U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

Multi-Year Program Plan

PRELIMINARY DRAFT

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List of Abbreviations and Acronyms

AC – Air Conditioning
AEDG – Advanced Energy Design Guides
AERG – Advanced Energy Retrofit Guides
AEO – Annual Energy Outlook
AFUE – Annual fuel utilization efficiency
AHRI – Air-Conditioning, Heating & Refrigeration Institute
AIA – American Institute of Architects
API – Application Programming Interface
ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASRAC – Appliance Standards and Rulemaking Federal Advisory Committee
ARRA – American Recovery and Reinvestment Act
BAS – Building Automation System
BBNP – Better Buildings Neighborhood Program
BBRN – Better Buildings Residential Network
BEC – Building Energy Codes
BTO – Building Technologies Office
BEC – Building Energy Codes Program
BEDES – Building Energy Data Exchange Standard
BEM – Building Energy Modeling
BLAST – Building Loads and System Thermodynamics
BOMA – Building Owners and Managers Association
BPD – Building Performance Database
BR – Bulge Reflector
CALiPER – Commercially Available LED Product Evaluation and Reporting
CBECS – Commercial Buildings Energy Consumption Survey
CBEI – Center for Building Energy Innovation
CBI – Commercial Buildings Integration
CCHP – Cold Climate Heat Pump
CEC – California Energy Commission
CERL – Construction Engineering Research Lab
CFL – Compact Fluorescent Lamp
COP – Coefficient of Performance
CRADA – Cooperative Research and Development Agreements
DOE – The Department of Energy
DR – Demand Response
EDAPT – Energy Design Assistance Program Tracker
EERE – Office of Energy Efficiency and Renewable Energy
EIA – Energy Information Administration
EIFS – Exterior Insulation and Finish Systems
EIMA – EIFS Industry Members Association
EISA – Energy Independence and Security Act
ER – Elliptical Reflector
ERDA – Energy Research and Development Administration
EPA –Environmental Protection Agency
EPACT – The Energy Policy Act
EPCA – Energy Policy Conservation Act
EPRI – Electric Power Research Institute
ET – Emerging Technologies
EUI – Energy Use Intensity
FACA – Federal Advisory Committee Act
FOA – Funding Opportunity Announcement
FLEXLAB –Facility for Low Energy Experiments in Buildings

FRP – Flexible Research Platform
FTC – Federal Trade Commission
GE – General Electric
GDP – Gross Domestic Product
GHG – Greenhouse Gas
GHP – Geothermal Heat Pump
GWP – Global Warming Potential
GSA – General Services Administration
Gsf – Gross Square Feet
HES – Home Energy Score
HERS – Home Energy Rating System
HIT – High-Impact Technology
HP – Heat Pump
HPWH – Heat Pump Water Heater
HSPF – Heating Seasonal Performance Factors
HVAC – Heating, Ventilation and Air Conditioning
HX – Heat Exchanger
IALD – International Association of Lighting Design
IBPSA – International Building Performance Simulation Association
ICC – International Code Council
IEA – International Energy Agency
IEA HPP – International Energy Agency Heat Pump Programme
IECC – International Energy Conservation Code
IEER – Integrated Energy Efficiency Ratio
IES – Illuminating Engineering Society
IEQ – Indoor Environmental Quality
IFC – Industry Foundation Classes
IHP – Integrated Heat Pump
IIR – International Institute of Refrigeration
IR – Infrared
kBtu – Kilo British Thermal Unit
Klm – Kilolumen
kWh – Kilowatt-Hour
LBNL – Lawrence Berkeley National Lab
LCCP – Life Cycle Climate Performance
LED – Light-Emitting Diode
LEED – Leadership in Energy and Environmental Design
LEEP – Lighting Energy Efficiency in Parking
Lm – Lumens
Low-E – Low-Emissivity
OLED – Organic Light-Emitting Diode
ORNL – Oak Ridge National Laboratory
NAS – National Academy of Sciences
NASA – National Aeronautics and Space Administration
NECAP – NASA Energy Cost Analysis Program
NETL – National Energy Technology Laboratory
NFRC – National Fenestration Rating Council
NGBS – National Green Building Standard
NIST – National Institute for Standards and Technology
NREL – National Renewable Energy Laboratory
MELS – Miscellaneous Electric Loads
MoWiTT – Mobile Window Thermal Test Facility
MW – Megawatt
MWh – Megawatt-Hour

MYPP – Multi-Year Program Plan
OLED – Organic Light-emitting Diode
PNNL – Pacific Northwest National Laboratory
PV – Photovoltaics
R&D – Research and Development
RBI – Residential Buildings Integrations
RECS – Residential Energy Consumption Survey
REEO – Regional Energy Efficiency Organization
RFI – Request for Information
RTU – Rooftop Unit
SCOP – Seasonal Coefficient of Performance
SEE – State and Local Energy Efficiency
SEED – Standard Energy Efficiency Data Platform
SEER – Seasonal Energy Efficiency Ratings
SHGC – Solar Heat Gain Coefficient
SSL – Solid-State Lighting
SSLC – Separate Sensible and Latent Cooling
tBTu – Trillion British Thermal Units
Tlm-hr – Teralumen-Hour
TWh – Terawatt-Hour
V_T – Visible Transmittance
WH – Water Heating
WUFI – Wärme und Feuchte Instationär

Executive Summary

The Department of Energy (DOE) Building Technologies Office (BTO) is leading a network of national laboratory, university, small business, and industry partners to develop innovative, cost-effective energy saving solutions for U.S. buildings, which are the single largest energy-consuming sector in the nation. In 2013, residential and commercial buildings used more than 40% of the nation's total energy and more than 70% of the electrical energy, resulting in an estimated annual national energy bill totaling $410 billion.[1] Widespread adoption of existing energy-efficient building technologies—and the introduction and use of new technologies—could eventually reduce energy use in homes and commercial buildings by 50%. This would save more than $200 billion annually and reduce U.S. energy-related greenhouse gas (GHG) emissions by about 20% compared to 2010 levels.

The United States has made significant progress in improving energy efficiency over the last 30 to 40 years, due in part to the successful efforts of BTO. These efforts have led to game-changing achievements, such as transformative new technologies in solid-state lighting, energy saving windows, heat pump water heaters, and high-efficiency furnaces and air conditioners. Other noteworthy achievements include implementation of energy conservation standards for more than 60 categories of appliances and equipment, as well as building energy codes leading to more efficient homes and commercial buildings. Efficiency gains from these codes and standards will result in $950 billion in cumulative utility bill savings for U.S. consumers by 2020.[2]

BTO is one of eight technology offices within DOE's Office of Energy Efficiency and Renewable Energy (EERE), which is leading DOE efforts to help build a strong clean energy economy while also reducing our reliance on foreign oil, saving families and businesses money, and reducing pollution. BTO's work is a key part of the Obama Administration's "all-of-the-above" energy strategy and the president's Climate Action Plan, contributing to two of four national energy goals.[3,4] (See text box titled *BTO Contributes to National Goals*, on page 13.

BTO focuses on accelerating the pace of innovation in technologies for both existing buildings and new construction. BTO also supports public and private sector efforts to make available cost-effective products and solutions that will greatly reduce energy use, improve building comfort, and enhance the services provided to building occupants. With targeted investments and effective public and private partnerships in both the new and existing buildings markets, BTO will continue to drive innovations to market and raise the bar for energy efficiency.

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[1] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[2] Office of Energy Efficiency & Renewable Energy. *Appliance and Equipment Standards: History and Impacts*. Washington, DC: U.S. Department of Energy. Accessed August 19, 2015.

[3] *Obama Administration Record on an All-of-the-Above Energy Strategy*. Washington, DC: The White House, March 2012. Accessed May 8, 2014: http://www.whitehouse.gov/sites/default/files/docs/clean_energy_record_0.pdf.

[4] http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

BTO's **vision** is a strong and prosperous America in which all homes and buildings operate at peak energy performance, are affordable, and provide optimal health conditions and comfort.

BTO's **mission** is to develop, demonstrate, and accelerate the adoption of technologies, techniques, tools, and services that are affordable, as well as to enable high-performing, energy-efficient residential and commercial buildings in both the new and existing buildings markets.

This mission requires a multi-pronged strategy to address diverse market, technology, and regulatory challenges. BTO's strategy, or ecosystem, shown in Figure 1 below, includes:

- **Research and development** to reduce cost and improve performance of high-impact energy saving technologies.
- **Market stimulation** activities to validate energy-efficient technologies and practices in new and existing buildings; reduce risk for builders, building owners and operators, and consumers to incorporate new energy-efficient solutions; and spur private sector investments in energy efficiency.
- **Codes and standards** to remove market barriers, lock in lasting energy savings for all Americans, and drive further technology innovation.

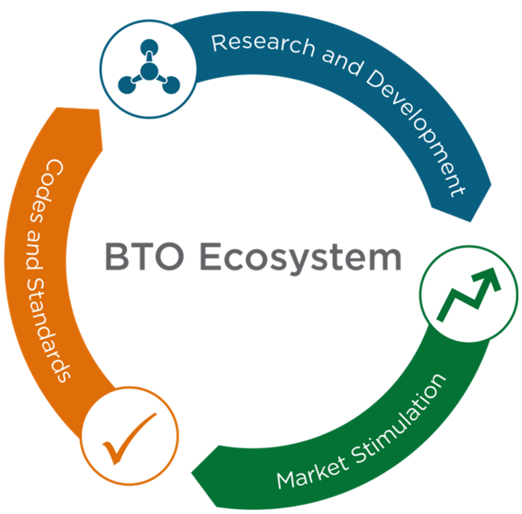

Figure 1. BTO Ecosystem

BTO's ecosystem functions through five interdependent programs:

1. **Emerging Technologies (ET)** supports research, development, and commercialization of high-impact building technologies that will generally be market-ready in 5 years or less.
2. **Residential Buildings Integration (RBI)** accelerates energy performance improvements in existing and new homes by integrating technologies and practices to optimize performance in buildings; providing data, design, and decision support tools; and partnering with public and private stakeholders to increase adoption of energy efficiency services, technologies, and practices.

3. **Commercial Buildings Integration (CBI)** accelerates energy performance improvements in existing and new commercial buildings by demonstrating cost-effective, high-impact technologies to improve building energy performance and operations; partnering with market leaders to increase the adoption of these technologies; and providing design and management tools and performance data to reduce perceived risks and address market barriers that have inhibited wide-scale adoption.
4. **Building Energy Codes (BEC)** accelerates minimum energy efficiency requirements in commercial and residential buildings by providing technical analyses to support regular upgrades of model building energy codes, and by providing technical assistance and reports on the value of more advanced building energy codes to support states and municipalities as they adopt and implement them.
5. **Appliance and Equipment Standards** develops and regularly updates energy conservation standards for appliances and equipment, ensures the availability of reliable and effective test procedures, and enforces standards and labeling through product testing and compliance efforts.

BTO engages with hundreds of internal and external partners—including national laboratories, industry, small businesses, universities, building owners and operators, other DOE offices and federal agencies, state and local governments, nonprofits, international organizations, and other entities—in planning and executing its diverse portfolio and breaking down market barriers to achieve national energy goals.

BTO's overarching long-term goal is to reduce the energy use per square foot of U.S. buildings by 50% compared to 2010 levels. Based on current analysis of the building sector and BTO program planning, BTO has established a goal of reducing building energy use intensity (EUI) 30% by 2030.[5] To support the achievement of this 2030 goal, each BTO program has identified market-focused interim goals:

- **Emerging Technologies Program:** By 2020, accelerated technology development will make available new, cost-effective technologies capable of reducing the energy use of typical buildings by 30% compared to high-efficiency technologies available in 2010.[6]
- **Residential Buildings Integration Program:** By 2025, improvements in the efficiency of space conditioning and water heating in typical single-family homes will reduce these energy uses by 40% from 2010 levels.
- **Commercial Buildings Integration Program:** By 2025, actions by market leaders, representing 20% or more of the sector, will cut the energy use of their buildings by at least 35% relative to typical commercial buildings in 2010.
- **Building Energy Codes Program:** By 2025, improvements in the typical design and construction of new buildings will be sufficient to reduce their energy use by 40% compared to typical new buildings in 2010.
- **Appliance and Equipment Standards Program:** By 2025, increases in the efficiency of new products will cut the energy use per square foot of the buildings sector by at least 20% from 2010 levels.

BTO Contributes to National Goals

BTO's work is critical to two national energy goals:

- *Reduce energy-related GHG emissions (carbon pollution) 17% by 2020 and 83% by 2050 from 2005 levels*
- *Double energy productivity relative to 2010 by 2030 (100% increase)*

U.S. energy productivity—measured as dollars of gross domestic product (GDP) per unit of energy—has more than doubled over the last 40 years, in large part due to improved energy efficiency. New energy-efficient technologies installed in homes and buildings will allow the nation to continue this progress and produce more with less.

Source: "Accelerate Energy Productivity 2030." US Department of Energy. http://energy.gov/epsa/accelerate-energy-productivity-2030

BTO is committed to tracking its progress toward achieving each of these goals and will report annually the results of these assessments.

This Multi-Year Program Plan (MYPP) describes the activities that BTO will pursue over the next 5 years to enable these market outcomes and provide compelling, affordable energy efficiency options for our nation's homes and buildings.

[5] Assessment of building floor area and energy use is assessed using information on the residential and commercial sectors as defined by the U.S. Energy Information Administration. More information can be found on the residential sector here, http://www.eia.gov/consumption/residential/reports/2009/methodology-square-footage.cfm and on the commercial sector here, http://www.eia.gov/consumption/commercial/data/2012/conducted.cfm.

[6] "2010 technologies" are defined as technologies available in 2010 that could, on a life-cycle basis, cost effectively save energy in a typical residential or commercial building.

The U.S. Buildings Landscape

The strategies and activities described in BTO's MYPP are designed to work in the large and complex landscape of new and existing residential and commercial buildings in the United States.[7]

Residential Buildings. There are about 114 million households in the United States, and the average house size is 1,678 square feet.[8] Figure 2 illustrates distinguishing characteristics between the existing homes and new construction markets.

RESIDENTIAL MARKETS	Existing Homes	New Construction
What is the size of the market?	114 million households • 80 million single-family • 28 million multi-family units • 6 million mobile homes 223 billion sq. ft.	~1 million housing units were built in 2014 14% of all occupied housing units (built in the 2000s) in 2009
How much energy is used?	21 quads of total energy or about 21% of all energy used in the U.S. 176 million Btu per average home	>20% less energy for space heating on average than older homes ~18% more energy on average than older homes for appliances, electronics and lighting.
How much is spent on energy?	Total cost of energy used in U.S. homes is >$230 billion; ~$2,000 per year to power the average home	Today's households are paying ~$180 less per year than 20 years ago due to more efficient equipment and appliances.
Who are the primary stakeholders?	General and Trade Contractors, Real estate, Financial Institutions, Utilities, State and Local Governments	Builders, Architects, Designers, Manufacturers Real estate, Financial Institutions, Utilities, State and Local Governments
How does BTO help improve the energy efficiency in these markets?	• Demonstrate energy efficient technologies and practices across a variety of climate zones • Prove successful business models for energy service providers & increase investments in energy efficiency • Increase homeowner understanding of the value of energy efficiency	• Demonstrate highly energy efficient homes that are ready for renewable energy systems • Prove and document new construction solutions on a national scale • Increase partnerships to scale more energy efficient homes

Figure 2. Existing and new residential buildings market characteristics

As shown above, residential buildings use an estimated 21 quads of total energy.[9] Natural gas provides more than 5 quads and electricity more than 14 quads of source energy in the residential

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[7] Most of the statistics in this document that describe the buildings market are based on the U.S. Energy Information Administration's *Annual Energy Outlook 2014* for purposes of consistency with BTO's rigorous goals analysis.

[8] U.S. Energy Information Administration *Annual Energy Outlook 2014*, Residential Sector Key Indicators and Consumption, Reference case.

[9] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

sector.[10] Electricity, including the energy lost to generate and deliver it, represents more than 65% of residential energy consumption. Figure 3 shows how energy is used in residential buildings.

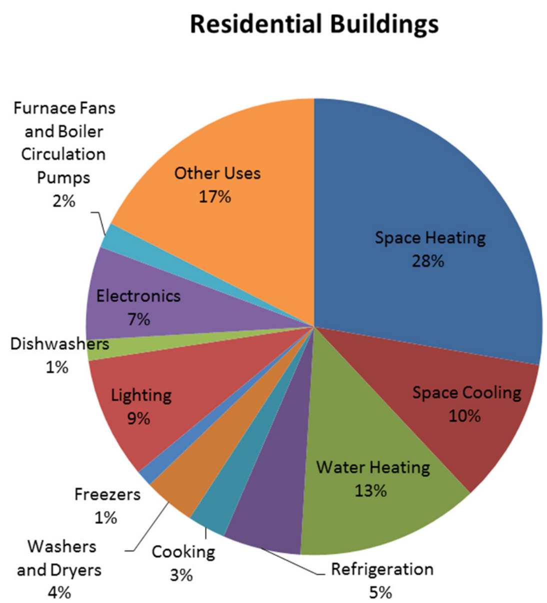

Figure 3. Residential building total energy consumption by end use, 2013

Source: *Annual Energy Outlook 2014 with Projections to 2040,* U.S. Energy Information Administration, April 2014.

For decades, space heating and cooling (space conditioning) accounted for more than half of all residential energy consumption. However, estimates from the U.S. Energy Information Administration's (EIA'S) *Annual Energy Outlook (AEO 2014)* indicates that space conditioning now account for only 38% of that energy consumption, as shown in Figure 3. Factors underpinning this trend are increases in energy efficiency (more efficient equipment, better insulation, more efficient windows, etc.), population shifts to warmer climates, and increased energy use by other types of appliances and equipment. The shift in how energy is consumed in homes has occurred as per-household energy use has gradually declined since 1980.[11]

While energy used for space conditioning has declined, energy use for appliances and electronics continues to increase. Although more than 90% of the energy used in residences is subject to federal conservation standards and substantial efficiency gains have already been made, the increasing number of devices that use energy in homes has offset these efficiency gains. For

[10] Electric source energy consumption includes both the value of the kilowatt-hours consumed (retail sales) and the energy lost in generation from the EIA 2014 Monthly Energy Review 2014.
[11] U.S. Energy Information Administration, "Heating and cooling no longer majority of U.S. home energy use"

example, in 2009, non-weather-related energy use for appliances, electronics, water heating, and lighting accounted for 5.3 quads of site energy,[12] up from 4.2 quads in 1993.[13]

Commercial Buildings. There are about 5.6 million commercial buildings in the United States, comprising 87 billion square feet of floor space. From 2003 to 2012, there was a 14% increase in the number of buildings (4.9 million in 2003) and a 22% increase in floor space (72 billion square feet in 2003).[14] Figure 3 illustrates many of the characteristics of the existing and new commercial buildings markets.

COMMERCIAL MARKETS	Existing Buildings	New Construction*
What is the size of the market?	5.6 million commercial buildings comprised of 14 principle building types 87 billion sq. ft. in total	~300,000 new buildings were constructed between 2008 to 2012 comprising over 5.7 billion sq. ft. Average size of a new building constructed in 2000s is ~ 17% bigger than new buildings constructed between 1960-1999
How much energy is used?	18 quads of total energy or about 18% of all energy used in the U.S. ~217 thousand Btu per sq. ft.	
How much is spent on energy?	Total cost of energy used in U.S. commercial buildings is ~$180 billion	
Who are the primary stakeholders?	Market Leaders	Building Designers, Architects, Builders
	Building Owners and Operators, Real estate, Financial Institutions, Utilities, State and Local Governments	
How does BTO help improve the energy efficiency in these markets?	• Demonstrate energy efficient solutions in a variety of buildings types and climate zones • Increase partnerships with market leaders to scale adoption of energy efficiency solutions • Develop data-driven decision support tools to measure and verify building energy performance as a result of upgrades	• Demonstrate energy efficient and integrated design solutions • Incorporate building energy performance information in real estate transactions • Improve design and decision data and modeling tools to verify building performance • Prepare the clean energy buildings workforce

*To be updated upon release of CBECS 2012 Consumption & Expenditures statistics

Figure 4. Existing and new commercial building markets characteristics

The commercial building sector is diverse and has disparate sets of energy needs including varying types of lighting systems; large-scale appliances; many types of heating, ventilation, and air conditioning (HVAC) systems, and more. The 2012 Commercial Buildings Energy Consumption Survey (CBECS) shows 14 principal building types (Figure 5). These include small buildings, such as

[12] U.S. Energy Information Administration, Residential Energy Consumption Survey 2009, Table CE 3.1
[13] U.S. Energy Information Administration, Residential Energy Consumption Survey 1993, Table 5.11
[14] "U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed September 23, 2014: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm?src=Consumption-b1.

freestanding banks or fast food restaurants, and buildings as large and complex as an office building with hundreds of tenants or a major airport terminal.

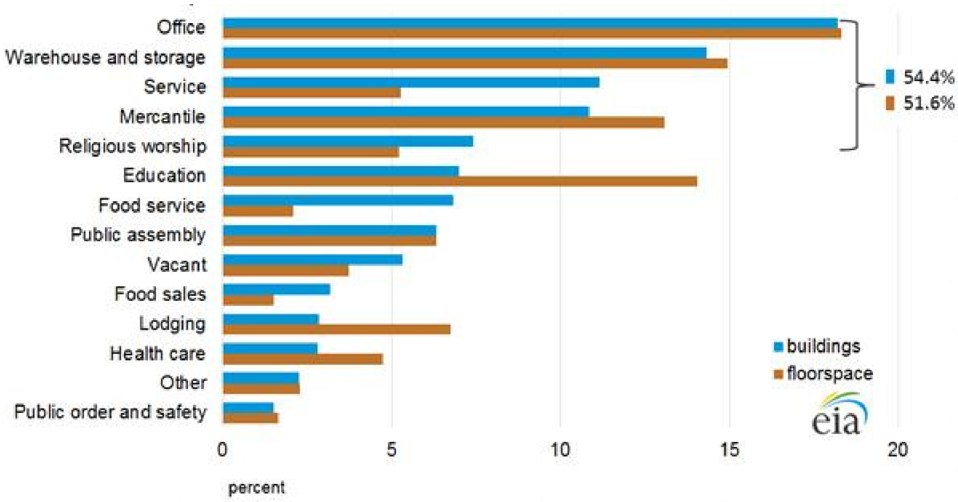

Figure 5. Commercial building types

Source: U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, D.C.: U.S. Department of Energy. Accessed September 23, 2014: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm.

Commercial buildings use an estimated 18 quads of energy, about 18% of all energy used in the United States.[15] Electricity provides almost 14 quads of source energy, and natural gas provides more than 3 quads; together these account for about 94% of all energy used in commercial buildings. Commercial building energy costs were approximately $178 billion in 2013.[16]

Figure 6 shows how energy is used in the commercial sector, although energy uses within different types of commercial and institutional buildings widely vary. For example, water heating is a major end use in hospitals and hotels, but not in offices or retail stores. Hospitals have 24-hour operations, while shopping malls and theaters have concentrated energy use periods. Recognizing the variation in building use and type helps identify specific opportunities to reduce energy demand.

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[15] U.S. Energy Information Administration 2014 Monthly Annual Energy Outlook Review, p. 23, July 2014. Accessed August 19, 2014: http://www.eia.gov/totalenergy/data/monthly/?src=Total-f1

[16] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, D.C.: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

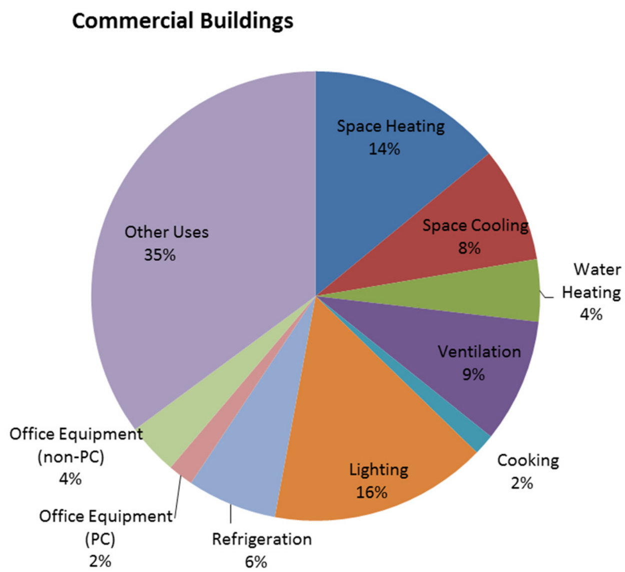

Figure 6. Commercial building total energy consumption by end use, 2013

Source: *Annual Energy Outlook 2014 with Projections to 2040,* U.S. Energy Information Administration, April 2014.

1.0 Introduction

1.1 The Opportunity

Improving the energy efficiency of U.S. homes and buildings presents an enormous opportunity for the nation's families and businesses to lower their energy costs and reduce greenhouse gas (GHG) emissions. A considerable amount of energy used in buildings is wasted due to inefficiencies in design, materials, equipment, and building operation. We can reduce energy use in existing and new buildings through focused efforts to use energy-efficient technologies and practices that are already cost effective today. We can realize even greater savings by bringing new, affordable, cutting-edge technologies and solutions into the marketplace. Energy efficiency also contributes to a healthier economy and improved productivity by reducing the cost of doing business, increasing U.S. economic competitiveness, and creating new jobs.

