Virginie Letschert, Jing Ke
Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

Yamina Saheb
OpenExp

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Acknowledgements and Contact Info

Co-authors: David Fridley, Michael McNeil, Virginie Letschert, Jing Ke and Yamina Saheb

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Nina Zheng
Email: xzheng@lbl.gov
Phone: +1-510-486-4537

Nan Zhou
Email: nzhou@lbl.gov
Phone: +1-510-486-5534

Website: http://china.lbl.gov
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS90R4000
Berkeley, California, 94720
U.S.A

Diffusion Model of Appliance Ownership

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$$Diff(year) = \frac{\alpha}{1+\gamma \exp\left(\beta_{Inc} \times I(year)\right)}$$

- α is the maximum diffusion per 100 households (could be greater than 100). For rural households, α is the diffusion in urban household for the same income level.
- I (*year*) is the average per household income in *year*
- γ and β_{Inc} are scale parameters based on the regression model

End Use	α	$\ln\gamma$	β_{year}	β_{Inc}	R^2
Clothes Washer	100	-0.9		-6.64E-05	0.97
TV	150	1.06		-9.63E-05	0.96
Refrigerator	100	0.93		-9.76E-05	0.98
Air Conditioner	100	439.54	-0.22	-1.12E-04	0.99