The potential benefits from increased energy efficiency in our homes and buildings are significant. In 2013, residential and commercial buildings used more than 40% of the nation's total energy and more than 70% of the electrical energy, resulting in a national energy bill of $410 billion.[17] The total cost of energy used in U.S. homes is more than $230 billion per year, with Americans spending an average of approximately $2,000 a year to power their homes. This amounts to about 3% of annual household income and is the lowest percentage in 10 years.[18] Increased energy efficiency has already led to reduced costs: today's households are paying about $180 less per year than they were 20 years ago due to more efficient lighting, heating and cooling systems, home appliances, and other products that have resulted from the U.S. Department of Energy's (DOE's) work in appliance and equipment energy conservation standards.[19] Building energy codes and other energy efficiency efforts have provided additional savings. However, home energy costs can be reduced much further by targeted efforts to spur broader adoption of cost-effective, yet underutilized, technologies that exist today, as well as continued efforts to develop and integrate cutting-edge technologies with higher efficiencies.

BTO Contributes to National Benefits

Improving building energy efficiency offers a wide range of national benefits for all Americans:

Protection of the Environment

- *Reduce GHG emissions and energy-related environmental damage*
- *Conserve valuable natural resources*

Strengthened Economy

- *Cut energy bills for homes and businesses*
- *Increase energy productivity*

Energy Security

- *Increase flexibility and reliability of energy system*
- *Provides alternative to creating new infrastructure for traditional energy sources*

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[17] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[18] U.S. Energy Information Administration, "Lower residential energy use reduces home energy expenditures as share of household income." *Today in Energy*. Washington, DC: U.S. Department of Energy, 2013. Accessed Aug 2014: http://www.eia.gov/todayinenergy/detail.cfm?id=10891#

[19] Equipment Standards, History and Impacts, EERE, 2013

The nation's commercial buildings, with an annual energy bill of $175 billion, also present opportunities for significant improvements in energy efficiency. New technologies and practices and the cost-effective technologies available today offer large savings for both new and retrofitted commercial buildings. These savings directly affect the bottom line for the diverse set of commercial buildings in the United States, including schools, hospitals, grocery stores, hotels, and office buildings.

DOE's BTO has played a major role in the United States' energy efficiency improvements, driving widespread adoption of the first building energy codes in the 1970s, establishing efficiency labels and standards for appliances in the 1980s, developing and introducing to market high-performance windows in the 1990s, and more recently, ushering development and adoption of transformative new technologies in solid-state lighting and high-efficiency rooftop air conditioning (AC) units. BTO will continue to partner with public and private sector organizations to provide higher efficiency products with improved performance, improved designs for homes and buildings, new approaches for improving existing buildings, and better ways to integrate our buildings with our electricity system to increase their capabilities and value. BTO's work is critical to achieving the goals of its parent office, the EERE, and to national goals of doubling energy productivity and reducing GHG emissions.

EERE and National Goals

BTO's work is critical to EERE and national goals related to energy efficiency, reliability, and productivity; and environmental health.

EERE:

- *Goal 3: Improve the energy efficiency of our homes, buildings, and industries*
- *Goal 5: Enable the integration of clean electricity into a reliable, resilient, and efficient grid*

National Goals:

- *By 2030, double energy productivity relative to 2010*
- *Reduce energy-related GHG emissions 17% by 2020, 26%–28% by 2025, and 83% by 2050 from 2005 levels*

BTO IS BUILDING ON PAST ACHIEVEMENTS

The efficiency of new appliances and building components has improved dramatically in recent decades; these improvements were driven by research and development (R&D) and market priming efforts and solidified with federal regulatory actions.

- *Average electricity use of new refrigerators sold in 2007 was about 71% less than that of new refrigerators sold 30 years ago, despite a one-third increase in their size and a one-quarter increase in storage. In 2011, BTO partnered with industry to design and demonstrate an advanced refrigerator-freezer that uses less than 1 kilowatt-hour (kWh) per day—half as much energy as allowed by current standards and one-fifth of the amount used by 1972 models.*
- *Today's dishwashers consume almost 40% less energy, clothes washers use 70% less, air conditioners use more than 50% less, and furnaces use 10% less compared to 1990s models. Currently, a typical U.S. household saves about $247 per year on energy bills by using newer models. By 2030, as consumers continue to replace old appliances with more energy-efficient models, they can expect to save $360 annually.*
- *The energy performance of most new residential windows has more than doubled since the 1980s. Double panes, low-E glass coatings, insulated frames, improved window construction and installation, and standardized testing and labeling—all supported by BTO—have transformed the windows market. Advanced window systems with triple panes, dynamic glazing, and other technologies, are poised for market growth.*
- *R&D in energy-efficient water heating solutions has led to the new electric heat pump water heater (HPWH), which does not require new or additional plumbing and electrical connections in homes. One new HPWH developed through a BTO-industry partnership uses less than half the energy of a conventional 50-gallon tank water heater, and could save a typical U.S. household $320 each year.*
- *In 2011, DOE partnered with industry in the Better Buildings Alliance High Performance Rooftop Unit Challenge to release a design specification for 10-ton-capacity commercial air conditioners, also known as rooftop units (RTUs). To date, five manufacturers have produced RTUs that meet the specification. Units built according to the specification are expected to reduce energy use by as much as 50% compared to the current ASHRAE 90.1 Standard. Businesses nationwide would save about $1 billion each year in energy costs if they replaced their 10- to 20-ton commercial units with units that meet this specification.*
- *In 2011, Philips Lighting won BTO's $10 million L Prize® for developing a high-performance, energy saving replacement for conventional 60W A19 light bulbs, which had a national stock of 971 million. The replacement uses only 10W—an energy savings of 83%. If all 60W incandescent lamps in the United States were replaced by the 10W L Prize winner, the country would save approximately 35 terawatt-hours (TWh) of electricity in 1 year, and avoid 20 million metric tons of carbon emissions. Philips has incorporated technology from the L Prize winner into a growing family of products and estimates the products have resulted in more than $51 million dollars in energy savings.*
- *Appliance and equipment energy conservation standards issued from 1987 to 2014 are projected to save consumers $1.8 trillion in utility costs, save 128 quads of primary energy and avoid 7 billion tons of carbon emissions through 2030.*
- *Building energy codes are expected to save U.S. businesses and consumers 44 quads of primary energy between 1992-2040.*

Sources: "Real Prospects for Energy Efficiency in the United States," National Academy of Sciences, 2010; "Appliance Success Stories," U.S. Department of Energy, Emerging Technologies, 2011. "Saving Energy and Money with Appliance and Equipment Standards in the United States," U.S. Department of Energy, Building Technologies Office, 2015. "Install the highest efficiency units that meet the High Performance Rooftop Unit Challenge," https://www4.eere.energy.gov/alliance/activities/technology-solutions-teams/space-conditioning/rtu. "Philips Rises to the L Prize Challenge," http://www.saveenergyinmycommunity.com/media/12524/l_prize_media_kit.pdf.

1.2 Our Approach

BTO's **vision** is a strong and prosperous America in which all homes and buildings operate at peak energy performance, are affordable, and provide optimal health and comfort.

In the context of this vision, BTO's **mission** is to develop, demonstrate, and accelerate the adoption of technologies, techniques, tools and services that are affordable and enable high-performing, energy-efficient residential and commercial buildings for both new and existing buildings.

BTO has designed a three-part strategy (Figure 7) to accomplish its mission and realize its vision. This strategy targets the technology, market, and regulatory needs that enable emerging energy-efficient technologies and solutions to achieve substantial, long-lasting energy savings:

1. **Research and development** to reduce technology cost, improve performance, and accelerate commercialization.
2. **Market stimulation** to validate energy-efficient technologies and practices in new and existing buildings by confirming performance in real-world conditions; provide reliable, objective data, best practices, and benchmarks; and develop a skilled workforce—all to reduce uncertainty for investors and spur wide-scale adoption.
3. **Codes and standards** to lock in savings for the long term by providing a consistent regulatory framework for manufacturers, builders, and consumers, and driving technologies and buildings to greater energy efficiencies.

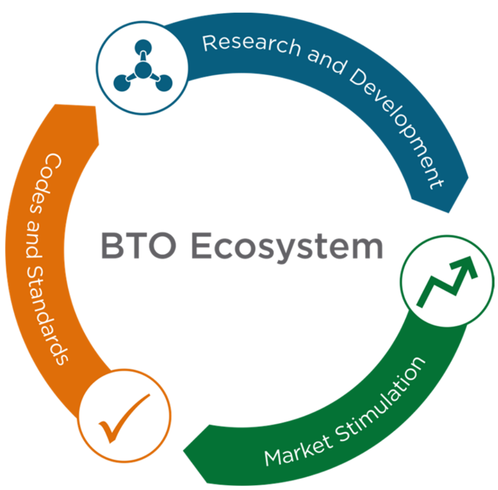


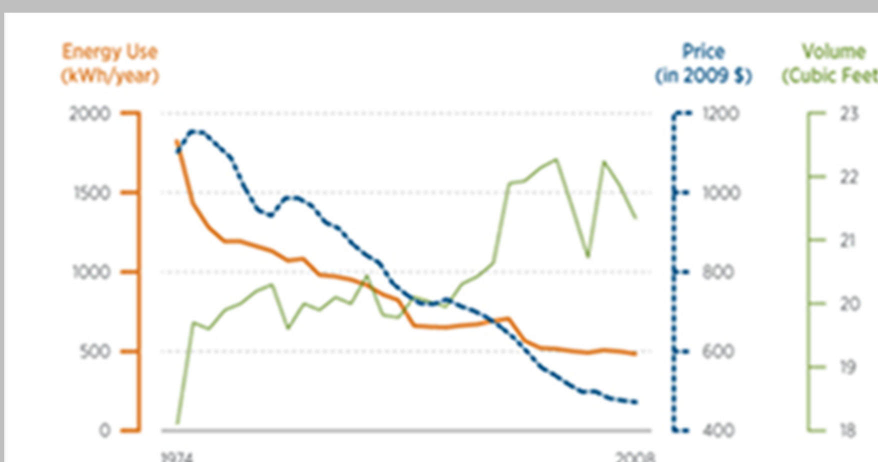
Figure 7. BTO Ecosystem

BTO's strategy integrates innovation with market priming efforts to accelerate the widespread adoption of energy saving technologies and practices, maximize benefits, and realize savings in new and existing buildings. BTO's efforts are then solidified with federal regulatory action to improve minimum standards. Like an ecosystem, each piece of the BTO framework supports the other pieces, and each are equally important. Refrigerators and freezers are one of many technologies that have come a long way in recent decades and serve as an example of how BTO's ecosystem strategy can result in significant public benefits that continue to increase year after year.

BTO's Ecosystem at Work: Improvements in refrigerators were the result of R&D, market transformation efforts, and voluntary and federal minimum standards

In partnership with industry, BTO has led the technological innovation to vastly improve the energy efficiency of refrigerators and freezers, saving consumers energy and money, while also allowing for more storage space, better design, and upgraded features. BTO R&D technology breakthroughs, such as the commercial introduction of a refrigerator compressor in the late 1980s that accomplished a 44% improvement in efficiency relative to existing compressors, enabled the commercialization of more energy-efficient products. Market priming efforts such as the ENERGY STAR® label, partnerships with utilities, stakeholders, and other initiatives helped to accelerate the adoption of high efficiency products. Due to these efforts, coupled with BTO-developed new minimum energy conservation standards for household refrigerators, which DOE has now raised three times, refrigeration labels and standards have increased in efficiency by 2% per year since 1975. This progression has translated to tremendous savings for the nation, as illustrated in the below figure.

New standards for both the ENERGY STAR label and federal minimum energy conservation standards went into effect for household refrigerators in 2014. If all refrigerators met the ENERGY STAR requirement, a 10% efficiency increase from previous products, the difference amounts to the equivalent of taking 1 million cars off the road and $890 million in energy savings. The federal minimum standard efficiency increase is estimated to save the nation close to 4.5 quads over 30 years or three times more than the total energy currently used by all refrigeration products in U.S. homes annually. BTO continues to invest in R&D to bring next-generation refrigerator technologies to market and to accrue more and more savings. BTO is currently working to eliminate the use of high global-warming-potential refrigerants and reduce harmful emissions and to develop a variable-capacity refrigerator that uses a linear compressor, which offers the potential to reduce energy use by up to 40%.



Graph source: U.S. Department of Energy. *The Proof is in the Pudding: How Refrigerator Standards Have Saved Consumers $Billions.* Washington, DC: U.S. Department of Energy, 2011. Accessed Sept 23, 2014: http://energy.gov/articles/proof-pudding-how-refrigerator-standards-have-saved-consumers-billions

Source: U.S. Environmental Protection Agency. *ENERGY STAR Version 5.0 specification for Refrigerators and Freezers*. Washington, DC: U.S Environmental Protection Agency, 2013. Accessed Aug. 21, 2015: https://www.energystar.gov/ia/partners/product_specs/program_reqs/Refrigerators_and_Freezers_CoverMemo_V5.0.pdf

The U.S. housing sector consistently and significantly underinvests in the R&D needed to improve home energy performance; R&D funding for construction is about 0.3 percent, or just one tenth of the U.S. industry average.[20] It can take the housing industry 10–25 years to adopt new technologies and techniques without a catalyst like DOE. Even when commercially competitive technologies capable of substantially reducing energy and life cycle costs are available, a number of persistent market challenges prevent their widespread adoption in both residential and commercial buildings. These challenges exist in a complex landscape across a number of industries, including architecture, construction, manufacturing, finance, utilities, real estate, and retail. BTO's approach is designed to overcome these market challenges for both new building construction and building improvements. Some of the challenges that BTO addresses are (1) the overall fragmentation of the businesses serving the buildings sector; (2) lack of reliable information on the energy use and efficiency of specific end uses; (3) uncertainties surrounding performance and the perceived risks associated with making significant investments in energy efficiency; (4) a lack of mechanisms for establishing the market value of more energy-efficient properties; and (5) split incentives between owners and occupants of rental properties. The transfer of information related to the economics, performance, and benefits of energy-efficient technologies and integrated solutions is often slow or unavailable, and the many options and risks are overwhelming for both consumers and building professionals.

With these market challenges in mind, BTO has designed programs that focus on key areas, maximizing the benefits and giving appropriate consideration to both the technology and market barriers to energy efficiency. Through rigorous technical analysis and an understanding of market structure (current trends, barriers, institutions, consumer preferences), and with stakeholder input, BTO has identified specific activities and critical targets. BTO's ultimate objective is to motivate decision makers to make investments in energy efficiency.

[20] Wolfe, Raymond M. (2013). Business Research and Development and Innovation: 2008-10 Detailed Statistical Tables. NSF 13-332. Arlington, VA: National Center for Science and Engineering Statistics. Accessed September 24, 2014: http://www.nsf.gov/statistics/nsf13332/pdf/nsf13332.pdf.

Our Partners. BTO works with many internal and external partners to plan and execute its programs. DOE national laboratories provide scientific, engineering, and analytical expertise, as well as world-class research facilities. Industry partners share the cost of R&D projects, demonstrate and gather data to validate technologies in real-world applications, and bring new technologies to the market. State and local governments and utilities make significant investments in energy efficiency, often developing innovative new approaches to building regional clean energy economies. BTO works with cities and states, including state energy offices and public utility commissions, to advance clean energy programs and policies. For instance, BTO provides support to the DOE Better Buildings Alliance, which promotes energy efficiency in U.S. commercial buildings through collaboration with almost 200 member organizations, representing approximately 10 billion square feet, including building owners, operators, and managers. Members agree to participate in at least one Alliance activity each year and share their successes, while DOE connects members with technical resources and provides a platform for information exchange.

BTO's partnerships with building professionals are especially important. BTO works with builders and building owners and operators—as well as related market actors such as finance experts, product retailers, and real estate professionals—to support the market infrastructure for energy efficiency. Many of BTO's partners are also active participants in the regulatory processes that lead to new building codes and product standards.

Internally, BTO collaborates with its sister offices in EERE and with other DOE offices to address cross-cutting energy needs. For example, BTO works with the Solar Energy Technologies Office and the Vehicle Technologies Office. Together, EERE offices collaborate with utilities and other stakeholders to design and develop approaches and tools that will seamlessly integrate technologies into the nation's electric grid and provide timely information about building system interactions to enable better decision-making and optimize building performance. These efforts work toward the EERE goal to enable the integration of clean electricity into a reliable, resilient, and efficient grid. As interdependencies among energy infrastructures continue to increase and communication networks across the energy system become necessary, integrating technologies and buildings into the power system at scale is a key step to reducing wasted energy. For example, intermittent and/or variable generation sources, such as photovoltaic (PV) systems, as well as new load sources, such as electric vehicles, are being installed on the grid in increasing numbers and at more distributed locations. To account for and fully utilize those increased, diversified, and dispersed loads, efficient transactions between buildings and the grid need to become a commercial reality. BTO works with other federal offices to overcome the current barriers to integrating a large portfolio of technologies into the energy system and enabling an interconnected and interoperable communication network using advanced sensors and controls.

BTO collaborates with many federal agencies to carry out joint responsibilities and achieve national goals. BTO works with the U.S. Environmental Protection Agency (EPA) to implement ENERGY STAR® programs. BTO also partners with the Department of Housing and Urban Development to design and develop financial solutions that lead to affordable, quality, energy efficient homes and sustainable communities. In addition, BTO provides technical expertise to the U.S. Department of Defense related to the installation of high-impact technologies to save energy and money in U.S. military operations and buildings.

Working Together to Improve the Energy Performance of Federal Buildings

BTO works with the Federal Energy Management Program to demonstrate advanced technologies and share best practices, tools, and resources to reduce building energy use in our nation's federal buildings. Examples include:

- ***The Technology Performance Exchange** is a jointly developed web-based portal in which manufacturers, utilities, researchers, and consumers share data on the performance of energy efficiency products such as photovoltaic modules, lamp ballasts, and advanced rooftop air conditioning units.*
- ***The Better Buildings Alliance Advanced Rooftop Unit (RTU) Campaign** encourages federal agencies to replace or retrofit old RTUs with more efficient units. Older RTUs can waste from $1,000 to $3,700 annually, depending on building size and type. In one project, the National Renewable Energy Laboratory (NREL) worked with the Navy at Joint Base Pearl Harbor-Hickham in Hawaii to retrofit nine RTUs that serve the Naval Exchange store, as well as two that serve small office buildings. Together, the retrofits are projected to achieve an annual savings of 100 megawatt-hours (MWh), with the system paying for itself in the fifth year. Future replacement projects are expecting net energy savings of 120 MWh, with a simple payback of 3 years. These new systems also lowered the relative humidity levels inside the buildings and improved occupant thermal comfort.*

BTO also engages with the international community when appropriate to facilitate information exchanges among experts worldwide and to prime global markets for clean energy products and services from the United States.

BTO's partnerships ensure that public- and private sector resources and expertise are aligned, leveraged, and targeted to address the most important technical and market barriers, advance energy efficiency in the building sector, and realize economic and societal benefits.

DOE National Laboratories: Strategic Partners to BTO

National laboratories are particularly important partners to BTO. These unique national resources offer expertise, capabilities, and state-of-the-art facilities in areas critical to achieving BTO's goals. BTO's investments are concentrated in four of the national labs:

Lawrence Berkeley National Laboratory *(LBNL) collaborates with BTO through its Environmental Energy Technologies Division, which conducts R&D aimed at accelerating deployment of efficient technologies and building systems. LBNL is enhancing DOE's Building Performance Database and related data analysis, disclosure, and decision support tools, as well as energy modeling tools, such as EnergyPlus™ and Modelica, to drive energy savings of up to 30% in commercial and residential buildings. The lab also supports the development and advancement of novel window technologies, as well as autonomous agent applications for transactive controls applied to lighting and whole-building efficiency and savings evaluation. LBNL also works with BTO to improve indoor air quality and ventilation in homes through the Building America effort. LBNL conducts engineering and economic analyses to inform new energy conservation standards, develops product test procedures, and supports certification and enforcement. FLEXLAB is a new facility at LBNL that consists of a set of test beds and simulation platforms for R&D; testing; and demonstration of low-energy building technologies, control systems, and integration.*

National Renewable Energy Laboratory *(NREL) develops market-relevant science, technologies, and analytical tools that leverage unique facilities and partnerships. A key emphasis is developing and integrating technologies to enable buildings to achieve zero- or near zero-energy status. NREL's scientists and engineers partner with industry to develop and test technologies and materials for windows, HVAC systems, plug loads, and sensors to yield market-ready products. NREL's campus has several buildings that are zero-energy and/or have received Leadership in Energy and Environmental Design (LEED) Platinum certifications. The Energy Systems Integration Facility enables NREL to study how to integrate systems (e.g., smart appliances, electric vehicles, building controls, integrated renewables) to increase building energy efficiency. NREL also designs, develops, and applies modeling tools, such as OpenStudio®, a free, open-source software development kit; and BEopt™, the residential energy modeling tool that BTO has used for more than 10 years.*

Oak Ridge National Laboratory *(ORNL) brings cost-effective building technologies to market by applying multi-disciplinary science and technology expertise and state-of-the-art facilities to Cooperative Research and Development Agreements (CRADAs) with industry. ORNL's CRADA strategy provides an easy means for industry to engage with BTO. It also allows the lab to benefit from industry's business discipline and market knowledge, and helps keep the research commercially relevant by translating science into technology and then into energy-saving market products. ORNL's Building Technologies Research and Integration Center (BTRIC) is a DOE-designated National User Facility that has drawn users from more than 100 industry and university partnerships. BTRIC is a world-renowned center for building energy efficiency research by sustaining technical leadership for more than 30 years in its core capabilities in HVAC; water heating and appliances; building envelope; and system/building integration, including sensors and advanced control systems, modeling, and use of whole research buildings to validate emerging building energy efficiency technologies.*

Pacific Northwest National Laboratory *(PNNL) contributes core capabilities to BTO in lighting and transaction-based and advanced controls, including technology development and market stimulation approaches. PNNL contributions have accelerated market penetration for solid-state lighting from two niche applications in 2003, to nine product categories in 2013 covering most market applications, and have identified more than 10 new control technologies that, if demonstrated to be cost-effective, could reduce commercial building energy consumption by 20–30%. PNNL also supports BTO's regulatory activities. The lab has helped BTO's Building Energy Codes Program achieve more than 4 quads of savings (1992 through 2012), an estimated return on investment of $400 in consumer energy savings per $1 of BTO funds. PNNL's analytical expertise in support of the Appliance and Equipment Standards Program has enabled energy conservation standards that will save an estimated 16 quads of energy over the life of the regulated equipment.*

1.3 Our Programs

BTO works to achieve its goals through five interdependent programs. These programs implement a broad portfolio of activities that drive the research, development, and commercialization of cost-effective, energy-efficient technologies and practices; provide information and tools that encourage private and public investment; and lock in energy savings achievements through support of building energy codes and development of energy conservation standards for appliances and equipment. BTO's five programs include:

- ***Emerging Technologies*** **(ET)** supports research, development, and commercialization of high-impact building technologies and tools that will be generally market-ready in 5 years or less, including solid-state lighting, HVAC systems, windows and building envelope, sensor and controls, and building energy modeling.

- ***Residential Buildings Integration*** **(RBI)** accelerates energy performance improvements in existing and new homes by integrating technologies and practices to verify and optimize performance in buildings; providing data, design, and decision support tools; and partnering with public and private stakeholders to increase adoption of energy efficiency services, technologies, and practices.

- ***Commercial Buildings Integration*** **(CBI)** accelerates energy performance improvements in existing and new commercial buildings by demonstrating cost-effective, high-impact technologies to improve building energy performance and operations; partnering with market leaders to increase the adoption of those technologies; and providing design and management tools and performance data to reduce perceived risks and address market barriers that have inhibited wide-scale adoption.

- ***Building Energy Codes*** **(BEC)** accelerates minimum energy efficiency requirements in commercial and residential buildings by providing technical analyses to support regular upgrades of model building energy codes and by providing technical assistance and reports on the value of more advanced building energy codes to support states and municipalities as they adopt and implement them.

- ***Appliance and Equipment Standards*** develops and regularly updates energy conservation standards for appliances and equipment, ensures the availability of reliable and effective test procedures, and enforces standards and labeling through product testing and compliance efforts.

The Federal Role

BTO follows EERE principles in designing its portfolio to make a significant impact in transforming the building energy landscape and maximizing the value it delivers to the taxpayer. BTO prioritizes its work using EERE's five core questions.

Is this a high-impact problem?

BTO focuses on technologies, tools, and practices that have the highest possible impact on building energy use and that contribute to national goals.

Will EERE funding make a large difference relative to existing funding from other sources, including the private sector?

BTO ensures its investments have a meaningful additional impact beyond funding from the private sector and other sources, and avoids investing in areas where other sources of funding—especially from the private sector—are significant relative to the levels of funding that BTO could provide.

Are we focusing on the broad problem we are trying to solve and open to new ideas, approaches, and performers?

BTO's work is guided by comprehensive long-term roadmaps that are created in collaboration with its key stakeholders. BTO also creates and sustains an internal culture that is receptive to new solutions and new partners. BTO regularly updates its roadmaps and provides mechanisms to quickly bring promising new approaches into its portfolio.

How will funding result in enduring economic impact for the United States?

As a steward of taxpayer funds, BTO develops strategic approaches to ensure that the technologies and solutions it supports enable long-term economic benefits to the country.

Why is this investment a necessary, proper, and unique role of government rather than something best left to the private sector to address?

The U.S. private sector is the primary engine that drives the transition to a national clean energy economy. BTO focuses its investments on topics and activities where there is a unique federal role to maximize its impact.

1.4 Our Goals

BTO's ultimate goal is to reduce the average energy use per square foot of all U.S. buildings by 50% from 2010 levels. Achieving this goal will require accelerated technology development, market stimulation for adoption of technologies and solutions, and more energy-efficient codes and standards—the elements of BTO's ecosystem. To ensure that all BTO activities align with this goal and to enable BTO to track progress toward achieving it, BTO has developed an integrated goals framework underpinned by rigorous analysis.

BTO's goals framework has three important elements: 1) a single baseline year, 2) a tiered structure, and 3) a primary metric. 2010 is the baseline year for these goals. The tiered structure includes program performance goals (largely focused on 2020), interim market outcome goals for 2025, and sectoral outcome goals for 2030. BTO's common metric is energy use intensity (EUI), measured as primary energy use per square foot of building space.

1.4.1 *Goals Hierarchy*

The sections below and Figure 8 describe the hierarchy of goals.

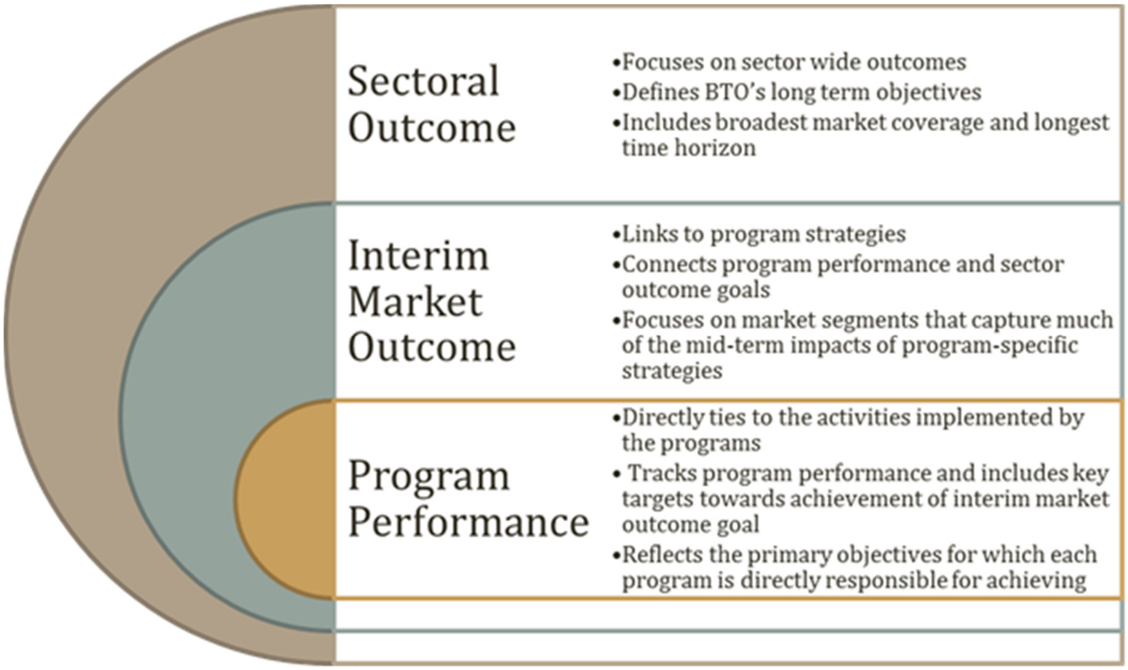


Figure 8. Elements of BTO's goals hierarchy

1.4.2 *Sectoral Outcome Goals*

BTO's key sectoral goal is to reduce the average energy use per square feet of all U.S. buildings by 30% by 2030. To set a fixed target that can be used to track progress over a number of years, BTO considered a variety of scenarios from the EIA's 2014 *Annual Energy Outlook* and the potential impacts of BTO and other efforts directed at accelerating the development and deployment of energy-efficient building technologies. Based on this preliminary assessment, BTO determined that a 30% sectorwide reduction in average EUI is an ambitious but achievable target. This target formed the basis of BTO's time-bound sectoral outcome analysis. As illustrated in Figure 9, with a 2010 baseline of 147 kBtu/ft^2 (the average energy use of all residential and commercial buildings), the 2030 target is 103 kBtu/ft^2.

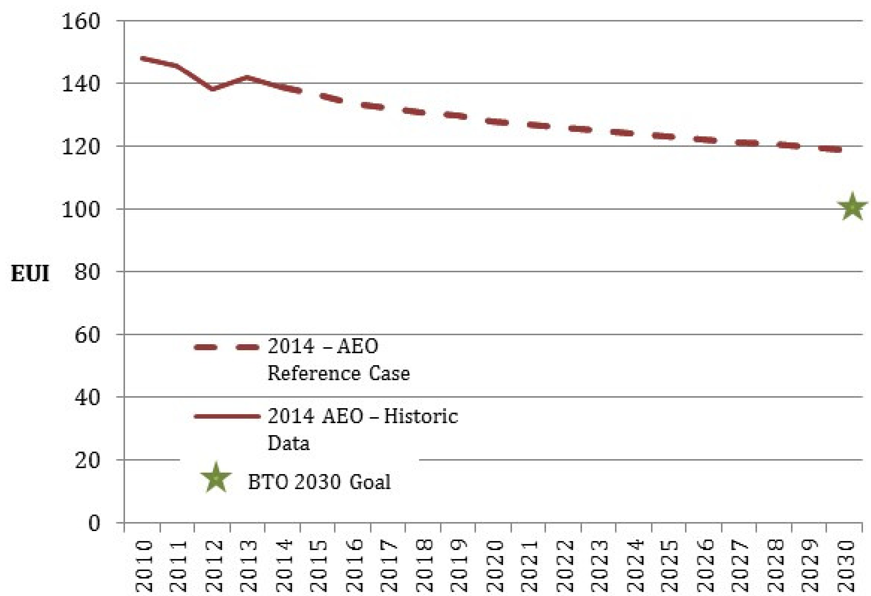


Figure 9. Building sector EUI (2010-2030) and the BTO 2030 goal

Source: *Annual Energy Outlook 2014 with Projections to 2040,* U.S. Energy Information Administration, April 2014.

To achieve this reduction in the average energy use intensity of all buildings, all major segments of the sector will have to realize substantial gains in energy efficiency, including both new and existing residential and commercial buildings. However, the achievable gains in each of these four sub-sectors will likely vary significantly. Figure 10 shows a breakdown of these sub-sectors and the 2030 targets that will reduce sectorwide EUI by 30%.

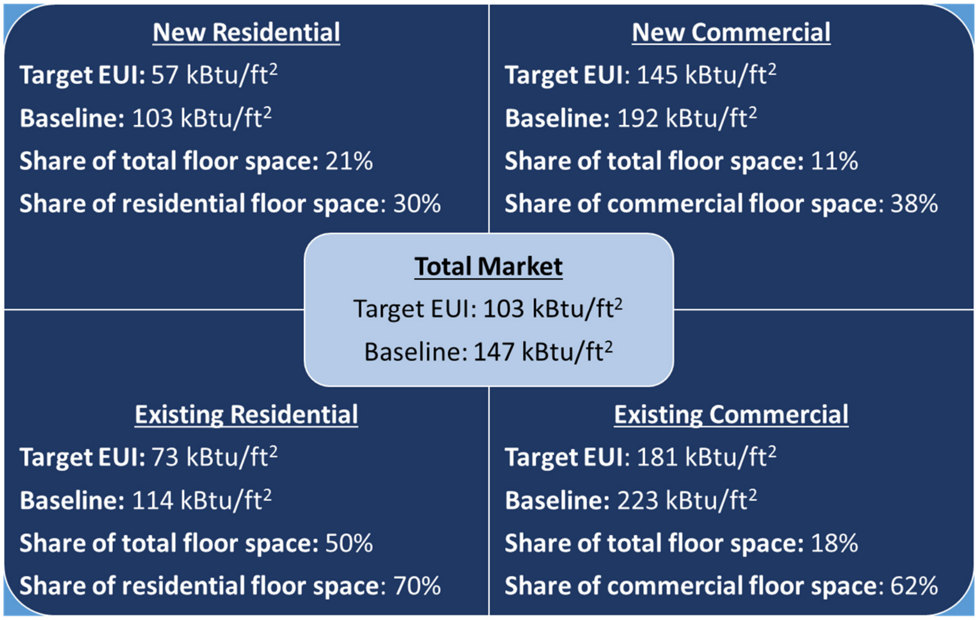


Figure 10. Sub-Sector targets for 2010-2030

1.4.3 *Interim Market Outcome Goals*

The interim market goals, most of which are set for 2025, are a critical element of BTO's goals framework and mark the pathway to BTO's 2030 sectoral outcome goals. When combined, the goals present a holistic picture of BTO's overall mid-term objectives. The interim market goals serve as a bridge between BTO's longer term sectoral goals and its numerous program performance goals. While BTO Programs' efforts are expected to make substantial contributions to each of the interim market goals, many other market actors will also play important roles in achieving them. Additional information on how each interim market goal was developed can be found in the various program sections in this Multi-Year Program Plan.

Emerging Technologies

BTO's ET Program focuses on accelerating the development of more energy-efficient technologies for the buildings sector. By 2020, accelerated technology development will make available cost-effective technologies capable of reducing the energy use of typical buildings by 30% compared to high-efficiency technologies available in 2010. In the longer term, by 2030, continued technology development will make available cost-effective technologies capable of cutting building energy use by 45%.

Because the ET Program is focused on accelerating technology development, the baseline for the goal is derived from the cost-effective high-efficiency technologies available in 2010.[21] BTO will determine progress toward achievement of the market outcome goals through annual assessments of improvements in the performance of cost-effective building technologies. Continual improvements in the performance and cost-effectiveness of building technologies will be key to the achievement of BTO's sectoral goals for 2030 and beyond.

BTO's ET Interim Market Goal

How was the goal developed?

BTO established this goal by:

- *Examining ENERGY STAR® 2010 product specifications, which reflect cost-effective, energy-efficient technologies on the market in 2010*
- *Examining ET Program 2020 technology performance targets, which reflect cost-effective, energy-efficient technologies BTO expects to be on the market in 2020*
- *Calculating the energy savings and weighting them based on the energy profiles of building types in the United States to create an aggregate energy savings projection*

How will BTO assess progress?

BTO will track the commercialization of technologies and assess their performance. BTO plans to use the building energy modeling programs EnergyPlus™ and OpenStudio® to estimate the combined performance of these technologies in a variety of building and climate situations. These results will be weighted based on the most recent EIA data on U.S. building types.

Residential Buildings Integration

The RBI Program contributes to the achievement of an interim market goal focused on reducing the energy used for space conditioning and water heating in single-family homes. The RBI market outcome goal focuses on those segments of the residential sector that offer the largest opportunities for energy savings and are largely unaddressed by other BTO efforts. Single-family homes represent more than 80% of the residential building floor area and energy use.[22] Heating, cooling and water heating account for more than half of all energy use in the sector, and the potential energy savings associated with these end uses is more than 70% of the total energy savings potential available in the sector in 2030.

[21] "2010 technologies" are defined as technologies available in 2010 that could, on a life-cycle basis, cost-effectively save energy in a typical residential or commercial building.

[22] U.S. Energy Information Administration. "2009 RECS Survey Data." *Residential Energy Consumption Survey*. Washington, DC: U.S. Department of Energy, 2012. Accessed July 18, 2014: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics

The 2025 market outcome goal is to improve the efficiency of space conditioning and water heating in typical single-family homes and reduce these energy uses by 40% from 2010 levels. This market outcome goal is comprised of two 2025 goals for the existing and new homes market:

- A 35% energy use intensity reduction in the heating, cooling, and water heating end uses in **existing** single-family homes.
- Cost-effective design and construction of **new** single-family homes that will consume 50% less energy per square foot for heating, cooling, and water heating relative to typical homes in 2010.

Commercial Buildings Integration

The CBI Program contributes to a 2025 market outcome goal focused on improving the performance of buildings in partnership with market leaders, which represent the top 20% of all commercial buildings (as measured on a square foot basis). Market leaders represent the segment of the market with the most energy-efficient buildings and play a vital role in the diffusion of technologies and innovative energy efficiency strategies. By successfully building the early adopter market for energy-efficient commercial buildings, CBI efforts are expected to accelerate adoption of these technologies and practices by the rest of the commercial sector.

To meet the 2025 market outcome goal, actions by market leaders will cut energy use per square foot of their buildings by at least 35% relative to typical commercial buildings in 2010. This market outcome goal is comprised of two goals for the existing and new commercial buildings markets in the market leader segment:

- Achieve a 30% reduction in EUI in market leaders' **existing** buildings.
- Cost-effectively design and construct **new** buildings that consume 50% less energy per square foot relative to the average commercial buildings in 2010.

Building Energy Codes

The BEC Program accelerates the widespread adoption of improved design and construction practices, primarily for new buildings. To reach the 2025 market outcome goal, improvements in the typical design and construction of new buildings will need to reduce newly constructed building energy use by 40% compared to typical new buildings in 2010. This market goal consists of two sector-specific targets:

- Cost-effective design and construction of new **residential** buildings that will consume 45% less energy per square foot relative to typical residential buildings in 2010.
- Cost-effective design and construction of new **commercial** buildings that will consume 30% less energy per square foot relative to typical commercial buildings in 2010.

Appliance and Equipment Standards

By establishing and regularly updating minimum efficiency standards for more than 60 types of residential and commercial energy-using appliances and equipment, the Appliance and Equipment Standards Program impacts the energy use intensity of virtually all existing and new residential and commercial buildings. The related 2025 market outcome goal translates to increases in the efficiency of new products that will cut the energy use per square foot of the buildings sector by at least 20% from 2010 levels. This market goal is aligned with the president's Climate Action Plan goal to avoid at least 3 billion metric tons of carbon emissions by 2030.

1.4.4 Program Performance Goals

The program performance goals are described in detail in each of the program sections along with their linkages to each of the programs' strategies and to the interim market goals. Most program performance goals are based on quantitative targets for achievement in 2020, relative to a 2010 baseline. Many are supported by more specific annual or multi-year targets. While some program performance goals use metrics directly tied to EUI, most use metrics that rely, at least in part, on other quantitative measures of program achievement.

1.4.5 Tracking Progress Toward Goals

BTO is committed to annual assessments of progress toward the achievement of all sector, interim market, and program performance goals. The results of these assessments will be posted on the BTO website. Progress toward the achievement of the sector and some interim market goals will be tracked by referring to updated data and estimates regularly released by the Energy Information Administration. Progress toward the achievement of technology and code improvement targets will be tracked by modeling expected changes in the performance of typical residential and commercial buildings based on the actual availability of new building technologies and the implementation of more energy efficient building energy codes. Progress toward the achievement of other interim market goals and most program performance goals will be based on data gathered by BTO on program-specific activities or technology advances. In many cases, the current status of program-specific progress is identified in the relevant sections below.

BTO is now developing the specific analytical tools and data gathering and analysis methodologies necessary to complete annual assessments of progress toward the achievement of all goals. As these tools and methods become available, appropriate documentation will be peer reviewed and ultimately made public.

1.5 The Multi-Year Program Plan

The sections that follow describe each of BTO's programs, providing a roadmap for their work over the next 5 years. Each program section provides an overview of the relevant market characteristics, including key market barriers, the program's history, and a description of the remaining opportunities for energy savings. This is followed by a description of each of the program's goals, the strategies used to achieve those goals, and a summary of specific program activities and key targets.

2.0 Emerging Technologies Introduction

The Emerging Technologies (ET) Program works with industry, national laboratories, and academia to advance the research, development, and commercialization of energy-efficient, cost-effective building technologies and systems.

The ET Program of the Building Technologies Office (BTO) supports research and development (R&D) of technologies and systems that are capable of substantially reducing building primary energy use and accelerates their introduction into the marketplace.

The ET Program focuses on improving energy efficiency in four major technology areas:

- Lighting
- Heating, ventilation, and air conditioning (HVAC); water heating; appliances
- Building envelope and windows
- Sensors and controls

The ET Program also works to advance state-of-the-art in open-source Building Energy Modeling (BEM), including improvements and greater use of the EnergyPlus™/OpenStudio® package.

These four technology areas are critical to improving building energy efficiency. They represent approximately 60% of the energy used in buildings (see Figure 11) and represent an even greater share of the potential efficiency gains over the next several decades. Rapid introduction and deployment of cost-effective technologies in these areas could cut future buildings' energy use in half, producing net consumer and economic benefits of tens of billions of dollars.

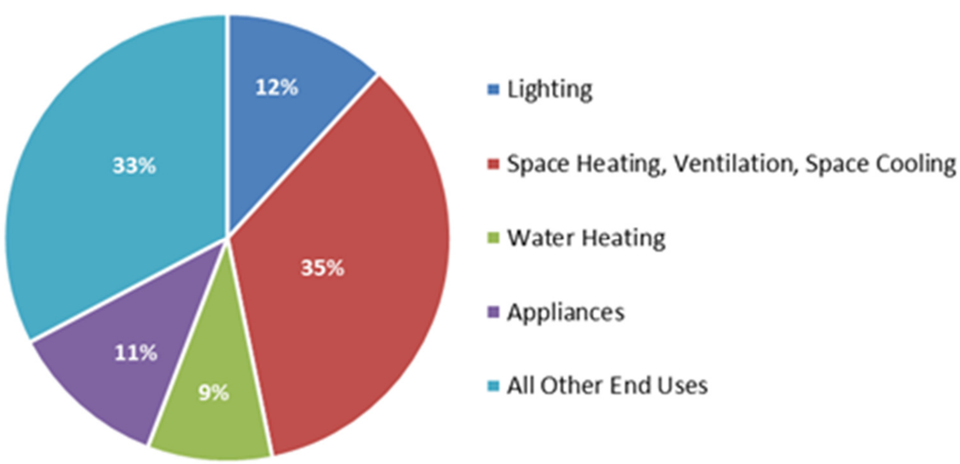


Figure 11. Building sector total energy consumption by end use (2012)

Source: U.S. Energy Information Administration. *Annual Energy Outlook* 2014. DOE/EIA-0383(2014). Washington, DC: U.S. Energy Information Administration, 2014. Accessed August 22, 2014: http://www.eia.gov/forecasts/archive/aeo14/pdf/0383(2014).pdf

The primary focus of the ET Program is R&D of relatively near-term building energy efficiency technologies (i.e., those that are expected to be commercialized within about 5 years). However, the ET Program supports a diverse portfolio, which includes some longer term energy solutions that are at an earlier stage of development.

The highly fragmented industries and businesses that serve the building sector have historically underfunded energy efficiency R&D.[23] Even when more energy-efficient, cost-effective technologies were available, barriers to investment in such technologies have limited their commercial success and further discouraged development efforts. With considerable government support for both technology development and deployment, significant improvements have been made in a range of building energy technologies over the past 30 years, including the development of energy-efficient water heaters, washing machines, refrigerators, and dishwashers. (See Section 1.1 for more examples.) Further advances will likely require the development of emergent and potentially transformative technologies, such as solid-state lighting. Continued government support is necessary to help shoulder some of these risks while greatly accelerating the time it takes for new technologies to move from the laboratory to the market. Once in the market, a range of government and utility programs are available to spur further investment in such technologies.

The ET Sub-Program sections in this Multi-Year Program Plan (MYPP) describe each technology area, provide information about the state of the market and current energy use, and discuss specific market barriers that inhibit private sector efforts.

Emerging Technologies Goals

The ET Program's goal is:

- **To enable the development of cost-effective technologies that will be capable of reducing a building's energy use per square foot by 30% by 2020 and of cutting a building's use by 45% by 2030, relative to 2010 high-efficiency technologies.**

Stated another way, the ET Program's goal is to support substantial improvements to the technologies that are available to reduce energy use in buildings, and, in general, are much better than those in the installed stock. Therefore, ET's 2020 and 2030 goals are defined relative to cost-effective, energy-efficient technologies available in 2010, simply referred to as the 2010 Energy Efficient Technologies Baseline. In the analysis, the 2010 Energy Efficient Technologies Baseline is also referred to as the ENERGY STAR® baseline, as 2010 ENERGY STAR specifications were used as proxies for cost-effective, energy-efficient technologies available in 2010. One way to visualize the 2020 goal is through bar charts, as depicted in Figure 12 and Figure 13.

[23] Vaidyanathan, S. et al. *Overcoming Market Barriers and Using Market Forces to Advance Energy Efficiency*. Research Report E136. Washington, DC: American Council for an Energy Efficient-Economy, 2013. Accessed August 22, 2014: http://www.aceee.org/research-report/e136.

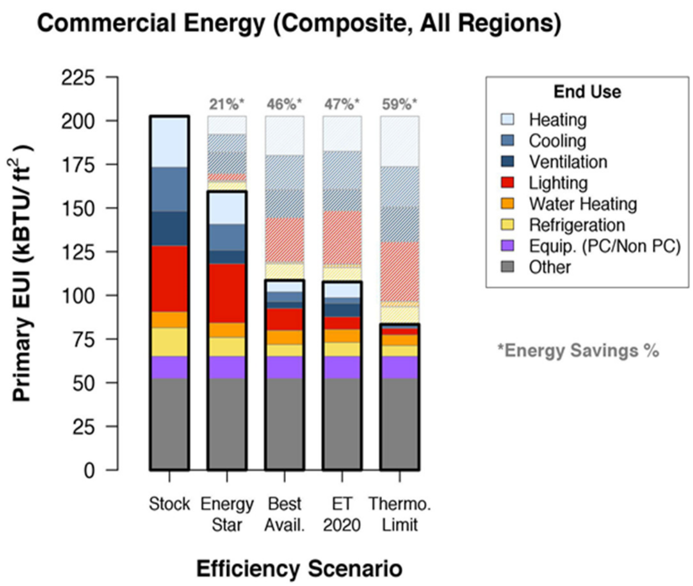


Figure 12. 2020 Commercial buildings energy savings goal

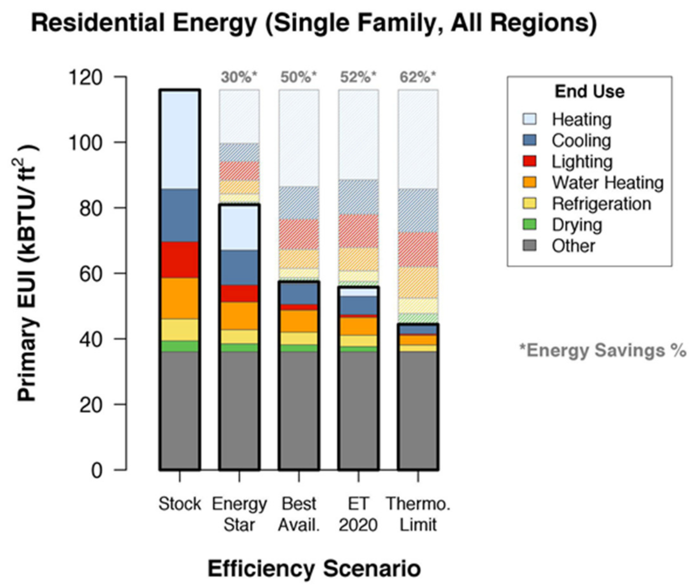


Figure 13. 2020 Residential buildings energy savings goal

Source: 2015 U.S. Department of Energy Quadrennial Technology Review, chapter 5

For most technologies, BTO uses the corresponding ENERGY STAR specification as the baseline from which to measure progress. For technologies that do not have an ENERGY STAR specification, BTO relies on either the most recent version of the applicable model energy code or the appropriate federal efficiency standard. Examining energy savings relative to the 2010 Energy Efficient Technologies Baseline shows how much the ET Program raises the efficiency ceiling for leading-edge technologies, but it provides only limited insights regarding the effect these technologies might have on the actual building stock over time.

To get a better understanding of the energy savings potential of such technologies relative to the building stock, ET uses the BTO Prioritization Tool (P-Tool).[24] The most recent analysis conducted with the P-Tool used the U.S. Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO 2014*) projection[25] as its baseline. Based on the presumed achievement of the 2020 performance targets (described in detail in the Sub-Program sections) and stock and flow modeling, this analysis estimated the potential energy savings under a number of technology deployment scenarios. The analysis concluded that if these technologies were rapidly deployed, which would require at least 20 years, they would decrease annual energy consumption of the U.S. building

[24] Farese, P.; Gelman, R.; Hendron, R. *A Tool to Prioritize Energy Efficiency Investments*. NREL/TP-6A20-54799. Golden, CO: National Renewable Energy Laboratory. Accessed August 22, 2014: http://www.nrel.gov/docs/fy12osti/54799.pdf

[25] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

sector by 20 quads and cut annual CO_2 pollution by 1 billion metric tons.[26] Even with only partial deployment, these technologies would make a significant contribution to the achievement of the 2030 goal of reducing sectorwide energy use intensity by 30%.

Analytical Basis for Emerging Technologies Goal

To develop the ET Program's interim market goal, the energy uses of a variety of technologies were analyzed, and the specific cost and performance targets for these technologies are the ET Program's performance targets. For the residential sector, a single-family home was used as the proxy for the entire sector, as single-family homes represent over 80% of residential floor area and total energy use. For the more diverse commercial sector, 11 building types were considered. The 2020 goal of enabling a 30% reduction represents an aggregate energy reduction across both the residential and commercial sectors. The 2030 goal of a 45% energy reduction is an aspirational goal that will depend on continued improvements in energy efficiency technologies, and on the more efficient systems integration and management of these technologies through improved and more widespread use of BEM and building sensors and controls. Table 1 shows examples of both the baseline level and the 2020 targets for the major R&D areas of the Program.

Table 1. Select ET Program 2020 targets compared to 2010 ENERGY STAR criteria efficiency levels

Technology Area	Metric	Baseline Level	ET 2020 Target
Lighting	Lumens/Watt	72†	210
HVAC	SEER	14.5	22
	AFUE	90%*	135%
Water Heating*	Energy factor	2.00	2.57
Refrigerators*	kWh/year	395	320
Dryers*	lb/kWh	3.9	6.0
Building Envelope	R-value§	24	36
Windows	SHGC	0.25	0.1
	U-factor	0.3	0.1

† Commercial only
** Residential only*
§ Commercial only, northern climates
Note: The Sensors and Controls Sub-Program and Building Energy Modeling Sub-Program do not have metrics that lend themselves to this kind of presentation. Targets are presented in their respective subsections.
SEER = seasonal energy efficiency ratio. AFUE = annual fuel utilization efficiency. SHGC = solar heat gain coefficient; numbers apply for commercial buildings in southern climates.
The U-Factor describes the rate of transfer of heat though an element within a building; it is also known as the U-Value. The numbers in the table apply to residential buildings in northern climates.

[26] These estimates will be analyzed with later versions of the P-Tool and updated each year.

Based on the ET Program goal and associated analysis, the Sub-Programs develop technology-specific targets. These program performance targets are described in detail in the Sub-Program sections that follow. Each Sub-Program carries out several R&D activities. Where possible, two metrics are used to measure the progress of each activity: one to describe the performance (i.e., efficiency), and another to describe the cost. Using lighting as an example, the applicable cost metric is the lumen per dollar and the performance metric is lumen per watt. For all R&D activities, the performance and cost targets, based on the applicable metrics, were determined through the P-Tool[24] analysis and vetted through workshops with stakeholders. The targets are updated as more information becomes available. Additional information on these targets is provided in the Sub-Program descriptions and in the technology roadmaps available on the BTO website.[27] The ET Program will track progress toward these performance goals by regularly collecting information on the cost and performance characteristics of the technologies commercialized as a result of BTO R&D funding.

Emerging Technologies Program Execution

Each ET Sub-Program collaborates with industry, national labs, universities, and small businesses to identify the strategies that are best suited to overcome the technical and market challenges associated with the technology area and to develop corresponding technology roadmaps. All Sub-Programs aim to improve building energy performance and reduce cost by developing improved materials or components, improving equipment design or engineering, developing lower cost manufacturing processes, or enabling easier installation.

While technology cost and performance targets are initially defined through internal analysis with the P-Tool, they are refined and research areas are prioritized with input from industry. These targets form the basis of ET's funding opportunity announcements (FOAs) and national lab R&D, along with the primary energy savings projected from meeting the targets. Input from external experts is also critical in identifying the technical and marketing challenges to achieving the targets, and the R&D approaches to overcoming them. Further details on the ET Program's R&D activities, priorities, and future directions are documented in technology roadmaps, which are available on the BTO website and updated every 2–3 years. ET also publishes technology reports, which highlight specific areas of interest, such as "Energy Savings Potential and Opportunities for Motors"[28] and "Energy Savings from Window Attachments."[29]

ET Sub-Programs also support technology-to-market activities, such as: Cooperative Research and Development Agreements (CRADAs) between ET and the national labs and manufacturers;

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[27] "Program Plans, Implementation, and Results." Washington, DC: U.S. Department of Energy, 2014. Accessed August 22, 2014: http://energy.gov/eere/buildings/program-plans-implementation-and-results.

[28] Goetzler, W.; Sutherland, T.; Reis, C. *Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment*. Washington, DC: U.S. Department of Energy, 2013. Accessed August 22, 2014: http://energy.gov/sites/prod/files/2014/02/f8/Motor%20Energy%20Savings%20Potential%20Report%202013-12-4.pdf.

[29] Curcija, D. C. et al. *Energy Savings from Window Attachments*. Washington, DC: U.S. Department of Energy, 2013. Accessed August 22, 2014: http://energy.gov/sites/prod/files/2013/11/f5/energy_savings_from_windows_attachments.pdf.

development of test methods and associated rating standards or certifications; and collaborations with the American Institute of Architects (AIA) to understand and promote the use of building energy modeling tools in the design of energy-efficient buildings. These types of activities accelerate commercialization by providing information on technology performance to manufacturers, retailers, and consumers, thereby increasing the confidence they need to invest in these technologies.

All applicants for ET funding are required to develop a market transformation plan that defines the path to commercialization for the proposed technology. ET projects are considered to be successful if they lead to a commercialized energy efficiency technology with significant market potential.

To be successful in the market, energy-efficient technologies must be life-cycle cost-effective and must perform as well as or better than the incumbent technologies. The ET Program strives to balance energy efficiency improvements with affordability and cost-effectiveness. For example, heat pump water heaters (HPWHs) based on the vapor compression cycle are the most efficient electric water heaters available in the market, but their higher cost limits their marketability. The ET Program, therefore, is now developing lower cost water heaters based on alternative (non-vapor compression) technologies that may be less energy-efficient than HPWHs but much more efficient than conventional electric resistance heaters. The ET Program also develops uniform testing methods for products not covered by the Appliance and Equipment Standards Program to provide reliable and objective technology performance information to buyers.

All ET Sub-Programs internally track the progress of R&D activities to inform ongoing and future efforts. The programs collect data on performance and cost, patents issued, refereed journal articles published, and the number of commercialized products brought to market.

New or Developing Emerging Technologies R&D Activities

The ET Program's sensors and controls effort reflects the emerging capabilities to utilize data collected from sensors to better and more cheaply and effectively manage building energy use. This is achieved via integrating building systems as well as connecting to the energy grid. As buildings become more energy-efficient and variable power generation (i.e., renewables) makes up more of the total electric generation capacity, the need to address grid integration issues is becoming more apparent to DOE and its stakeholders. For the buildings sector, the ability of buildings and building equipment to act like batteries—storing and releasing energy to help match supply and demand—is necessary to reduce the cost for the widespread integration of intermittent renewable power generation in the electricity grid. For example, building HVAC systems can provide ancillary services and load management capabilities by temporarily reducing or increasing power use. This improved control of a building can be efficiently integrated with the smart grid to reduce energy costs while maintaining occupant comfort.

Emerging Technologies Sub-Programs

The sections that follow provide more details about each Sub-Program supported through BTO's ET Program:

- Solid state lighting

- HVAC; water heating; and appliances
- Windows and building envelope
- Sensors and controls
- Building energy modeling

2.1 Solid-State Lighting

Lighting constitutes approximately 10% of residential building primary energy consumption and 16% of commercial building primary energy consumption.[30] Solid-state lighting (SSL) technologies offer one of the greatest opportunities for electricity savings in the building sector. The SSL Sub-Program seeks to create a U.S.-led market for high-efficiency light sources that save energy, reduce costs, and have fewer environmental impacts than conventional light sources. This Sub-Program focuses its efforts on accelerating innovation and product development, improving product efficacy and performance, reducing manufacturing costs, and overcoming technical challenges that inhibit market acceptance. These efforts result in energy saving SSL technologies, specifically inorganic light-emitting diode (LED) and organic light-emitting diode (OLED) technologies.

DOE is the lead federal agency for all research, development, and market transformation efforts related to energy-efficient lighting. Other offices within DOE also focus on advancing SSL technologies, products, and science, including the Basic Energy Sciences Program and the Advanced Research Projects Agency-Energy.

The Sub-Program works with researchers from academia, national laboratories, and industry to accelerate technology advancements. It partners with the building and lighting industries, energy efficiency program participants, manufacturers, and others to improve technical understanding and application of technologies. Working with industry also helps to lay the foundation for a cost-competitive manufacturing infrastructure in the United States.

The SSL Sub-Program also works closely with BTO's Commercial and Residential Buildings Integration Programs to accelerate deployment of SSL solutions in the market.

Solid-State Lighting Market Overview

Lighting Market and Energy Use: Lighting consumes more than 7 quads of primary energy, which represented about 18% of the total site electricity use in 2010 in the United States.[33] This is equivalent to the total primary energy consumed by about 40 million homes.[31]

Lighting technologies vary widely in their efficacy, useful life, cost, and light quality. Conventional incandescent bulbs, which have dominated residential lighting until very recently, are the least efficient (producing approximately 15 lumens per watt). They are also the least costly and have the shortest useful lives (1,000 hours). Halogen incandescent bulbs are somewhat more efficient (about 20 lumens per watt), but are more expensive and longer lasting (8,400 hours). Compact fluorescent bulbs (CFLs) (about 73 lumens per watt) are substantially more efficient, more costly, and longer lived (12,000 hours). Their commercial counterparts, linear fluorescent tubes, are also very efficient (about 108 lumens per watt) and long lived (25,000 hours). While the longer useful lives of CFLs more than offset their higher initial cost, various limitations in performance have restricted

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[30] Navigant Consulting, Inc. *2010 U.S. Lighting Market Characterization*. Washington, DC: U.S. Department of Energy January, 2012.

[31] U.S. Energy Information Administration. *2009Residential Energy Consumption Survey*. Table CE1.1. Washington, DC: U.S. Department of Energy, 2012. Accessed August 7, 2014: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary.

their use and reduced their appeal to many consumers. SSL products (including LEDs and OLEDs) are the most efficient (about 50–108 lumens per watt) and longest lived form of lighting (25,000–75,000 hours), but their higher cost and certain light quality characteristics have limited their ability to penetrate some residential and commercial lighting markets.[32]

Most lighting products are supplied by a few very large global lighting manufacturers and distributors, such as General Electric (GE), Philips, and Osram Sylvania. These companies manufacture and/or distribute products using all of the lighting technologies described above, as well as others. Most lighting products sold in the United States are now manufactured elsewhere, especially in Asia, although there have been some increases in United States manufacturing associated with SSL products. DOE requires recipients of our grants to manufacture a significant percentage of resulting products in the United States.

Between 2001 and 2010, there was a 9% drop in annual lighting electricity consumption in spite of an 18% growth in the number of installed lamps.[33] This trend is seen in all building sectors and applications, and is driven by a general migration away from conventional incandescent lighting and a move toward more efficient lighting such as halogens, CFLs, and LEDs. The percentage of incandescent lamp installations decreased from approximately 62% of all lamps in 2001, to 45% a decade later, meaning fewer new and replaced lamps are using these inefficient bulbs.[30] Figure 14 illustrates the drastic change in SSL market growth from 2013 to 2030 that the SSL Sub-Program has already achieved and depicts the projected installed base for 2030.

[32] DOE SSL Program. *Solid-State Lighting R&D Plan*. Washington, DC: U.S. Department of Energy, May 2015. Accessed September 2015: http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf

[33] Navigant Consulting, Inc. *2010 U.S. Lighting Market Characterization*. Washington, DC: U.S. Department of Energy, January, 2012.

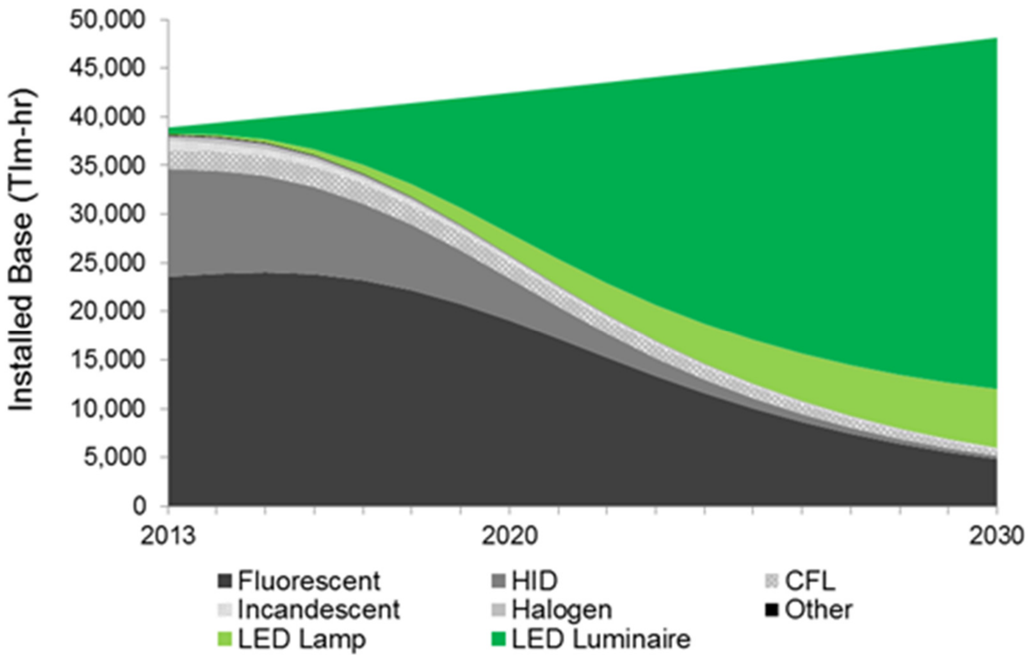

Figure 14. U.S. migration toward energy-efficient lighting

Source: Navigant Consulting, Inc. Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. Washington, DC: U.S. Department of Energy, August 2014. Accessed September 2015: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

Note: *Tlm-hr = Teralumen-Hour*

These market trends have been driven by several forces, such as government regulation, utility incentives for high-efficiency products, and cost reductions and lighting quality improvements for both CFLs and LEDs. While the most efficient lighting technology, LEDs currently represent around 3% of the general lighting market, its share is rapidly growing. From 2012 to 2014 alone, the total number of installed LED units more than quadrupled, reaching a cumulative total of 215 million units. These LEDs saved approximately 143 trillion British thermal units (tBtu) of source energy.[34] These trends indicate that the United States lighting market is shifting toward energy-efficient light sources. Continuing and accelerating these trends holds the promise of very large reductions in the energy demand for lighting.

Market Barriers: The high risks associated with the development of SSL technologies have long limited the willingness of private manufacturers to invest the funds necessary to develop and bring SSL products to market. Limitations in the performance of SSL light sources posed difficult challenges to researchers. Even if these challenges were overcome, the marketing of SSL products would require a major reorientation of consumer purchasing behavior (from low-cost, low-efficiency products with short useful lives to high-cost, high-efficiency products with very long

[34] Navigant Consulting, Inc. *Adoption of Light-Emitting Diodes in Common Lighting Applications*. Washington, DC: U.S. Department of Energy, July 2015.

useful lives). These barriers were compounded by a lack of reliable information on product performance and a lack of industry standards and test procedures on which more reliable information could be based.

Widespread information problems in the market related to LED technologies affect buyer perceptions and the ability to compare SSL products with traditional options. Buyers are unfamiliar with and have difficulty understanding the performance of new products, and in particular, whether selected products are suitable replacements for the conventional light sources they are presently using. Similarly, lighting professionals (typically having far more sophisticated understanding of SSL technology) still struggle with a wide range of conflicting information on LED performance characterization and appropriate application. Thus, continuing lack of objective information, as well as misinformation, substantially increases the risk (both perceived and real) of investment in SSL, slowing its market adoption.

In recognition of very large benefits that would result from a transition to high-efficiency lighting and the many barriers hindering private sector development of such technologies, DOE initiated the SSL Sub-Program, which has made great strides in improving the technology. There are now a wide variety of LED products available that can compete with conventional technology performance for most lighting applications.

Solid-State Lighting Program History

Since the 1980s, DOE has supported the development and commercialization of more energy-efficient lighting technologies, including CFLs and solid-state fluorescent lighting ballasts. In the early 2000s, BTO initiated the SSL Sub-Program to support the development of SSL technologies. The Energy Policy Act of 2005 (EPACT 2005) directed DOE to accelerate SSL technology development with a Next Generation Lighting Initiative. This was followed by the Energy Independence and Security Act (EISA) of 2007, which directed DOE to support R&D, demonstration, and commercial application activities related to advanced SSL technologies. BTO's SSL development and commercialization program has accomplished several key milestones in recent years, including:

- Cree's XLamp® achieved 115 lumens per dollar using its latest-generation die manufacturing process, which was developed with DOE support.
- Philips Lumileds™ stretched efficacy to 161 lumens per watt for a warm-white illumination-grade LED using a novel hybrid approach.

In parallel, EISA 2007 also set maximum wattage standards for general service incandescent lamps, which took effect between 2012 and 2014 and effectively require the efficacy of general service incandescent lamps to increase approximately 25%. Halogen incandescent lamps that meet these standards are currently commercially available; however, EISA 2007 also states that by 2020, the efficacies of general service lamps must be at least 45 lumens per watt. The only technologies capable of meeting these second-tier efficacy standards are fluorescent high-intensity discharge lamps and LED-based lighting.

The rapid growth of the LED lighting industry worldwide, and especially in Asia, highlights the importance of United States investments, past and present, to continue to maintain and grow a healthy domestic SSL industry. DOE's SSL manufacturing initiative started in 2009 in response to the need to assist in the growth of production capacity, the reduction of manufacturing costs to promote adoption, and quality improvement, all of which are aimed at maximizing energy savings.

In 2013, the National Academy of Sciences (NAS) reviewed the development of SSL and assessed the barriers to widespread market adoption. The NAS report praised DOE's efforts in advancing SSL technology, stating that "DOE has done an impressive job in leveraging a relatively small level of funding to play a leading role nationally and internationally in stimulating the development of SSL."[35]

Opportunities for Future Savings: LEDs and OLEDs have the potential to be 10 times more efficient than incandescent lighting and twice as efficient as fluorescent lighting. Figure 15 depicts the potential energy savings attributed to LEDs between 2013 and 2030 for two different scenarios. The first is business-as-usual LED energy savings based on the current market trajectory for SSL technology. The second scenario illustrates a case where the SSL Sub-Program goals are representative of all LED lighting products entering the United States lighting market. This scenario indicates how aggressive investment in LED technology has the potential to greatly affect the nation's energy footprint. Assuming that the SSL Sub-Program reaches its goals, SSL has the potential to reduce energy consumption by 395 TWh annually by 2030 relative to a scenario in which LEDs do not exist. This translates to an annual electricity cost savings of $40 billion.[36]

SSL Energy Savings Potential

In the year 2030, increased penetration of LED lighting is projected to enable the following savings assuming the Sub-Program meets its goals:

- *395 TWh annually, comparable to the annual electricity consumption of about 36 million U.S. homes*
- *$40 billion of cost savings in 2030 alone at 2014 energy prices*
- *More than 230 million metric tons of carbon of GHG emissions, assuming the 2030 forecasted mix of generating power stations*

Source: DOE SSL Program. *Solid-State Lighting R&D Plan*. Washington, DC: U.S. Department of Energy, May 2015. Accessed September 2015: http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf
U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014.

[35] National Academy of Sciences. *Assessment of Advanced Solid-State Lighting*. Washington, DC: The National Academies Press, 2013.
[36] DOE SSL Program. *Solid-State Lighting R&D Plan*. Washington, DC: U.S. Department of Energy, May 2015. Accessed September 2015: http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf

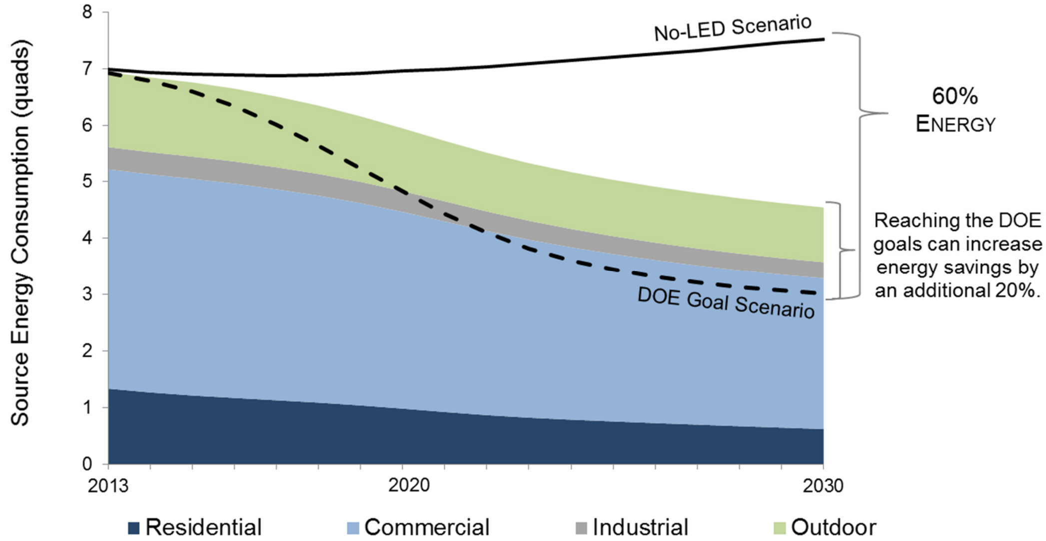

Figure 15. Forecasted U.S. energy savings if DOE SSL Sub-Program goals are realized

Source: DOE SSL Sub-Program, "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications," August 2014. Accessed September 11, 2015: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

Despite the rapid pace of LED technology development, further R&D is needed to address issues that limit performance. The goal is to maximize efficacy and address technology issues that hamper widespread market acceptance.

Solid-State Lighting Goals

The SSL Sub-Program has set ambitious goals and associated targets, which have been identified through roundtable and workshop discussions with industry stakeholders and R&D experts. These targets are listed in Table 2. Achieving these targets by 2020 would mean the potential to save approximately 2.8 quads of primary energy compared to the 2010 Energy-Efficient Technologies Baseline.[37]

The SSL Sub-Program tracks performance characteristics for all lighting categories and provides quarterly reports with this information. This allows the Sub-Program to easily track progress toward goals and understand the impacts of current activities. The analytical basis for these targets as well as detailed information on the status of each technology can be found in the SSL R&D Plan.[38]

The following figures provide historical information, current status, and future projections for LED and OLED efficacy. Cool-white and warm-white vary based on the color spectrum emitted by the

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[37] For more details on the 2010 Energy Efficient Technologies Baseline, see Section 2.0, Emerging Technologies Introduction.

[38] DOE SSL Program. *Solid-State Lighting R&D Plan*. Washington, DC: U.S. Department of Energy, May 2015. Accessed September 9, 2015: http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf.

package. Figure 16 shows the DOE SSL Sub-Program's progress in increasing efficacy of warm-white and cool-white LED packages and anticipated future improvements; Figure 17 provides the same information for OLED panel efficacy.

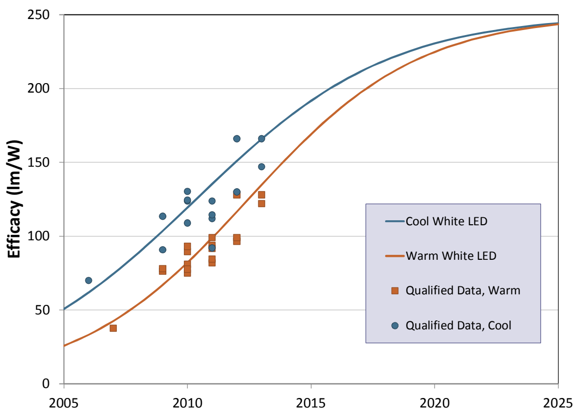

Figure 16. Efficacy projections for LEDs

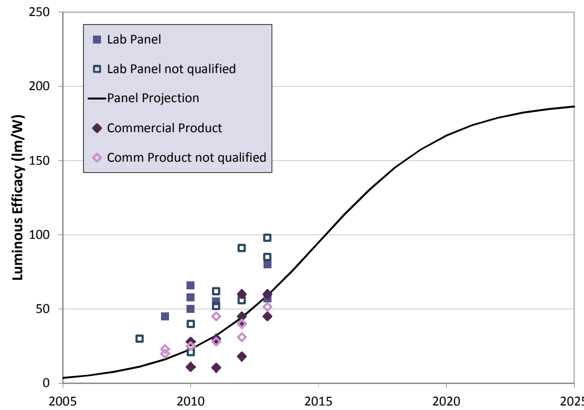

Figure 17. Efficacy projections for OLEDs

Source: Navigant Consulting, Inc. *2010 U.S. Lighting Market Characterization*. Washington, DC: U.S. Department of Energy, January, 2012.

These SSL source component improvement projections for LED package and OLED panel efficacy demonstrate the expected trends for the overall efficacy of the complete lamp and luminaire product. Tracking these trends allows the Sub-Program to regularly assess if the necessary progress is being made to reach anticipated targets and where shifts in focus may be needed.

Solid-State Lighting Technology Challenges

Though there are a wide variety of LED products available across most lighting applications and a clear shift has been made toward more energy-efficient lighting technologies over the past decade, there are a number of technical challenges that the SSL Sub-Program seeks to address to further improve SSL technologies.

High Cost: The cost of LEDs and OLEDs is high compared to traditional lamps. Improvements in manufacturing equipment and processes are needed to reduce the price of both LED and OLED technologies. Further, small-scale production of LEDs translates to high manufacturing costs. As the LED and OLED market grows, larger economies of scale in production can help reduce manufacturing costs.

Innovation is still needed on multiple fronts for the less mature OLED technology to increase the efficacy, lifetime, and output of OLED devices. However, as the technology advances, manufacturing infrastructure investments are critical to aid the transition of OLED products from prototype to product.

Unrealized Design Potential: Opportunities remain to further improve the efficacy of both LED packages and completed products through improved design and engineering. Innovation is needed to improve efficacy, commonly measured in lumens output per watt input. Today's LED R&D focuses on improving phosphor efficiency, simplifying package design, improving package efficiency, tuning the color spectrum, and addressing extraction efficiency and stability for both light output and color. Quality luminaires require precise design of a number of components, including LED arrays, electronic drivers, heat sinks, and optics. In general, LEDs must be carefully designed for integration into lighting fixtures because they are sensitive to thermal, optical, and electrical design. As controls come into greater use, new issues are emerging, and R&D is needed to learn how best to match electronics and LEDs.

Technical Performance Deficiencies: Beyond improving the qualities of LED and OLED products, their flaws must also be minimized. Performance barriers also exist that make these products unattractive to consumers; these are related to reliability, system lifetime, color, and lumen maintenance.

For many applications, LED-based light sources have a lower life cycle cost, given their long lifetimes. However, that requires achievement of their lifetime claims. New technologies can fail prematurely, which threatens the reliability of the products. Failure mechanisms, such as color shift, optics degradation, power supply failure, and solder detachment can lead to the luminaire falling out of specified performance or even catastrophic failure.

Consumers now expect entirely interchangeable LED lamps (bulbs) for conventional incandescent lamps. They expect replacement products to be compatible to incandescent lamps. An example is the legacy dimmer circuit. Consumers expect LED lamps to work with this type of light source and match expected characteristics like color quality, light distribution, form factor, and light output of the product they are replacing. This can add significant cost and complexities and can, in the case of the legacy dimmer, reduce the efficiency of the system.

Solid-State Lighting Strategies, Current and Planned Activities, and Key Targets

BTO accelerates the development and market acceptance of SSL by integrating three elements: competitive R&D, market-based technology advancement efforts, and market engagement. The SSL Sub-Program works closely with BTO's Commercial and Residential Buildings Integration Programs and the Appliance and Equipment Standards Program to accelerate deployment of energy saving SSL solutions. One cross-cutting area of interest is the improvement of networked lighting systems.

During the next 5 years, BTO will address challenges related to the LED and OLED technology areas through R&D and market transformation strategies.

Strategies

- *Improve performance and reduce manufacturing costs through competitive R&D.*
- *Improve networked lighting systems to reduce lighting energy use.*
- *Advance SSL technology and increase market penetration through laboratory testing, quality reporting, field demonstrations, technical education, and competitions.*

R&D and market-based activities are necessary to realizing energy savings in the lighting market. Figure 18 illustrates BTO's integrated approach to accelerate technology advances. Projects and activities are implemented in a highly integrated way, creating critical feedback loops among elements to focus and improve activities.

R&D efforts spur SSL technology advances in efficacy and performance that might not otherwise happen without DOE funding. Market activities also spur SSL technology advances via tight, rapid, information-rich feedback loops between the marketplace and technology R&D. Timely feedback is critical because SSL technology continues to change and evolve very quickly, without the traditional long lag times between technology R&D and market introduction. Many SSL R&D results move into the market within 12–18 months, a much faster schedule than in most other technology areas. DOE testing of today's commercially available SSL products often identifies performance issues and helps to inform and prioritize future R&D efforts. DOE shares testing results with manufacturers to help them improve their products, and with buyers to provide them with reliable, unbiased information and to accelerate market acceptance.

Market engagement efforts such as workshops, roundtables, and planning sessions enable frequent interaction with key researchers, manufacturers, lighting users, energy efficiency programs, utilities, retailers, and other stakeholders to share the latest information and data and to seek their input on industry and market needs. These feedback loops inform DOE R&D priorities and market activities.

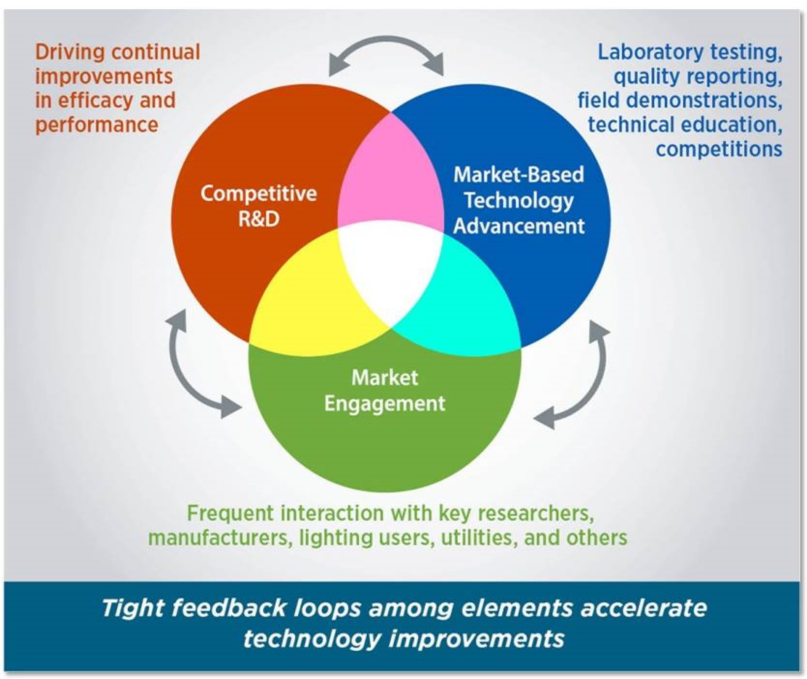

Figure 18. BTO's integrated approach to accelerate SSL technology advances

Each strategy is described below along with planned activities and associated metrics and targets.

Strategy 1: Improve performance and reduce manufacturing costs through competitive R&D.

The SSL Sub-Program works with hundreds of researchers through partnerships with industry, small businesses, academia, and national laboratories to accelerate technology advancements. Projects are competitively awarded, with partners providing an average of nearly 40% cost-share. The SSL Sub-Program requirements ensure that the intellectual property and patents from DOE-funded R&D remain in the United States. R&D activities are focused in three areas:

> **SSL R&D Success**
>
> *As of January 2015, 96 SSL patents have been awarded to research projects funded by DOE. Since December 2000, when DOE began funding SSL research projects, a total of 247 patent applications have been submitted. These applications come from a variety of organizations with the breakdown as follows:*
>
> - *Large businesses – 79 patent applications*
> - *Small businesses – 90 patent applications*
> - *Universities – 66 patent applications*
> - *National laboratories – 12 patent applications*
>
> Source: http://energy.gov/sites/prod/files/2015/01/f19/patents_factsheet_jan2015.pdf

Core technology R&D addresses efficiency, performance, and cost targets. Conducted primarily by academia, national laboratories, and research institutions, this work fills technology gaps and significantly advances the knowledge base related to LED and OLED technology.

Product development improves the commercial viability of SSL materials, devices, luminaires, and systems. Conducted primarily by industry, these activities focus on a targeted market application with fully defined prices, efficacies, and other performance factors necessary for success of the product.

Manufacturing R&D improves product quality and consistency, and lowers cost through development or improvement of materials, sub-systems, tools, processes, and assembly methods that are specific to SSL manufacturing.

Strategy 2: Improve networked lighting systems to reduce lighting energy consumption.

In fiscal year (FY) 2015, DOE launched a new effort aimed at improving technology used in networked lighting systems. The effort, which depends on close cooperation of the lighting industry, is focusing on three topic areas that DOE believes are critical for the successful development of a networked lighting systems industry:

- Improving application layer interoperability, including new standards development
- Verifying system configuration requirements
- Integrating energy use measurement into lighting devices

Strategy 3: Advance SSL technology and increase market penetration through laboratory testing, quality reporting, field demonstrations, technical education, and competitions.

The SSL Sub-Program works closely with industry, utilities, energy efficiency programs, retailers, distributors, and other lighting stakeholders to lay the groundwork for buyer satisfaction and successful product introductions in a rapidly evolving lighting marketplace. The blistering pace of technology advancement leads to a new generation of products every 6 months, but the quality and energy efficiency of today's products vary widely. Market activities focus on the following areas:

The Commercially Available LED Product Evaluation and Reporting (CALiPER) testing activity was established by DOE to provide accurate and comparable data on LED products by arranging for reliable independent testing of commercially available products. CALiPER testing and analysis identify trends that indicate SSL's suitability for particular applications, and detect secondary issues such as glare, flicker, physical format, and reliability concerns. The results not only guide DOE planning and help discourage low-quality products and inflated claims, but also serve as a useful tool for manufacturers seeking to improve their products, and for municipalities, utilities, and energy efficiency programs seeking to make informed program decisions.

Success with CALiPER

When LED products were first introduced in the market, many had unrealistic and unsupported performance claims. In the first two rounds of CALiPER testing in 2007, 15% of the products had light output claims within 30% of tested values. Of products CALiPER tested in 2012, about 67% had output claims within 10% of the tested value. A standard method to measure LED product performance enabled the development of minimum voluntary performance criteria for qualification by ENERGY STAR®. As of 2013, more than 2,800 LED integral lamps and 2,100 LED luminaires are ENERGY STAR qualified.

Source: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_lessons-learned_2014.pdf.

Gateway demonstrations enable detailed SSL product evaluation and hands-on experience that cannot be replicated in a lab for a variety of private- and public sector stakeholders, including large retail businesses, universities, and municipalities. High-performance SSL products are selected and installed in a variety of commercial and residential applications, providing valuable data on product performance and cost-effectiveness to stakeholders in real-world situations. These projects and the resulting data are then compiled into case studies (http://energy.gov/eere/ssl/gateway-demonstrations), often revealing important issues related to installation, interface, and control.

LED Lighting Facts® showcases LED products from manufacturers that commit to testing products according to industry standards and reporting performance results. For lighting buyers, designers, and energy efficiency programs, the effort provides information essential to evaluating SSL products via a web-based, searchable tool (http://www.lightingfacts.com/products) that summarizes verified product data.

Competitions provide additional incentive to technology improvements and heighten awareness of high-performance SSL products. The L Prize® competition challenges industry to develop products that meet 'stretch' performance targets and set leading-edge benchmarks for the industry. The Next Generation Luminaires™ competition, sponsored by DOE, the Illuminating Engineering Society, and International Association of Lighting Design, recognizes excellence in the design of energy-efficient commercial LED lighting.

Table 2 highlights several key metrics tracked by the SSL Sub-Program. It shows normalized values for two categories of LED packages. It should also be noted that the performance and price values are for products and processes that are still under development and therefore are not reflective of commercially available products. The SSL Sub-Program has many other metrics that it tracks;

information is available in the SSL technical reports,[39] CALiPER reports,[40] and through its lighting facts program.[41]

Table 2. SSL metrics, statuses, and targets: 2015-2020

Metrics, Statuses, and Targets: LED Package Price and Performance					
Package Type	**Project Areas**	**Metric**	**Status***	**2017**	**2020**
Cool-White	Efficacy	lm/W	185	205	226
	Price	lm/$	191	226	271
Warm-White	Efficacy	lm/W	162	190	220
	Price	lm/$	150	210	271

**Current status as of 2015*

[39] http://energy.gov/eere/ssl/technical-reports-briefs
[40] http://energy.gov/eere/ssl/caliper-testing
[41] http://energy.gov/eere/ssl/led-lighting-facts

2.2 Heating, Ventilation, Air Conditioning/Water Heating/Appliances

HVAC, water heating (WH), and other appliances represent more than half of the total energy used in U.S. residential and commercial buildings.[42] Space conditioning is critical to household and business activities, indoor air quality, and comfort, and represents a vast opportunity for increasing building energy efficiency. The HVAC/WH/Appliances Sub-Program supports the research and development of affordable, cost-effective technologies that reduce building energy consumption and environmental burdens. The Sub-Program strives to reduce barriers to greater market adoption of premium-efficiency technologies in the near term by refining and reducing the cost of available technologies, such as heat pump technologies for space conditioning and WH. The Sub-Program concurrently seeks to develop and introduce next-generation, transformative technologies for the future, such as non-vapor compression heat pumps and advanced compressors and heat exchangers.

To advance energy efficiency, the Sub-Program pursues solutions that are systems oriented to optimize energy use in the entire building. R&D priorities include developing integrated systems that combine end uses, such as energy cascading (where heat from one process is used as the source of energy for another, as in integrated heat pump technologies). Another Sub-Program priority is to explore new or different next-generation components to find the best possible cost-effective combination. These efforts will result in innovative energy saving components and technologies for HVAC, WH, refrigeration, and laundry systems that have the potential to fully replace or be integrated with conventional technologies, often across end uses.

The Sub-Program works with national laboratories, academia, small businesses, manufacturers, and other industry stakeholders to advance technology R&D and commercialization toward maintaining the competitiveness of American industry. The Sub-Program also works with standards and certifying bodies and technical organizations, such as the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and the Air-Conditioning, Heating & Refrigeration Institute (AHRI), to help accelerate market acceptance.

The Sub-Program coordinates closely with the Windows and Building Envelope Sub-Program to reduce heating and cooling energy consumption, and with the Residential and Commercial Building Integration Programs to bridge the gap from technology commercialization to broad market acceptance. The Sub-Program also works with the Building Codes and Appliance and Equipment Standards Programs to identify equipment or appliances that require further R&D support and to facilitate development of appropriate codes and standards.

[42] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Energy Information Administration, 2014.

HVAC/WH/Appliances Market Overview

HVAC, WH, and Appliances Market and Energy Use: HVAC, water heating, and appliances accounted for an estimated 22 quads of primary energy consumed in the United States in 2013, nearly the total amount of primary energy consumed in all residential end uses combined.[42] Figure 19 illustrates the breakout of these end uses in both the residential and commercial building sectors.

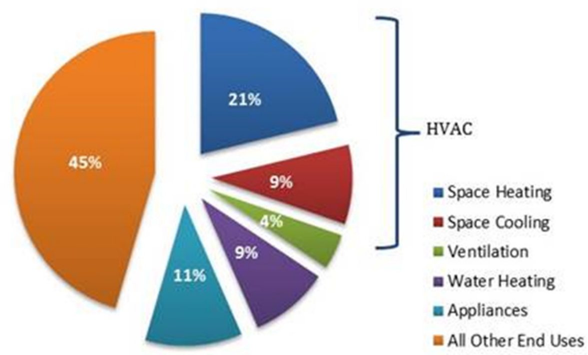

Figure 19. Total energy consumption by end use in residential and commercial buildings, 2013

Source: U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Energy Information Administration, 2014. Accessed August 25, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

HVAC is the largest energy end use in both residential and commercial buildings. Water heating is primarily a residential function, constituting nearly 80% of all water heating energy use. Commercial water heating occurs primarily in hotels, hospitals, and food service buildings. Residential appliances also consume large amounts of energy. Daily use of refrigerator/freezers, dishwashers, laundry equipment, and cooking equipment accounts for approximately 15% of residential building primary energy consumption. Appliances used for cooking and refrigeration are a potential source of energy savings for commercial buildings such as grocery stores and hotels. For appliances, the Sub-Program primarily focuses on refrigerator/freezers and clothes washers and dryers, which have the most opportunity for energy savings.

In the United States, energy uncertainties of the 1970s gave impetus to a wave of government initiatives directed at energy conservation. This led to the promulgation of mandatory efficiency standards for household appliances. In 1992, federal mandatory standards for unitary air conditioners and heat pumps were instituted and utilized new efficiency indicators: seasonal energy efficiency ratios (SEERs) for air conditioners and heat pumps in the cooling mode, and heating seasonal performance factors (HSPFs) for heating performance of heat pumps. Seasonal performance requirements were also issued for gas and oil warm air furnaces and boilers. The requirements for the initial performance standards for cooling efficiency began with the 1992 standard (10 SEER) and have led to an increase of more than 50% in operating efficiency during the last 22 years. Figure 20 shows the date for seasonal efficiencies in cooling operation for both cooling-only and heat pump units. Heating seasonal performance levels have shown a similar increase over the period. A new standard level became effective in January 2006 (13 SEER). The next step in the efficiency standard level takes place in 2015 when the minimum SEER is raised to 14 (8.2 HSPF for heat pumps). Currently, there are products in the AHRI directory with SEER levels up to 23 (with variable speed compressors).The increased efficiency standards taking effect in 2015 for residential air conditioners (and gas and oil furnaces) will have different levels for different climate regions of the country. The minimum performance standard for residential heat pumps will be the same for the entire United States.[43]

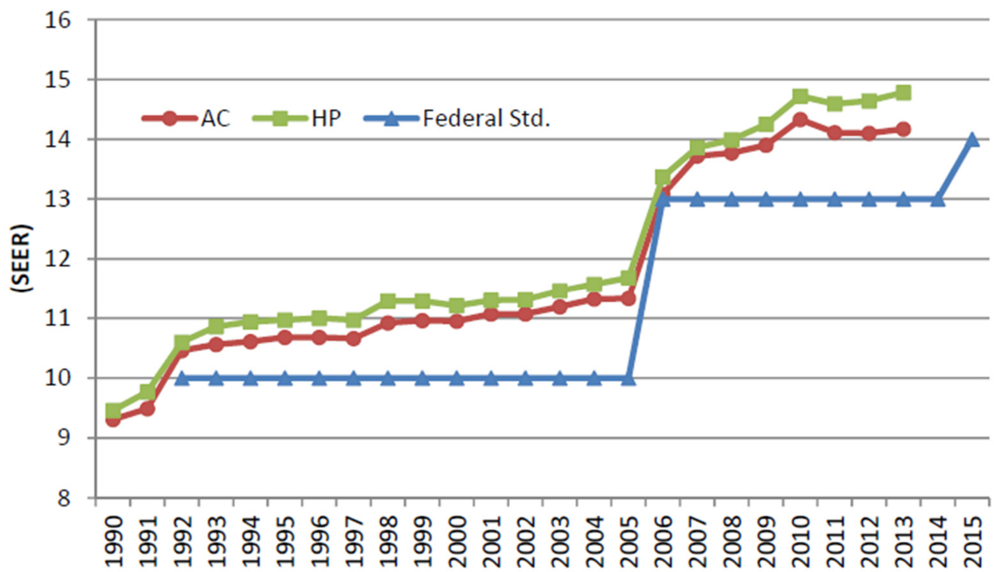

Figure 20. Shipment history of unitary residential split air conditioning and heat pump cooling equipment by weighted seasonal efficiency

Source: Groff, G. *Heat Pumps in North America 2014*. North America Regional Report. U.S. Energy Information Administration, 2014.

Overall, market sales in appliances, HVAC, and water heating products correlate with the new construction and renovation of residential and commercial buildings. In recent years, total unit shipments have trended up as the number of building starts and building retrofits has slowly increased with the recovery of the construction industry since 2009. In particular, an aging building stock requires new HVAC equipment, water heaters, and appliances; some 37 million residential water heaters will be replaced in the next 5 years.[44]

Even though high-efficiency appliances, water heating, and space conditioning systems are available in the market, the majority of equipment sold in the United States just meets, rather than exceeds, DOE's energy conservation standards. Figure 21 illustrates the most common HVAC and water heating equipment technologies sold in the United States. For example, water heaters in U.S. homes are still primarily storage-tank type, compared to newer, tankless systems, with the former having more than 96% market share. This is largely due to the high equipment cost and the

[43] Groff, G. *Heat Pumps in North America 2014*. North America Regional Report. U.S. Energy Information Administration, 2014.

[44] Ryan, D.; Long, R.; Lauf, D.; Ledbetter, M.; Reeves, A. *ENERGY STAR Water Heater Market Profile*. Prepared by D&R International, Ltd, Silver Spring, MD, for Oak Ridge National Laboratory. Washington, DC: U.S. Department of Energy, 2010. Accessed July 7, 2014: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/Water_Heater_Market_Profile_2010.pdf.

additional cost and complexity associated with installing a tankless water heater, especially when replacing tanks in existing buildings. In existing buildings, replacements most often occur in a situation of equipment failure, which requires an immediate decision and installation, leaving little time for considering alternatives or system conversions. However, tankless water heaters are slowly gaining traction in homes and small commercial buildings.

ENERGY STAR® assists in the uptake of higher efficiency products because its certification signals higher efficiency and implied quality to consumers, thus simplifying purchasing decisions. The market for higher efficiency equipment is growing annually, although overall market penetration is low and progress is slow, as Figure 21 illustrates.

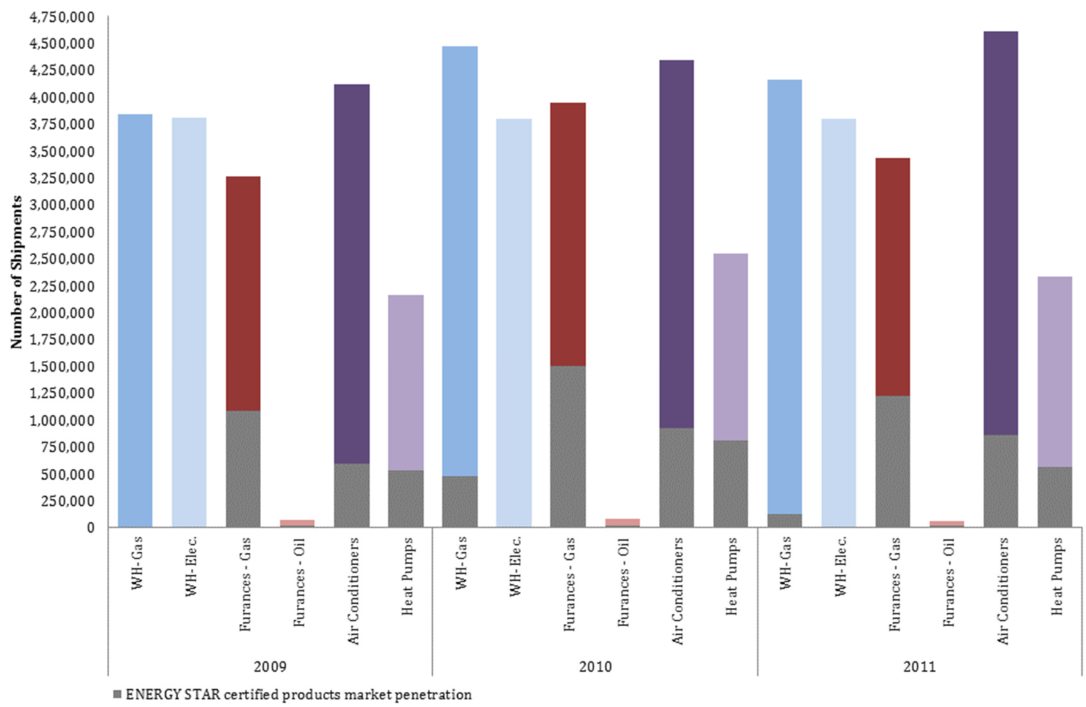

Figure 21. HVAC and water heating shipments and ENERGY STAR market penetration, 2009–2011

Sources: "Historical Research Data." Arlington, VA: Air-Conditioning, Heating, & Refrigeration Institute, 2014. Accessed Aug 14, 2014: http://www.ahrinet.org/site/493/Resources/Statistics/Historical-Data

ENERGY STAR. "ENERGY STAR Unit Shipment Market Penetration Report Calendar Year 2009 Summary." Washington, DC: U.S. Environmental Protection Agency. Accessed Aug 14, 2014: https://www.energystar.gov/ia/partners/downloads/2009_USD_Summary.pdf?9ca2-9053

ENERGY STAR. "ENERGY STAR Unit Shipment Market Penetration Report Calendar Year 2010 Summary." Washington, DC: U.S. Environmental Protection Agency. Accessed Aug 14, 2014: https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2010_USD_Summary_Report.pdf?ac6a-f243

ENERGY STAR. "ENERGY STAR Unit Shipment Market Penetration Report Calendar Year 2011 Summary." Washington, DC: U.S. Environmental Protection Agency. Accessed Aug 14, 2014: https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2011_USD_Summary_Report.pdf?17e4-fe0d

Heat pumps can provide space conditioning and/or hot water by capturing energy from their surroundings: ambient air, ground, or water. These technologies have been commercially available for many years in the United States. In the water heating market, heat pumps have only recently begun to see increased market penetration. Heat pumps are more common in the space conditioning market, and air-source heat pumps are the most common type in residential buildings. They are used primarily in moderate climates, although manufacturers have recently introduced air-source heat pumps that are optimized for cold-climate conditions. Overall, shipments of air-source heat pumps increased 16% in 2013 from the previous year.[45]

Through DOE's energy conservation standards and the ENERGY STAR program, refrigerators, washers, and dryers in all building sectors have become substantially more energy efficient in recent years, while also providing greater capacity. Yet, there is still substantial opportunity for enhancing energy efficiency through technological improvements. For example, clothes dryers available on the market use up to 4 kilowatts (kW) for their heating elements alone; for vented clothes dryers, this includes additional HVAC burden. In comparison, a successfully tested prototype heat pump dryer shows energy savings of almost 70% compared to energy use by conventional electric clothes dryers.

Partner Spotlight: ClimateMaster's Revolutionary Heat Pump

A partnership between ClimateMaster and DOE with Oak Ridge National Laboratory (ORNL) started as an effort to develop a more efficient ground-source integrated heat pump. It has led to the revolutionary Trilogy 45 Q-Mode™ geothermal heat pump, which can save users as much as 60% of annual energy use and cost for space heating and cooling and WH in homes compared to less efficient conventional systems. The Trilogy heat pump uses heat from the earth to heat and cool a home, as well as supply 100% of the home's hot water. This product is about 30% more efficient than any other available ground-source heat pump. ClimateMaster received the 2013 R&D 100 award from R&D Magazine, which highlights commitment to deploying cutting-edge technology and helping people save money and energy.

Manufactured in the United States

ClimateMaster manufactures the Trilogy 45 Q-Mode in Oklahoma City. The plant not only produces heat pumps that enable consumers to cut annual energy usage in half, but also strengthens the U.S. economy by adding jobs at its production plant and corporate headquarters, also located in Oklahoma City. ClimateMaster's history in American geothermal heating and cooling manufacturing extends back more than 50 years. The facilities in Oklahoma sustain 600 American jobs and 4,000 independent dealers across the United States.

[45] "AHRI Releases December 2013 U.S. Heating and Cooling Equipment Shipment Data." Arlington, VA: Air-Conditioning, Heating & Refrigeration Institute, 2014. Accessed July 7, 2014: http://www.ahrinet.org/App_Content/ahri/files/Statistics/Monthly%20Shipments/2013/December2013.pdf

Improved HVAC, water heating, and appliance technologies offer significant opportunity for energy savings. Energy savings can be realized not only in individual end uses, but in optimizing and reducing building energy use through integrated systems. This requires improving the design and sizing of systems and integrating them into the building design and for operation and control. One example of this is an integrated packaged heat pump system capable of cooling and heating indoor spaces and water heating simultaneously for various applications.

Market Barriers: Despite the availability of high-efficiency products, sales volumes have only modestly increased in recent years, and the majority of appliances and HVAC and WH products sold in the United States still meet only minimum DOE energy conservation standards. High first costs, long payback periods, and the perceived risk of investing in new, seemingly unproven technologies limits market acceptance. Manufacturers, equipment distributors, design engineers, mechanical contractors, builders, and consumers must understand the benefits of new energy technologies and have awareness of what is available before consumers will invest on a large scale.

Long payback periods are often not acceptable to consumers. Recent focus group studies have suggested that many consumers have an implicit 1-year payback maximum on investment in energy-saving technologies.[46] Many such options do provide positive life cycle returns through lower operating costs, but the additional upfront cost represents a seemingly insurmountable financial commitment.

Split incentives in the equipment market also affect consumer purchasing decisions. In new construction, the building designer or installation contractor may choose the equipment rather than the utility bill-paying consumer. Hot water distribution HVAC systems may be chosen by an engineer in new buildings but are often invisible to developers and consumers. Those choices are often driven by the familiarity or business ties of the installation contractor, building designer, or engineer.

The nature of the market also hinders investment in high-efficiency products (i.e., HVAC and hot water systems are often purchased in emergency replacement situations). Often, building owners make purchase decisions where the impact of lost business at a restaurant or retail store or lack of comfort in a home are the primary drivers. As such, the immediate availability of the product drives decision-making (e.g., being in stock locally and/or already on the contractor's truck). Products are usually selected for non-energy benefits, such as low noise, aesthetic value (for home appliances), enhanced comfort, compact size, enhanced functionality, and reliability. In the commercial sector, improved indoor environmental quality also is a factor.

Lack of awareness and information on high-efficiency products and their potential benefits limits consumers' and building professionals' willingness to invest. Some new products and systems also require additional training for building professionals to be able to easily and correctly install and service them, especially in buildings where existing infrastructure can add complexity. Building professionals may also hesitate to advocate for new systems for which they have little knowledge or prior experience. For example, absorption systems use thermal energy to drive chemical

[46] Goetzler, B. "Air Conditioning Market & Technology Trends." Presented at ARPA-E BEETIT, December 7, 2010.

compression in heat pump systems. While many large commercial and industrial contractors are familiar with these systems, they are brand new to plumbers, building inspectors, and contractors in the residential market. Without knowledge of such systems, all involved trades will charge more for installation, assuming they are comfortable taking on the job at all. Additionally, system designers or installers who lack knowledge of high-efficiency systems will never include such systems in building specifications or be able to properly educate consumers when retrofitting a building or replacing equipment. Consumers can be overwhelmed by the available selection of products and need educated designers/installers to guide them through the process.

HVAC/WH/Appliances Program History

Since the 1980s, DOE supported the development and commercialization of more energy-efficient HVAC, WH, and appliance technologies. Most of the equipment in this section is covered by federal equipment and appliance standards.

The HVAC, WH, and appliance development and commercialization program has achieved several key milestones over the years, including:

- Initial development and ongoing improvement and enhancement to the heat pump design model, which continues to be used to guide heat pump research efforts in HVAC, WH, and appliances.
- Establishment of the total equivalent warming impact, as a measure of global warming impacts of heating, refrigeration, and AC systems, enabled the Program's recent efforts in developing its life cycle climate performance model at ORNL and the University of Maryland.
- BTO's past effort and experience in the first publication of laboratory-measured vapor compression system performance for refrigerant R-134a, R-32, R-125, and R-143a enabled the Program to pursue its current low global warming potential (GWP) refrigerant research.
- Development of high-efficiency water heaters: a 90% efficiency condensing gas water heater, launched by A.O. Smith, and a HPWH launched by GE.

Following the American Recovery and Reinvestment Act (ARRA) of 2009, the HVAC, WH, and Appliance Sub-Program has taken a leadership position in the development of several new technologies. An increase in fiscal year funding and the program's initial ARRA funding allowed BTO to pursue several new and important research thrusts, including:

- **Integrated heat pump (IHP) research,** including the development of centrally ducted IHP technology, air-source and ground-source. IHP potential has been shown to achieve approximately 50% energy savings in all five of the major U.S. climate zones.
- **Cold climate heat pump (CCHP) research** and equipment have the potential to reduce annual electricity use for building space heating in cold climates by at least 25% and improve grid reliability during winter months.
- **Low-GWP refrigerant research,** including several research equipment projects with the National Institute for Standards and Technology's (NIST) fundamental search for new

refrigerants. This project searches for and evaluates potential low-GWP alternative refrigerants based solely on their molecular structure, allowing researchers to evaluate fluids that may have never been physically synthesized.

- **Heat exchanger research,** including both conventional designs and unique designs like the rotating heat exchanger technology, an innovative and award-winning energy efficiency technology, which was one of three technologies to receive the prestigious *R&D Magazine's* 2012 Editor's Choice Award and one R&D 100 award.
- **Non-vapor compression research** started with ARRA's Advanced Energy Efficient Building Technologies FOA (DE-FOA-0000115). Recently, GE partnered with ORNL researchers to develop magnetic cooling technology—an innovative approach that uses a 50-stage system combined with a new type of iron-manganese alloy to remove heat and reduce temperatures by up to 80°F. GE has stated that it plans to bring this technology into the marketplace within 6 years.

Opportunities for Future Savings: Potential cost reductions, efficiency improvements to available technologies, and development of next-generation components and technologies for new products represent a significant opportunity for savings. Future opportunities include the development of next-generation technologies and moving them to the point of commercialization. For example, BTO is working with NIST to identify new refrigerants that are low-GWP, and is intending to accelerate the transition to these refrigerants across the entire HVAC and refrigeration industry. Other prospects for the future include gaining a better understanding of technologies already commercialized in other parts of the world. Some advanced technologies are already available in European and Asian markets but either are not manufactured in the United States or have not gained traction in the U.S. market. For example, heat pump clothes dryers were developed in 1997 in Europe; as of 2010, about 25 models were available on the European market. The first of these models is not expected to become available in the United States until late 2014. Heat pump clothes dryers can be as much as 50% more energy-efficient as conventional electric resistance clothes dryers, representing a clear opportunity for U.S. energy savings.[47] Traditionally, Europeans tend to have smaller, more compact appliances and be more accepting of long dryer cycle times. Americans, however, demand fast cycle times and want to be able to dry very large loads, two major U.S. market barriers for this technology. As a result, manufacturers have shied away from introducing certain European products in U.S. markets. Opportunities for the future address a wide range of applications, climates, and user behavior. DOE is focused on the R&D necessary to enable these potential energy savings through advanced and integrated HVAC, WH, and appliance technologies.

HVAC/WH/Appliances Goals

The HVAC/WH/Appliances Sub-Program established goals that require improvement of current technologies for the mid-term and significant innovation of components and technologies for the long term. The Sub-Program goals and targets are informed by stakeholder discussions as part of

[47] Meyers, S.; Franco, V.; Lekov, A.; Thompson, L.; Sturges, A. *Do Heat Pump Clothes Dryers Make Sense for the U.S. Market?* Washington, DC: American Council for an Energy-Efficient Economy, 2010. Accessed July 9, 2014: http://www.aceee.org/files/proceedings/2010/data/papers/2224.pdf.

technology-specific workshops. These targets are listed in Table 3, Table 4, and Table 5. Achievement of these targets by 2020 would mean that the potential energy use intensity (EUI) for HVAC would be 60% lower than the 2010 energy-efficient baseline, WH would be 25% lower, and appliances would be 15% lower.[48] These EUI reductions correspond to an approximate primary energy savings of 2.8 quads.

The Sub-Program tracks both cost and energy efficiency metrics for those technologies it has identified as high priority. The Sub-Program uses targets to guide its R&D investments and to determine R&D progress and progress toward goals. As an example, Figure 22 shows historical and projected targets based on cost and performance for various WH technologies. These targets are analyzed and adjusted each year. The Sub-Program develops these targets using the P-Tool to balance cost and performance tradeoffs, resulting in realistic targets that prepare the technology for market success instead of simply adopting the highest expected values as the targets. The values reflect realistically achievable results that are verified through discussion with researchers and technology designers. Similar charts and additional detail related to each of the Sub-Program's activities can be found in the technology roadmaps for HVAC, WH, and appliances. The targets and technology R&D approaches are summarized in the Strategies, Current and Planned Activities, and Key Targets in this section.

[48] For more details on the 2010 Energy Efficient Technologies Baseline see section 2, Emerging Technologies Introduction.

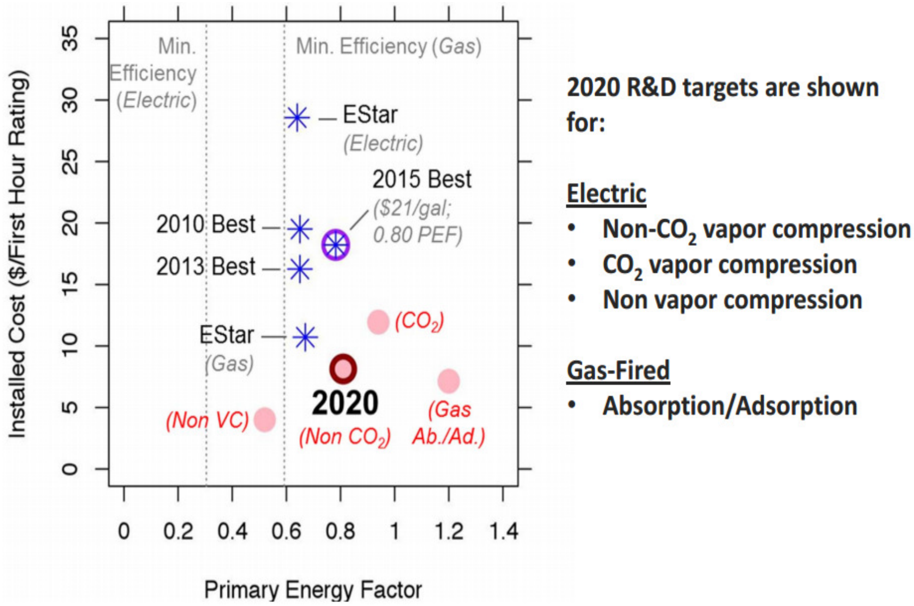

Figure 22. Water heater cost and performance targets

Sources: 2015 Best Source: Lowe's, Home Depot, and Sears product data for ~50–60 gallon residential heat pump water heater
ENERGY STAR: http://www.energystar.gov/index.cfm?c=water_heat.pr_crit_water_heaters
Federal Minimum Standards: *Electric* and *Gas* – https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/27

HVAC/WH/Appliances Technology Challenges

The Sub-Program focuses on the following technical challenges that prevent the commercial success of current and developing HVAC, WH, and appliance technologies.

High cost: The first cost of high-efficiency HVAC systems, water heaters, and appliances is higher than conventional technologies. The high-efficiency options already available in the marketplace are expensive and are difficult to upsell from conventional products due to few additional non-energy benefits and a long payback period that is unacceptable to most home or building owners. Particularly for existing buildings, more affordable systems that are cost-competitive with conventional technologies are needed.

Unrealized design potential: Opportunity exists to improve or radically change the design and engineering of advanced technologies. These changes can make the systems even more efficient, without consumers having to sacrifice in regard to size, ease of installation, capacity, indoor air quality, environment impacts, or other non-energy benefits. For example, many current systems can provide better energy and non-energy performance at lower cost via tailor-made components with advanced materials and designs, rather than with the generic components now in use.

For a specific example, a key driver of energy consumption in refrigerator/freezers is the vapor compression cycle, which uses a compressor and multiple heat exchangers to transfer heat from inside the food compartments to outside the appliance. A great potential for energy efficiency improvement exists in better heat pumping technology that surpasses traditional vapor compression systems. Overcoming barriers to performance in non-vapor compression technologies or heat exchangers also can provide pathways to increasing the efficiency of a variety of end-use systems. Development of such technologies is underway.[49]

The Sub-Program also will face new engineering challenges related to the interoperability of sensors and controls for equipment of the future. Innovation is still needed to incorporate sensors and controls to meet occupant expectations. These technologies can improve indoor air quality and comfort while minimizing energy consumption; however, space conditioning systems require further innovation to properly distribute air and water and satisfy occupant comfort.

Lack of sustained performance/reliability: Performance—including product lifetime, maintenance required, and overall reliability—must not be sacrificed when achieving high energy efficiency. Even where design and technical performance barriers are overcome, consumer expectations and perceived reliability must be addressed. Systems must be designed to sustain their initial efficiency throughout the life of the equipment, or have the ability to clearly notify users when performance has deteriorated.

Lack of reliability can also be a barrier to the success of new prototypes and to manufacturer investment in technologies. New technologies that are deployed without thorough reliability testing can quickly fail and introduce a lingering product stigma in the market. For example, some early ground-source heat pumps were sized poorly and suffered from reliability issues. While new systems have overcome these challenges, some consumers remain skeptical of the technology due to the poor performance of the first generation of products.

High manufacturing cost or lack of manufacturing method: To introduce new components or technologies to the mass market, manufacturers must develop cost-effective techniques and appropriate manufacturing processes. For example, thermoelectric HPWHs may be viable in the market if manufacturers can reduce costs through better production methods.

Some high-efficiency technologies are manufactured in Europe and Asia but not yet in the United States due to high costs or the lack of appropriate manufacturing techniques. European and Japanese companies are currently the market leaders for manufacturing CO_2-based HPWHs. However, these Japanese models are not designed for typical American usage, so they cannot be imported and sold as is. Manufacturers must develop new large-scale production techniques and refine the manufacturing design, approach, and assembly process to develop cost-effective products and promote the viability of the product in the United States.

HVAC/WH/Appliances Strategies, Current and Planned Activities, and Key Targets

The HVAC/WH/Appliance Sub-Program uses the strategies outlined below to develop and advance affordable, cost-effective technologies that improve system energy consumption. R&D includes both

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[49] U.S. Department of Energy. Using Magnets to Keep Cool: Breakthrough Technology Boosts Energy Efficiency of Refrigerators. Washington, DC: U.S. Department of Energy, 2014. Accessed August 25, 2014: http://energy.gov/eere/articles/using-magnets-keep-cool-breakthrough-technology-boosts-energy-efficiency-refrigerators.

near-term advances as well as development of next-generation technologies that leapfrog existing technologies and result in drastically improved efficiency. The Sub-Program aims to introduce next-generation technologies in the simplest applications first for the highest probability of success. Subsequently, DOE can utilize these approaches in more complex technologies with confidence in the additional investment. For example, the Sub-Program would consider implementing advanced, non-vapor compression heat pump technologies into refrigeration systems before rollout to space-conditioning applications.

1. ***R&D Strategy—Near-Term Technology Improvement****: Improve performance and reduce the cost of near-term, highly energy-efficient technologies.*
2. ***R&D Strategy—Next-Generation Technology Development****: Develop the next generation of technologies that represent entirely new approaches and cost-effectively achieve significant performance improvement.*
3. ***Commercialization Support Strategy****: Accelerate the market availability of technologies through CRADA projects with manufacturers.*

Figure 23 illustrates the Sub-Program's R&D strategy to accelerate cost and efficiency improvements needed in the near term, while preparing for the transformative technological shift needed to maintain U.S. competiveness and meet BTO's energy saving goals.

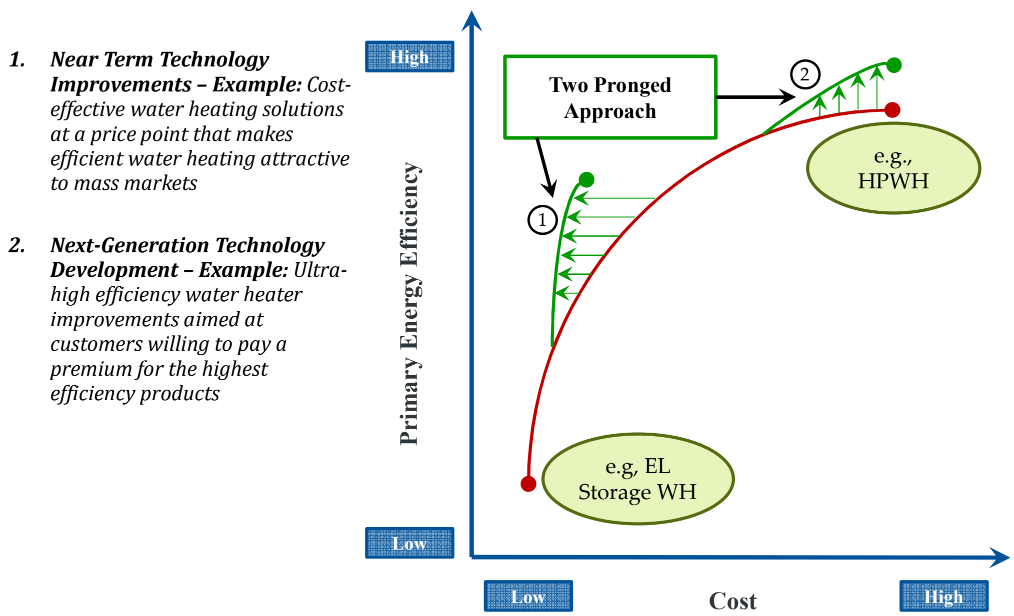

Figure 23. Approach to water heating R&D, where EL = energy level, WH = water heating, and HPWH = heat pump water heater

Each of the Sub-Program's strategies includes planned activities and associated targets between 2015 and 2020, and includes a discussion of how the Sub-Program intends to reach its goals within that timeframe. Cost and energy performance targets are identified in Table 3, Table 4, and Table 5 in the Metrics and Targets section. These targets cover both the residential and commercial building sectors.

Strategy 1: Near-Term Technology Improvement

The Sub-Program works with researchers—including national laboratories, industry, academia, and small businesses—to improve existing technologies. These R&D activities focus on system affordability so that the high-efficiency products are cost-competitive with conventional technologies. R&D also includes product improvements that facilitate easy installation and maintenance, which minimizes the need for additional trade/installer training. The Sub-Program also supports reliability testing and performance improvements that can improve equipment life. For example, incorporating fault detection and diagnostic systems, particularly in HVAC systems, can promote proper maintenance and promote high performance for the duration of equipment life. Due to the commodity nature of appliances and HVAC and WH products, cost and reliability must be in line with conventional products to increase the probability of market success.

R&D activities also include other performance advances that increase product appeal to consumers who do not buy solely based on energy saving features. The Sub-Program recognizes and supports efforts to improve non-energy benefits of energy-efficient equipment, including indoor air quality. For example, traditional residential HVAC systems do not provide adequate humidity control under low sensible cooling load conditions, and do not provide sufficient fresh air ventilation, which is necessary to ensure indoor air quality in air-tight homes. The Sub-Program addresses this challenge via support for HVAC systems that separate temperature control from humidity control.

These R&D activities primarily focus on advancement of heat pump technologies for both HVAC and WH products. Within this technology area, the Sub-Program focuses on three opportunities (see text box for more details):

- IHPs for multiple end uses that utilize energy cascading for overall energy use reductions
- Advancing regional solutions to improve performance of heat pumps in cold and hot-humid climates
- Developing WH heat pump options

Heat Pump Technology Projects

IHP: *This technology is able to provide 50% or greater annual energy savings for space conditioning, dehumidification, and WH services when integrated into a single piece of equipment; the "Swiss Army knife" of HVAC equipment.*

- *Two-speed air-source IHP (AS-IHP), 40%–45% energy savings versus minimum efficiency equipment and suitable for retrofit applications.*
- *Advanced AS-IHP, variable speed, 45%–55% energy savings versus minimum efficiency equipment.*
- *Multifunction natural gas-driven heat pump, 10–17.5 kilowatt thermal (kW_{th}) 70% peak demand savings, 40% source energy savings versus minimum efficiency electric heat pump.*
- *Ground-source IHP, variable speed, 55%–65% energy savings.*

HVAC Heat Pump Technologies, non-IHP: *BTO still needs to develop individual end-use equipment, as some consumers are not going to replace several pieces of equipment with a single unit.*

- *Next-generation window AC, 30% energy savings versus minimum efficiency unit.*
- *Cold climate HP, 10–17.5 kW_{th}, 50% to 70% energy savings at low ambient versus minimum efficiency air-source HP.*
- *Next generation RTU, 70 kW, 25% energy savings versus ASHRAE 90.1 RTU.*

Water Heating Heat Pump Technologies, non-IHP: *BTO still needs to develop individual end-use equipment, because some consumers would not replace several pieces of equipment with a single unit.*

- *Electric HPWH with low-GWP, 15% energy savings compared to ENERGY STAR-certified HPWH.*
- *Absorption HPWH, 45% energy savings compared to ENERGY STAR-certified gas storage water heater.*
- *Non-vapor compression HPWH units, low-GWP solutions.*

Additionally, the Sub-Program is trying to raise the efficiency of smaller systems such as smaller capacity heat pumps and air conditioners for residential applications. As system capacity is reduced, certain losses (e.g., clearance volume flow in compressors, high-to-low pressure section leakage in reversing valves) have a greater percentage impact on efficiency. Significant improvements to system performance are necessary to realize the benefits of efficient HVAC and water heating systems. As the building envelope becomes better, addressing dehumidification with today's HVAC equipment is not feasible. Conventional air conditioning (AC) systems have limited control of sensible cooling and latent cooling capacities. In addition, a large portion of the current building stock is located in hot and humid environments, which have the potential to create large latent loads within buildings. Separate sensible and latent cooling AC systems have the potential to save energy by separating the total cooling load for a building and optimizing the system for cooling and heating. The reheat process in conventional systems is a major deterrent to energy efficiency and limits the independent control of the sensible and latent cooling loads. In warm and humid climates, AC not only has to reduce the air temperature but also reduce the temperature down to the dew point to dehumidify the air. Conventional AC systems provide reasonable humidity control (i.e., below 60% relative humidity) in warm-humid and mixed-humid climates, but lack capabilities in more extreme conditions. Higher performing equipment with enhanced dehumidification capabilities operate at part load and vary blower speed, or operate at lower cooling set points.

The Sub-Program also focuses on improving HVAC and WH distribution systems, including near-zero-loss systems. Improved systems will also permit efficient zoning and allow for sensors to optimize indoor air quality and humidity, while minimizing energy consumption.

Strategy 2: Next-Generation Technology Development

To create next-generation technologies that leap frog today's technologies and dramatically reduce energy use, the Sub-Program focuses on technologies that are in the early stages of R&D and can be more open-ended in nature rather than work that focuses on existing technologies. The activities include applied research focused on increasing the knowledge and understanding of possible technical pathways, then developing and demonstrating prototypes.

These longer term R&D activities focus on components and technologies that can wholly replace today's available technologies and lessen their environmental impact. For example, creating a new generation of refrigerants can both improve equipment efficiency and performance and reduce the use of harmful chemicals. The Sub-Program's related activities primarily address three opportunities, some of which overlap with the first strategy related to improving existing technologies:

- Non-vapor compression technologies to replace vapor compression
- Advanced compressor technologies to enable energy use reductions in appliances
- Advanced heat exchanger technologies to improve heat transfer

For non-vapor compression technologies, the Sub-Program supports development of alternative refrigeration cycles, such as magnetocaloric, thermoacoustic, and thermoelectric cooling. All have been explored for many years, but to date have had limited commercial success. The precise HVAC requirements will vary considerably depending on the building type; however, it is evident that industry needs new approaches to providing comfort conditioning and ensuring indoor air quality while reducing the global warming impacts of refrigerants. The goal is to develop technologies that have the potential to reduce commercial HVAC energy consumption by 40–60% compared to typical direct-expansion conditioning systems. Magnetocaloric refrigeration, for example, eliminates the use of high-GWP refrigerants, and can be implemented in a residential refrigerator/freezer to reduce energy consumption to 25% lower than DOE energy conservation standards.

For advanced compressor technologies, the Sub-Program is pursuing development of a next-generation variable-capacity household refrigerator that uses a linear compressor and other novel features that offer the potential to reduce energy use up to 40% compared to current refrigerators. Work to date has included system modeling, conceptual system design/architecture development, and preliminary testing of components, such as calorimeter testing of the linear compressor. This work has led ORNL and an industrial partner to develop a revolutionary refrigerator concept. The primary energy savings from this project is estimated to be 0.95 quads over 13 years (2018–2030), assuming a 2% per-year market penetration rate to U.S. households; this is approximately equivalent to the annual energy consumption of 10 million U.S. households. In addition, this refrigerator concept could place the U.S. industry ahead of its international competitors.

For both vapor compression and non-vapor compression technologies, the Sub-Program is interested in developing solutions with enhanced grid integration capabilities. This would allow, for example, HVAC units and appliances to provide demand response as needed by the utility. The cost-effective incorporation of thermal storage may be an effective approach to realizing grid-integrated systems.

The Sub-Program is developing the next-generation advanced heat exchanger (HX) technology, which could improve heat transfer, reduce pressure drop, increase robustness, and improve cost-competitiveness in HVAC and refrigeration equipment. Heat exchangers are the means to exchange heat for heating or cooling, as well as for rejecting or absorbing heat from the ambient air. The rotating HX technology intends to improve the heat transfer rate by several orders of magnitude over conventional air heat exchangers. The product's axial geometry has the potential to provide both AC and heat pump functionality in a single device. In addition, non-rotating HX technology could contribute to developing a new generation of air-to-refrigerant heat exchangers with at least 20% less volume and material that can deliver the needed temperature change compared to current multiport flat-tube designs. This technology is currently being explored for a new air-bearing heat exchanger for a residential refrigerator evaporator. Accelerated frost accumulation testing has shown that the rotating heat exchanger has resistance to frost accumulation, which could eliminate the need for a defrost cycle and increase refrigerator energy efficiency. As an ice crystal grows on the surface of the rotating blades, centrifugal force becomes large enough to break it. The proposed technology could produce energy savings of at least 13%.

The Sub-Program implements activities to increase U.S. competitiveness in manufacturing and to learn of promising new technologies through international collaboration. Participation in the International Energy Agency Heat Pump Programme and the International Institute of Refrigeration (IIR) activities builds awareness of and insight into the latest international R&D and technology developments in Europe and Asia on improved building energy efficiency and CO_2 emission reductions. (The IIR is the only independent intergovernmental organization which promotes the advancement of basic scientific knowledge of refrigeration and associated technologies, including energy-efficient HVAC equipment and the use of non-ozone-depleting and low-GWP refrigerants).

The Sub-Program also explores advanced manufacturing techniques being used by other countries. For example, the Sub-Program is exploring next-generation clothes dryers that use heat pump technologies, which are commercially available in other countries but not in the United States.

Strategy 3: Accelerate the market availability of technologies through cooperative R&D agreement projects with manufacturers.

To accelerate commercialization and market viability of technologies, the Sub-Program supports R&D and demonstration that engage key manufacturers. After product development, the Sub-Program partners with industry through CRADAs to accelerate market introduction. CRADAs allow non-federal entities to collaborate with DOE to accelerate the transfer the technologies DOE has supported to the private sector for commercialization.

CRADA projects can accelerate market acceptance by up to 10 years by pairing researchers with private industry and bringing together key skills required to successfully commercialize a technology.[50] A common goal of a CRADA is to refine and demonstrate a system, not just the technology. CRADAs are focused on engineering development and making compromises so that the resulting product is market viable and energy-efficient.

Completion of a CRADA, when the product is commercially available, typically signals the project's transition from the Sub-Program to the Residential and Commercial Building Integration Programs to help promote the products, increase awareness, and ensure that the Sub-Program's R&D efforts have as high an impact as possible in the marketplace.

Table 3, Table 4, and Table 5 outline the metrics and targets associated with HVAC strategies by technology end use.

Table 3. HVAC metrics, statuses, and 2020 targets

Metrics, Statuses, and Targets: HVAC				
Project Area	**Metric**	**Building Type**	**Status**	**2020 Target**
Advanced vapor compression technologies	Primary seasonal COP; Installed cost premium per kBtu/hr, in 2013$	Residential and commercial	1.84; $68.5†	2.01; $22.9
Non-vapor compression HVAC systems		Residential and commercial	Not on market	2.28; $20.3
Natural gas driven heat pumps		Residential and commercial	1.2; $101.8*	1.38; $23.9
Cold climate heat pump		Residential and commercial	0.85; $36†	1.07; $25.0
Air-source- integrated heat pump	Primary energy savings; Installed cost premium per sq. ft.	Residential	Not on market	49%; $1.5
Multifunction natural gas-driven heat pump		Residential and commercial	30%; $9.4‡	44%; $1.1

† Based on Navigant HVAC historical and market analysis comparing best in market to typical of 2013.

** No BIM Natural gas driven HP exist on market; compared typical natural gas heat pump to typical AC.*

‡ Currently available only for commercial markets.

[50] Ten years is a BTO estimate.

Table 4. Water heating metrics, statuses, and 2020 targets

Metrics, Statuses, and Targets: Water Heating				
Project Area	**Metric**	**Building Type**	**Status**	**2020 Target**
Non-CO_2 vapor compression HPWH	Primary energy factor; Installed cost premium per first hour rating ($/gal)	Residential and commercial	0.79; $21.4†	0.81; $8.13
CO_2 vapor compression HPWH		Residential and commercial	Not on the market	0.94; $11.94
Non-vapor compression HPWH		Residential and commercial	Not on the market	0.52; $4.00
Gas-fired absorption/ adsorption HPWH		Residential and commercial	Not on the market	1.20; $7.14

† Based on Navigant water heater historical and market analysis comparing best in market to typical of 2013.

Table 5. Appliances metrics, statuses, and 2020 targets

Metrics, Statuses, and Targets: Appliances				
Project Area	**Metric**	**Building Type**	**Status**	**2020 Target**
Advanced compressor technologies	Primary energy savings; installed cost premium per unit	Residential	Not on market	25%; $225
		Commercial	10%; $63,000*	15%; $1,000
Advanced refrigerators		Residential	28%; $162†	47%; $420
		Commercial	37%; $8,840‡	28%; $3,000
Heat pump dryer		Residential and commercial	Not on the market	50%; $565
Non-vapor compression refrigeration technologies		Residential	Not on the market	55%; $285
		Commercial	Not on the market	32%; $2,100
Low-emission refrigeration	Life cycle direct emissions in at least 5 HVAC & refrigeration applications capturing >50% of the national HVAC & refrigeration direct emissions	Residential and commercial	Not on the market	75% Reduction

** For compressor racks based on http://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf, for a 1077 MBtu/hr system*

† Cost premium is for low end 18.5 cubic feet top mount freezer white refrigerator.

‡ Based on an average for walk-in and reach-in refrigerator and freezers as presented in http://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf, normalized for 18 kBtu/hr systems.

2.3 Windows and Building Envelope

Space heating and cooling represent approximately 30% of the primary energy consumed in residential and commercial buildings.[51] The building envelope, which includes the walls, windows, roof, and foundation, forms the primary thermal barrier between the interior and exterior environments, and plays a key role in determining levels of comfort, natural lighting, ventilation, and how much energy is required to heat and cool a building. The Windows and Building Envelope Sub-Program seeks to develop and accelerate next-generation, energy-efficient windows and building envelope technologies that reduce the amount of energy lost through the building envelope, contribute to improved occupant comfort, and have low product and installation costs to enable market adoption.

Window R&D efforts are focused on technologies and systems that dramatically reduce thermal losses and gains, actively modulate and control solar load to minimize summer cooling and offset winter heating, maximize effective use of daylight to offset electric lighting, and provide outside ventilation air displacing mechanical ventilation whenever possible. This includes R&D of low-cost advanced materials, improved manufacturing processes, and technologies with cost-effective installation techniques. To reach lower installed product cost, it is important to lower manufacturing costs with automated, high-throughput processes that can handle large and custom products.

Building envelope R&D efforts are concentrated on cost-effective technologies that include insulating materials for retrofitting walls, commercial building roofing systems, and air-sealing system technologies that simultaneously prevent the uncontrolled flow of heat, air, and moisture. To enable widescale market adoption, these next-generation technologies must maintain or improve building indoor air quality, acoustics, and enclosure durability. The building components also must protect against moisture and fire and meet structural requirements.

The Windows and Building Envelope Sub-Program works with researchers and technology developers in industry, academia, and national laboratories to advance windows and building envelope technologies. Specifically, the Sub-Program funds national laboratories to measure, simulate, and verify the performance of window and building envelope technologies. Public and private industry collaboration helps the Sub-Program prioritize and address the technical challenges and the market drivers that can affect adoption. For example, when BTO analyzed insulating and reflective window attachments in 2012, it determined that the technologies have the potential to save a significant amount of energy. With improved market penetration, their use could save the United States nearly 800 tBtu by 2030 in the residential and commercial sectors combined, due to the technologies' low product cost and a rapid turnover of the installed base. As a result, BTO obtained recommendations from the Window Coverings Manufacturers Association on the necessary steps to establish a third-party energy efficiency labeling program. BTO organized a technical analysis workshop for window attachments to identify goals and knowledge gaps for the development of performance indices, simulation, and test procedures for window attachments.

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[51] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Energy Information Administration, 2014.

Workshop participants, including interested parties from industry, the R&D community, government, and public interest organizations agreed upon several window attachment characteristics and attributes and determined that the primary product performance metrics are U-factor and solar heat gain coefficient. They also identified gaps to realizing proper testing and simulation methodologies that could be addressed through simple and cost-effective methodologies. The Sub-Program started to fund development of test procedures and simulation tools, and measurement of the optical properties of fenestration attachment fabrics and components. In November 2013, BTO released a Funding Opportunity Announcement (FOA) regarding the rating, certification, and labeling of fenestration attachments to develop a set of energy performance-based rating and certification standards and oversee the implementation of verification procedures. The FOA also set out to develop and maintain a publicly available and searchable electronic database of fenestration attachment product performance to provide consistency and transparency in the window attachment market.

The development of advanced technologies in the Windows and Building Envelope Sub-Program complements advancements made in the HVAC, Water Heating, and Appliance Sub-Program to reduce energy used for heating and cooling. Once advanced technologies are developed and ready for commercialization, the Windows and Building Envelope Sub-Program coordinates with the Commercial and Residential Buildings Integration Programs to help bring technologies to market, as well as to integrate into cross-functional systems that enhance performance and market value (e.g., active daylighting linked to smart lighting controls).

Windows and Building Envelope Market Overview

Windows and Building Envelope Market and Energy Use: Next-generation windows and building envelope technologies have substantial potential to reduce energy consumption in buildings. Transparent and opaque components of the envelope protect building occupants from undesirable external environmental conditions. Alternatively, the envelope can be constructed to take advantage of desirable external conditions by providing natural lighting or ventilation. Both strategies may reduce the use of energy-consuming machinery in buildings. While lighting, HVAC, and appliances are replaced in relatively short timeframes (between 2 and 25 years), envelope elements must be selected carefully since they last much longer. Many survive more than 100 years with proper maintenance. To make significant progress toward the Program goal, any next-generation technologies must be developed with a specific emphasis on achieving a market-acceptable installed cost to facilitate wide scale adoption.

The envelope components that can have the most impact on energy saving opportunities in both residential and commercials buildings are infiltration from heating and cooling and conduction through windows and walls. In cooling-dominated climates, solar heat gain from windows has a significant energy impact. Table 6 illustrates the energy lost through windows (both conduction and solar heat gain) and opaque building envelope components, as well as infiltration from heating and cooling in both the residential and commercial building sectors.

Table 6. Primary energy consumption attributable to fenestration and building envelope components in 2010 (quads)

Building Component	Residential (quads)		Commercial (quads)	
	Heating	Cooling	Heating	Cooling
Roofs	1.00	0.49	0.88	0.05
Walls	1.54	0.34	1.48	-0.03
Foundation	1.17	-0.22	0.79	-0.21
Infiltration	2.26	0.59	1.29	-0.15
Window (conduction)	2.06	0.03	1.60	-0.30
Window (solar heat gain)	-0.66	1.14	-0.97	1.38

Note: A negative value in the table indicates the building component reduces thermal load. This data does not account for the impact of window technologies on reducing lighting loads.

Source: Sawyer, K. *Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies*. Washington, DC: U.S. Department of Energy, 2014. Accessed Sept. 2, 2014: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf.

Integrating these components is critical to a building's performance, and it is easier to design and build an integrated systems approach in new construction than it is to upgrade existing buildings. For example, building envelope components in existing buildings are usually updated individually and often require installation solutions that can be done while the building is occupied, increasing costs and time to complete. Although more difficult, the existing buildings market contains far more buildings and thus has the largest national energy impact and is therefore the larger focus area for the Sub-Program.

Diffusion of advanced window and envelope technologies into the marketplace is shaped by both technical and non-technical factors. These include economic conditions (health of the construction market and economy in general), regional climate, labor costs, transportation methods for technologies, and ease of installation. Aesthetic appearance of windows, thermal and visual comfort, privacy, security, and acoustics are also important factors that drive market adoption.

Windows: Windows contribute to building energy efficiency and can provide natural lighting, especially in commercial buildings where there is significant opportunity to reduce the use of artificial lighting. A window's energy efficiency is dependent upon its components, such as the frames, operating types (e.g., hinged vs. sliding), number of panes and the panes' fill space, glazing, and coatings. Other advanced window technologies, such as window attachments and dynamic windows, control solar heat gain.

High-performance insulating windows are now available in the market but are very expensive. The highest-performing insulating windows available for both the residential and commercial building sectors have an R-value as high as 10. In the residential space, window technologies that are on the market at an R-value of 5 are part of the ENERGY STAR® Most Efficient Program. On the commercial side, DOE helped fund the development of an R-5 Alcoa window using ARRA funds. The high installed cost of state-of-the-art dynamic windows limits market penetration. While there are commercially available dynamic window technologies, as well as automated shading systems, dynamic window film technologies are still under development. Additionally, window light redirection technology has the potential to reduce energy consumed for lighting in some types of commercial buildings, but the market is currently limited due to technical performance and glare and controls integration issues. Desirable next-generation light redirection technologies distribute light into the interior of the building cost-effectively (including the cost of lighting sensors and controls) without unacceptable glare levels.

Success Story: ORNL and EIMA Partnership

Exterior insulation and finish systems (EIFS) were imported to the United States from Germany in the 1970s as a means of improving the energy efficiency of wall systems in both new and retrofit constructions. In the 1990s, this technology was the target of numerous lawsuits due to moisture-related building failures that were further exacerbated by substandard windows and poor workmanship in installation.

The penetration of moisture through a building envelope can affect the building's durability, the indoor air quality, and the energy efficiency of the envelope itself. The lawsuits and negative press caused EIFS products to lose almost all market share in the residential sector. In 2003, to overcome these obstacles, DOE partnered with the EIFS Industry Members Association (EIMA) in a Cooperative Research and Development Agreement to develop a new family of drainage-type EIFS. ORNL assisted in developing these new technologies that alleviated the problems of the older systems. EIMA contributed more than 50% of the cost to develop a moisture-resistant version of its wall systems, while the public gained an energy-efficient technology that is now widely used in both the commercial and residential sectors. More recently, ORNL has used simulation tools to analyze these technologies across additional climate zones.

Source: Karagiozis, A.; Childs, P. The Hygrothermal Performance of the Net Exterior Insulation of Walls. BTC/ORNL 05-UF-05-550. Oak Ridge, TN: Oak Ridge National Laboratory, 2006. Accessed September 1, 2014: http://web.ornl.gov/sci/roofs+walls/research/EIFS/Year1_Hygrothermal_Exterior_Insulation_ANK.pdf

The market for high-performing window and envelope technologies has matured in recent decades. According to the EIA's 2009 Residential Energy Consumption Survey (RECS), almost 60% of housing units had multi-pane windows, up from 36% in 1993. Approximately 80% of houses built after 2000 have double- or triple-pane energy-efficient windows. The EPA estimates that the typical home could save up to $500 a year when replacing single-pane windows;[52] the Window and Door

[52] "Benefits of ENERGY STAR Qualified Windows, Doors, and Skylights." U.S. Environmental Protection Agency. Accessed August 28, 2014: https://www.energystar.gov/index.cfm?c=windows_doors.pr_benefits.

Manufacturers Association estimates the residential windows market will grow 8% in 2015.[53] In addition, buildings built before the 1980s—and therefore before modern energy codes—had little or no insulation; now insulation and air-sealing are more commonplace. The U.S. demand for insulation has been projected to increase more than 7% annually through 2017.[54]

Building Envelope: Insulating materials provide resistance to heat flow, measured as R-value, to reduce the amount of energy necessary to maintain a building's internal temperature. Radiant barriers or reflective insulation systems instead work by reducing radiant heat gain. Numerous types of insulation materials exist, from fiber materials to rigid foam boards and from spray foam to reflective foils.[55]

Air-sealing system technologies help to control airflow across a building's thermal barrier and complements insulation. Leaks or infiltration can typically be sealed with caulk, spray foam, weather stripping, or air-sealing membranes. More advanced technologies will consider moisture control and proper ventilation.

Roofs are another source of building energy loss, but roofing design and materials can help to reduce the amount of cooling required in certain climates by reflecting solar heat rather than absorbing it. For example, ENERGY STAR qualifying roofs

Success of Low-E Windows:

Collaboration among DOE, private industry, and the Lawrence Berkeley National Lab in the early 1980s led to the development of the first low-emissivity (low-E) window technology available to the public in the form of window coatings. Since the advent of commercially available low-E technology, DOE and its partners have continued to improve low-E window technology with innovative designs.

These designs include the replacement of the air between windowpanes with an insulating gas and the development of a triple-pane window with two low-E coatings and an argon and krypton gas mixture that fills the space between each pane. These highly insulating window designs developed by DOE can perform as well as a highly insulating wall and, as a result, are included in more than 80% of residential windows and nearly 50% of commercial windows sold every year in the United States.

The high adoption rate of DOE's low-E window technology has resulted in billions of dollars of saved energy costs each year for consumers. Furthermore, the application of low-E technology can reduce the energy lost through conventional windows as much as 35%.

Sources: "Top 4 Energy Department Inventions Saving You Energy & Money at Home." U.S. Department of Energy, 2014. Accessed September1, 2014: http://energy.gov/articles/top-4-energy-department-inventions-saving-you-energy-money-home
"Seeing Windows Through." Lawrence Berkeley National Laboratory, 2014. Accessed September 1, 2014: http://eetd.lbl.gov/l2m2/windows.html
"Low-Emissivity Windows." J. Rissman & H. Kennan, American Energy Innovation Council, 2013. Accessed March 20, 2015: http://americanenergyinnovation.org/wp-content/uploads/2013/03/Case-Low-e-Windows.pdf

[53] "Growth in U.S. Residential Window Market to Continue into 2015." Window & Door Manufacturers Association, 2014. Accessed: September 1, 2014: http://campaign.r20.constantcontact.com/render?ca=bb248c72-d389-4b7b-a510-4b0f9e48dfc6&c=8427ff20-bb48-11e3-bfb6-d4ae52806905&ch=844f8450-bb48-11e3-bfb6-d4ae52806905.

[54] *Insulation- Industry Market Research, Market Share, Market Size, Sales, Demand Forecast, Market Leaders, Company Profiles, Industry Trends*. Freedonia, 2013. Accessed: September 1, 2014: http://www.freedoniagroup.com/Insulation.html.

[55] "Energy Saver Insulation." U.S. Department of Energy, 2012. Accessed: September 1, 2014: http://energy.gov/energysaver/articles/insulation.

are estimated to reduce the demand for peak cooling by up to 15%.[56] Single-family homes are less affected by energy losses to roofs than commercial buildings because attics add thermal resistance between the roof and the conditioned space.

The manufacturing of windows and building envelope technologies is almost entirely domestic. Therefore, developing new technologies in this space can spur job growth in the United States. The market for installation of advanced building envelope products is growing rapidly year-over-year, up an estimated 28% in the last year, with over $9 billion in U.S revenue from energy-efficient homes and approximately $266 million from zero net energy buildings.[57] Further, there is a growing market for building envelope materials, which can deliver better material efficiency. This increased efficiency effectively reduces the overall raw material inputs and/or overall finished volume, which can create healthier indoor environments and reduce up- and downstream externalities in the environment. Product manufacturers are increasingly investing in these healthier materials.

Market Barriers: Although advanced high-performance energy-efficient window and building envelope technologies have substantial potential to reduce energy loss in buildings, high installation costs and a lack of consumer awareness or understanding of the benefits of these technologies hinder their market penetration. The high-performance windows on the market today require a significant upfront expenditure and have a long payback period, but they are also visually appealing and contribute to building aesthetics.

The factors on which consumers base their purchasing decisions can affect investment in high-efficiency products. Homeowners are likely to purchase windows according to aesthetics, comfort, and first cost. On the other hand, architects purchase primarily with aesthetics in mind and commercial customers with small- to medium-sized buildings are almost exclusively focused on price. Even if aesthetic challenges are addressed, replacement windows are often a once-in-a-lifetime purchase. Due to the high cost, homeowners often purchase new windows once, unless the old ones become damaged. This is one reason that diffusion of new window technologies into the market can take longer than other energy-efficient technologies. When making purchasing

[56] "Roof Products for Consumers." U.S. Environmental Protection Agency. Accessed September 4, 2014: http://www.energystar.gov/products/certified-products/detail/roof-products.

[57] Navigant Research. *Advanced Energy Now 2015 Market Report: Global and U.S. Markets by Revenue 2011-2014 and Key Trends in Advanced Energy Growth.* Washington, DC: Advanced Energy Economy, 2015; p. 9. Accessed April 21, 2015: http://info.aee.net/hs-fs/hub/211732/file-2583825259-pdf/PDF/aen-2015-market-report.pdf?t=1429543507687.

decisions, consumers are also concerned about being able to see out of windows and connecting with the outdoors. Maintaining visible light transmittance in insulating windows, as well as the aesthetics of glazing and window films, is a challenge to researchers. Additionally, commercial windows must meet more demanding structural tests (i.e., design pressures, deflection limits, torsion, other hurricane ratings, operability), as well as market demands for design flexibility, durability, and integration into wall facades to ensure marketability.

Traditional insulating materials are inexpensive, but installation can be costly and inconvenient. Insulation and air-sealing are installed in wall cavities, attics, crawlspaces, and other areas that are not readily visible or obvious and can require complex or lengthy installation techniques, which affect the technology's performance if not done well. Advanced technologies must also address durability and moisture challenges, and they are not always obvious to the building owner. These barriers are compounded by the widespread lack of reliable information on insulating materials in the market. Buyers are unfamiliar with the many technology options and the various price points. For example, materials can vary greatly, from inexpensive, bulky fiberglass to higher performing but more expensive foam board. Buyers often do not understand the life cycle energy savings that can be gained from adding insulation and air-sealing, which can result in a short payback period to recover the cost of the installation. Further, buyers, especially homeowners, largely make purchases based on aesthetics, which makes the market diffusion of external insulation options that are currently on the market difficult.

Success with Envelope Simulation Software Tools

DOE and LBNL developed the WINDOW suite of engineering design and analysis software. WINDOW, THERM, Optics, RESFEN, COMFEN, and Radiance™ were developed to provide manufacturers with the ability to rapidly design and optimize the energy performance of new window products, and to allow building designers to perform energy efficiency analyses on windows and building envelopes to select the best products for any climate and building type. The tools are also used by the National Fenestration Rating Council (NFRC) to generate national energy rating labels, which are referenced by ENERGY STAR Windows and state and federal codes and standards. WINDOW references a database of more than 5,000 glazing products and allows users to analyze all aspects of the thermal and optical performance of a variety of glazing and shading systems and complete fenestration products. THERM allows users to analyze two-dimensional heat transfer through building products and local temperature patterns, where thermal bridges may cause problems with condensation, moisture damage, and structural integrity. Radiance is a software suite that allows designers and engineers to predict light levels, visual quality and appearance of innovative façade and building designs, and researchers to optimize new lighting and daylighting technologies. COMFEN is an early-stage façade design energy modeling tool that uses Radiance and the EnergyPlus whole-building energy simulation engines to explore the impact of glazing and façade parameters on energy, demand, and thermal and visual comfort.

The WINDOW suite of tools has been validated in lab and field tests. In 2013, these tools were downloaded more than 40,000 times; they are used more than 2,000 times each day by building industry professionals.

Windows and Building Envelope Program History

DOE has supported the development and commercialization of advanced window and building envelope materials, technologies, and practices since the mid-1970s. In the aftermath of the oil shock in the 1970s, DOE recognized the opportunity to partner with national laboratories and industry to support the development of emerging technologies, to help develop standardized test procedures and performance ratings, and to provide data and information to manufacturers and consumers in the form of guidelines and best practices.

In the late 1970s, DOE initially funded an R&D partnership between Southwall, a Massachusetts Institute of Technology spinout that had developed a low-E window film, and LBNL to continue R&D into low-E windows and spur the private sector investment needed to bring the technology to the mass market. As the new products gained market share, there was confusion about the performance attributes since the coatings were invisible to the human eye. In the 1980s, with support from DOE, LBNL worked with the window industry to create a window rating organization (NFRC) so that the energy performance of all products could be easily determined. When claims were made that low-E windows had poor performance, LBNL built a unique test facility for outdoor testing and conducted definitive field tests to publish results backing the 30%–40% energy improvements expected.

Similarly, funded by DOE, ORNL began working with the Consumer Products Safety Commission and industry to develop testing standards associated with cellulosic insulation materials. By 1990, ORNL had also become a major player in developing and evaluating alternative substances that could replace ozone-depleting ones while retaining insulating performance levels.

In the late 1990s and early 2000s, DOE worked with the national laboratories to develop sophisticated building simulation and analysis tools, which have given engineers, architects and homeowners the power to make informed, data-driven decisions. In 1999, DOE, ORNL, and the Fraunhofer Institute of Building Physics developed the first version of WUFI, a hygrothermal modeling system for envelope assemblies that considers heat, air, and moisture flow; storage of heat and moisture; and moisture thresholds for onset of failure modes. By 2009, WUFI's influence on the development of codes, standards, and industry designs for new envelope assemblies and retrofits had grown. For example, the first moisture control envelope design standard (ASHRAE 160) was issued and adopted by a federal agency (GSA P100).

LBNL developed the WINDOW suite of engineering design and analysis software, which empower users to make energy efficiency decisions backed by analysis that was previously unavailable outside of the scientific community. Innovative product design and optimization that previously took weeks to months can now often be completed in hours to days. Window selection to meet ever tighter building performance goals can now be made more rapidly and reliably throughout the design process. The same toolset is also used by NFRC for rating and labeling window performance and results from the simulations underpin the DOE/EPA ENERGY STAR window program.

The laboratories also began to serve as test bed facilities for DOE. In the late 2000s, ORNL partnered with Schaad Companies to add new research houses including four ZEBRAlliance research houses and with the Tennessee Valley Authority to develop three Campbell Creek research houses. In support of windows R&D, LBNL has developed three generations of field test facilities. The Mobile Window Thermal Test Facility (MoWiTT) has high thermal measurement accuracy and has been in use for more than 30 years supporting manufacturers' technology development and validation of new simulation tools. The Advanced Façade Testbed provides three side-by-side, carefully metered office rooms, with replaceable glazing, shading, daylighting and lighting systems for comparative studies, including occupant comfort. The Facility for Low Energy Experiments in Buildings (FLEXLAB), completed in 2014, provides larger spaces (30 feet by 40 feet) for comparative studies and allows the study of the dynamic interaction of windows and skylights with all building systems so as to optimize overall performance (energy, demand, comfort) of smart windows as elements of integrated building systems.

Working with national laboratories and industry stakeholders, the Windows and Building Envelope Sub-Program has advanced window and building envelope materials and technologies and achieved a number of important milestones and recognition in recent years:

- ORNL's hygrothermal research collaborations with industry (cool roofs, air barriers, insulation systems) in 2011 resulted in widely adopted and affordable moisture-durable products in the market.

- WUFI was recognized as a 2013 Top-10 Green Building Product by BuildingGreen, Inc. at the U.S. Green Building Council's annual GreenBuild conference.

- LBNL completed the underlying technical analysis for the DOE/EPA ENERGY STAR Windows program, which sets enhanced performance targets for windows. Over 70% of all windows sold now meet those targets.

- LBNL partnered with the *New York Times* to successfully implement the largest installation of automated shading and daylight controlled lighting in the United States in the newspaper's new 52-story headquarters building in New York City. A study in 2013 measured 50% lighting savings and 25% energy savings compared to a code-compliant building, as well as a high level of occupant satisfaction.[58]

- The partnership between Southwall and LBNL yielded the successful private sector investment and commercialization of low-E windows. Low-E windows now represent more than 80% of the residential window market and more than 50% of the commercial window market.

- In 2009, DOE awarded more than $3.4 million to Soladigm (now View Dynamic Glass) to mature a lab-scale prototype of its electrochromic window technology to full-scale manufacturing and commercialization. The coatings for these smart windows switch optical

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[58] *A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in The New York Times Building.* Accessed September 2015:https://buildings.lbl.gov/sites/all/files/lbnl-6023e.pdf

properties to manage cooling load and daylight and can improve energy use in perimeter spaces by up to 40%. View Dynamic Glass opened its manufacturing facility in 2012 in Olive Branch, Mississippi. That facility has a production capacity of 5 million square feet of electrochromic glazings and employs roughly 200 people. View Dynamic Glass has since raised $300 million in private sector investment.

Opportunities for Future Savings: Lower installed cost and improved efficiency of advanced window and building envelope technologies represent a significant opportunity to reduce the energy lost through building enclosures. Future savings are expected in the near term from technologies that have been developed but are not yet widely available on the market, such as daylighting technologies integrated with building light controls or R-5 highly insulating windows. Overall, window technologies are expected to penetrate the market slowly due to the significant upfront cost. Further savings are to be gained with next-generation technologies that are under development, such as dynamic and insulating window films and air-sealing systems that regulate heat, air, and moisture flow to achieve increased energy performance. To realize these savings, BTO R&D is focused on improving performance and lowering the cost to install highly efficient window and building envelope technologies.

Improved air tightness of building envelopes is also a growing requirement in voluntary and mandatory codes, which will affect the pace of market growth for energy-efficient building envelope and window technologies. Regional differences in code application and enforcement will also affect market acceptance.

Windows and Building Envelope Goals

BTO has set specific goals and targets for windows and building envelope technologies with input from experts in academia, national labs, and industry. These targets are listed in Table 7 and Table 8; achieving these targets by 2020 would mean that the potential energy use intensity for heating and cooling buildings would be about 60% lower than the 2010 energy-efficient baseline because of improvements made in windows and envelope technologies.[59]

The Windows and Building Envelope Sub-Program tracks progress toward both installed cost and respective energy efficiency performance metrics for those technologies identified as high priority. The Sub-Program then uses the status and targets to track progress against goals. For example, Figure 24 shows targets for building envelope insulation. Similar charts and additional detail related to each of the technologies can be found in the Windows and Building Envelope Research and Development Roadmap for Emerging Technologies, which was published in February 2014.[60] The metrics and targets are summarized in the Strategies, Current and Planned Activities, and Key Targets in this section.

[59] For more details on the 2010 Energy Efficient Technologies Baseline, see Section 2, Emerging Technologies Introduction.

[60] Sawyer, K. *Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies*. Washington, DC: U.S. Department of Energy, 2014. Accessed September 2, 2014: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf.

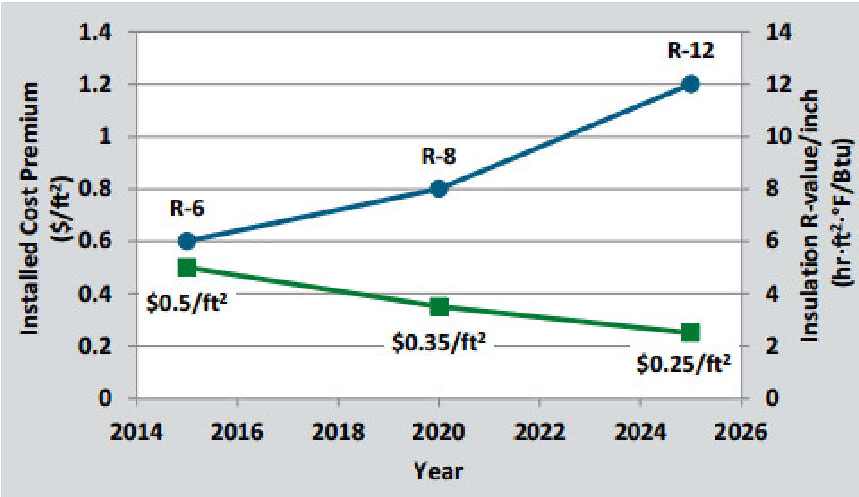

Figure 24. Envelope insulation material cost and performance targets

Windows and Building Envelope Technology Challenges

To achieve technology performance and cost targets, the Windows and Building Envelope Sub-Program works to overcome the following technical challenges:

Lack of High-Performing Materials for Windows: While technically feasible, advanced concepts for high-performance windows are limited by the availability of high-performance, next-generation materials. Increased costs to produce and obtain new materials leads to greater upfront costs that must be passed down the supply chain to building owners.

Glass and glazing materials require next-generation low-E coatings, multi-pane glazing systems, and highly insulated translucent panels. Durability improvements are necessary for vacuum glazing edge seals to maintain vacuum over the expected lifetime of a window.

For typical window frames, the R-value drops significantly at the insulated glass edge. Improved frame materials can reduce the need for ultra-high-performance glass and lead to super-low-conductivity frames. Advanced window frames should be able to pass long-term air infiltration and structural requirements to gain a high-performance window label.

High Manufacturing Costs for Windows: To facilitate mass-market adoption of next-generation window technologies, manufacturing costs must decrease. Cost reductions are needed for the overall assembly of triple-glazed units with a thin glass middle layer, krypton gas fill, and multiple low-E coatings. Cost savings could be captured through manufacturing advances that enable automated, high-throughput production, while still being able to produce the large and/or custom sizes required in diverse building applications.

Costly Installation of Windows: Window installation is currently labor-intensive, expensive, and variable. Cost reductions are needed for the assembly of windows, especially for triple-glazed units or those units that have gas between the panes or multiple low-E coatings, and for easier installation of the entire window system, such as those with snap-in capability. Further, to enable mass-scale and automated window production and installation, windows must be simplified and able to handle custom components. High-efficiency windows must be developed at reduced or at least comparable thickness and weight to the currently installed window base to work in existing structures and meet building energy codes. A bulky and heavy window is also difficult to transport.

Lack of Cost-Effective Materials for the Building Envelope: In the commercial building sector, a lack of high-performing and cost-effective envelope materials prevents smooth transitions between walls and roofs. The composition of roof systems is often very different from wall materials. As such, the joints can be abrupt, leading to thermal bridges and undesirable aesthetic characteristics, especially in large buildings. Sealing between these envelope components can be difficult during new construction and is close to impossible during retrofits. Therefore, development of new envelope materials that can function for both walls and roofs is needed to produce architecturally acceptable and affordable air seals between the roof and the walls.

Costly, Labor-Intensive Installation for Building Envelope: In both the residential and commercial sectors, quick and easy building envelope retrofit solutions are needed to better address the existing buildings market. In the commercial sector, building owners cannot afford to close their business and lose revenue for days or weeks at a time, effectively increasing payback time for energy efficiency measures. Along the same line, residential consumers are more likely to perform energy efficiency upgrades that do not disrupt their lives by requiring extensive construction.

Additionally, installation costs of building envelope technologies are dominated by labor costs associated with installation methods because they are generally low-tech and performed on a case-by-case basis. Novel manufacturing and easier installation methods that could reduce onsite installation costs have the potential to change the cost structure and reduce the overall costs for building envelope upgrades, especially for existing buildings.

High-quality standardized construction subcomponents (e.g., plug-and-play panels) may help reduce installation time and costs, as would the increased use of nonintrusive and non-destructive retrofit installation approaches. If materials and products with a high tolerance for error in installation can be developed, installation requirements can be less stringent and less costly.

Lack of Performance Metrics or Measurement Techniques for Building Envelope: Measurement and verification information and techniques related to the performance of envelope technologies are needed to estimate the potential energy savings and other metrics more accurately and to better communicate the benefits to consumers. The lack of techniques and metrics related to durability, comfort, and infiltration/exfiltration in particular, complicates implementing building code requirements. While blower door tests are used to assess infiltration in residential buildings, no analogous technology exists for large commercial buildings. As a result, commercial building codes do not require infiltration measurements. In particular, low- or no-cost uncontrolled heat and mass-flow diagnostics can lessen the need to prove performance through repeated measurements.

A lack of standardized test methods for evaluating envelope materials' performance over service life for R-values, energy efficiency, and other factors also affects how well performance of the envelope materials can be predicted or confirmed during a typical service life.

Lack of Ability to Simulate Windows or Building Envelope: More advanced and updated simulation tools are necessary to better design and construct buildings with next-generation energy-efficient envelope materials. As new technologies are developed, models and simulation tools require updates to account for increased performance and durability.

Windows and Building Envelope Strategies, Current and Planned Activities, and Key Targets

The Windows and Building Envelope Sub-Program focuses on advancing technologies that have the greatest potential for energy savings and are cost-effective to install. To push technologies to a wider market, the Windows and Building Envelope Sub-Program is careful to consider non-energy drivers and other key variables that will affect the successful market adoption of a new technology, such as installation improvements, overall aesthetics, role of building professionals, acoustics, and building occupant thermal comfort. The Sub-Program's strategies are focused on accelerating technology development, reducing the cost of materials and installation, and scaling up and reducing manufacturing costs.

Window Strategies

- *Develop low-cost, next-generation window technologies, including highly insulating windows, dynamic windows, and window film and visible light redirection technologies, with focus on low-cost materials and manufacturing processes to reduce the total installed cost.*
- *Improve testing and modeling capabilities, including window design tools.*

Building Envelope Strategies

- *Develop low-cost materials and manufacturing processes for thermal insulation that can be applied to walls in existing residential and commercial buildings and roofing technologies for commercial buildings.*
- *Develop new air sealing systems that are capable of preventing uncontrolled heat, moisture, and airflow at reduced installation costs.*

The following sections describe each strategy along with planned activities and associated metrics and targets. Installed cost and energy performance targets are identified in Table 7 and Table 8. Targets include both the residential and commercial building sectors. Included with the activities are key targets; these are updated as needed to reflect progress or course changes.

Strategy 1: Windows – Develop low-cost, next-generation window technologies, including highly insulating windows, dynamic windows, and window film and visible light redirection technologies, with focus on low-cost materials and manufacturing processes to reduce the total installed cost.

R&D window efforts are focused on reducing the total installed cost of the technologies to make them more cost-effective and accessible to the wider market. New, cost-effective, and efficient manufacturing methods that are capable of handling custom-size and large-size windows are likely necessary to reduce the installed cost of these high-performance technologies. The Sub-Program is careful to develop technologies that address consumer aesthetic preferences and improved durability and performance over the lifetime of the window for next-generation technologies. These windows must be developed with comparable thickness and weight to the currently installed window base so that they are amenable for commercial and residential building improvements. A number of materials improvements are likely necessary to develop low-cost, highly insulating windows, including, but not limited to, next-generation low-E coatings, low-cost krypton glazing systems for multiple panes, and highly insulated panels.

State-of-the-art dynamic fenestration systems are currently cost-prohibitive for mass adoption in both the commercial or residential sectors. The Sub-Program currently concentrates efforts on reducing materials cost, improving manufacturing processes, and making installation easier. Focus areas in materials improvement include color control in visible- and low-contrast ratio in the infrared, spectral and thermal truncation, glare mitigation, automation of fenestration technologies, and rating and certification of window attachments.

To improve and scale up manufacturing, the Sub-Program is working to improve coating processes. Specific R&D focus areas include cost reduction of glazing and coating processes, improvement of yields, durability, improving the quality of coatings, and developing alternative deposition methods.

Window light redirection technology reduces the amount of energy consumed for interior lighting, but the reach of the technological benefits is currently limited due to high cost of installations and aesthetic issues. The Sub-Program's focus is on reducing the high cost of daylighting and improving deep light redirection technologies at a low cost and without glare. Demonstrations related to appearance, the energy savings impact based on season and time of day, and appropriate integration with building controls and operation in coordination with R&D will help drive the technologies to the market.

Cost and performance metrics and targets for all of these technology areas are shown in Table 7 and are broken out by building sector where possible. Commercial windows must also meet much more demanding structural tests (design pressures, deflection limits, torsion, other hurricane ratings, operability), as well as very different market demands to ensure market acceptability. Sufficient $V_{T,}$ or visible transmittance, must be maintained to provide daylighting for both residential ($V_T \sim 0.6$) and commercial buildings ($V_T \sim 0.4$).

The metrics and targets for windows are outlined in Table 7.

Strategy 2: Windows – Improve testing and modeling capabilities, including window design tools.

As the R&D of windows evolves, new prototypes developed by industries need to go through a thermal and optical optimization process to meet industry standards or market acceptance. Such performance optimization involves different design configurations and various combinations of usage factors such as climate zone and market sector. Energy modeling capabilities are necessary to properly optimize, rate, and label the performance of new prototypes, as well as commercially available window products. The Sub-Program supports the R&D and improvement of software tools to adequately evaluate window characteristics. Such software tools have to be open-source or available to the public and preferably compatible with EnergyPlus™. To validate the performance of new window technologies, in addition to energy modeling tools, the Sub-Program supports testing facilities to measure U-factor, solar heat gain coefficient (SHGC), V_T, and air leakage; condensation resistance; net energy impacts of window and shading products; and durability of the insulating glass unit.

Table 7. Windows and window film metrics, statuses, and targets for 2020 and 2025

Metrics, Statuses, and Targets: Windows & Window Films							
Project Area	**Metric**	**Status**		**2020 Target**		**2025 Target**	
		Res	**Com**	**Res**	**Com**	**Res**	**Com**
Highly Insulating Windows	R-value with weight & thickness amenable to retrofits; V_T > 0.6 (R) and V_T > 0.4 (C);	R-5.9	R-5.9	R-10	R-7	R-10	R-7
	Installed Cost Premium ($/sq.ft.)	$63	$75	$10	$8	$6	$3
Dynamic Windows	(ΔSHGC) with V_T bleached state > 0.6 (R) & 0.4 (C);	0.38	0.38	0.4		0.4	
	Installed cost premium incl. cost of sensors & controls ($/sq. ft.)	$28	$43	$15		$8	
Dynamic Window Films	(ΔSHGC) with V_T bleached state > 0.6 (R) & 0.4 (C);	Not on market	Not on market	0.4		0.4	
	Installed ost premium incl. cost of sensors & controls ($/sq. ft.)	Not on market	Not on market	$8		$2	
Daylighting Technologies	Lighting energy use (% reduction) 50 ft. floor plate;	16%		35%		50%	
	Installed cost prem. incl. sensors & controls ($/sq.ft.)	$9		$13		$5	

Strategy 3: Building Envelope – Develop low-cost materials and manufacturing processes for thermal insulation that can be applied to walls in existing residential and commercial buildings and roofing technologies for commercial buildings.

Lowering the cost of high-performance thermal insulation that can be applied to the walls of existing buildings is one of the highest priorities for the Sub-Program. The insulation may also be applied to other building components to reduce the impact of thermal bridging, which occurs when structural elements that connect the building exterior to the interior are not properly insulated to stop the transfer of interior heat or cool air outwards or vice versa. This technology might include the development of novel materials that provide reliable, long-term performance and exceptional moisture and mold control. The Sub-Program supports the development of new insulation materials and manufacturing processes to achieve improved energy performance, reduce installed cost, and reduce the payback period for improving the thermal performance of existing buildings. R&D is focused on taking advantage of novel, high R-value, energy-efficient thermal insulation materials that are also durable.

The Windows and Building Envelope Sub-Program also pursues novel installation methods that, by reducing onsite installation cost, could affect the overall installation cost for building envelope upgrades, specifically for existing buildings. Standardized construction subcomponents (e.g., plug-and-play panels) may help reduce installation time and costs, as would additional nonintrusive and non-destructive retrofit installation approaches. Finally, R&D focuses on material and product development that have high tolerance for error in installation, resulting in less of a need for time-intensive and stringent techniques.

The cost of manufacturing insulation is largely contingent on the emergence of an integrated supply chain of materials. The Sub-Program is pursuing more integrated and innovative assemblies that fit seamlessly into existing fabrication methods. Increased modular manufacturing and standardization of sizes will provide greater material performance control and increase yields for mass-scale production. The seamless interfacing between elements of the manufacturing system will enable the production of low-cost, standardized products, simplifying installation and reducing soft costs to increase market adoption.

Another R&D priority is to develop improved roofing systems for commercial buildings that reduce the energy use, equivalent to doubling the R-value of ASHRAE 90.1 standards at an incremental cost increase of less than $1 per square foot.

The metrics and targets for building envelope are outlined in Table 8.

Strategy 4: Building Envelope – Develop new air-sealing systems that are capable of preventing uncontrolled heat, moisture, and airflow at reduced installation costs.

R&D activities related to air-sealing focus on developing cost-effective, integrated systems that simultaneously control the flow of heat, air, and moisture. Currently, there is no technology on the market capable of this. This is one of the highest priority areas for the Sub-Program. In addition, techniques are needed to more easily install and verify completeness of air-sealing processes during application to ensure consistent implementation. This includes simple, non-destructive techniques to quickly and properly detect flaws and remediate them.

Quality control and verification of performance is integral to proper and cost-effective air-sealing installation, especially due to the number and sequence of building trades involved. Because existing air-sealing technologies cannot be installed to seal the systems immediately after or during building construction, R&D is focused on low-cost verification and validation techniques for building professionals that can be performed prior to or right after the completion of construction to cost-effectively remediate any flaws stemming from the construction process.

The metrics and targets for air-sealing and roofing technology R&D are also outlined in Table 8. Note that the building envelope thermal insulation material must be applicable to walls of existing buildings, but can also be applicable to other parts of the building enclosure to reduce the impact of thermal bridging among building components. Additionally, the air-sealing activities are focused on developing a new system that is not currently available on the market, which is capable of concurrently regulating heat, air, and moisture flow.

Table 8. Building envelope metrics, statuses, and targets for 2020 and 2025

Metrics, Statuses, and Targets: Building Envelope				
Project Area	**Metric**	**Status**	**2020 Target**	**2025 Target**
Building Envelope Material for Retrofit Applications	R/in	R-6/in	R-8/in	R-12/in
	Installed cost premium ($/sq.ft.)	$1.1	$0.35	$0.25
Air-Sealing System: Residential	ACH50	7	3	1
	Installed cost premium ($/sq. ft. finished floor area) Incl. mechanical ventilation	$1.4	$0.5	$0.5
Air-Sealing System: Commercial	CFM75 per 5-sided envelope;	0.25	0.25	0.25
	Installed cost premium ($/sq. ft. 5-sided envelope) incl. mechanical ventilation	$1.40	$0.60	$0.50
Highly Insulating Roof: Commercial	R-value (climate zones 2; 6);	R-17	R-35; R-45	R-50; R-60
	Installed cost premium over today's roofs ($/sq. ft.)	$4.4	$3	$1

2.4 *Sensors and Controls*

DOE's ET Program maintains a cross-cutting focus on sensors and controls. This Sub-Program concentrates on developing sensors and controls solutions to achieve building energy savings, to better utilize building end uses to increase and enhance the penetration of energy efficiency and renewable generation at scale, and to unlock new building market and financial opportunities for owners, operators, and end uses. Some—but not all—of these opportunities arise from the continuous engagement and management of building systems, devices, or equipment (including appliances, lighting, and HVAC systems) and through the addition of communications and information technologies (including commingling energy and information). Researchers principally focus on R&D of sensor solutions and foundational controls opportunities that are near market-ready. All projects are driven by use cases and have clear end-use applications. This way, implementation and service companies can adopt and drive the solutions into the market or into utility-supported programs.

The National Energy Technology Laboratory (NETL) found that only 10% of customers participate in demand dispatch, or demand response (DR), which is one application of building controls. Yet, the potential nationwide value of full participation could be several billion dollars per year in reduced energy costs.[61] Sensors and controls technologies are at the core of any demand dispatch solution, and provide an opportunity to increase building energy efficiency. Technology solutions and implementation models that have clear consumer and grid benefits are the key to realizing this opportunity nationwide and are a focus for the Sub-Program. Future technology developments will also benefit the work of the Office of Energy Efficiency and Renewable Energy (EERE) and have secondary benefits for the Office of Electricity.

BTO envisions a future in which buildings will be self-configuring, self-commissioning, and self-learning, so that the integrated result is optimized operations, maximized energy savings, and participation in grid services. According to this vision, energy is capable of being transacted within the building (through the offering of end-user services), between buildings (through the offering of energy market services), and with the electric grid (by offering grid services).[62]

To accomplish this vision, researchers sponsored by the Sensors and Controls Sub-Program focus on three key areas:

- Long-lasting wired and wireless, self-powered multi-component sensor packages (sensor platforms)

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[61] NETL defines demand dispatch as "a possible end state that can optimize grid operations beyond what can be achieved with Supply Dispatch alone. Supply Dispatch relies on "generation following the load" while Demand Dispatch allows "load to follow the generation" enabling full optimization of both supply and demand."
National Energy Technology Laboratory. *Demand Dispatch –Intelligent Demand for a More Efficient Grid*. DOE/NETL- DE-FE0004001.Washington, DC: U.S. Department of Energy, 2011; p.1. Accessed April 20, 2013: http://www.smartgrid.gov/document/demand_dispatch_intelligent_demand_more_efficient_grid.

[62] Clear use cases and value propositions of the various services that buildings can provide or access from sensors and controls are outlined in: Somasundaram, S. et al. *Reference Guide for a Transaction-Based Building Controls Framework: Unlocking energy efficiency and grid service values for building energy consumers*. PNNL-23302.Richland, WA: Pacific Northwest National Laboratory, 2014.

- Control algorithms and the resulting application of the controls, including solutions for retro-commissioning (foundational control theories)
- Open-architecture control platforms for buildings that are transactive and energy-ready (transaction-based controls and transactive energy)

Buildings utilizing sensors and controls technologies can provide a greater degree of comfort for occupants, savings for the building owners, and optimize energy use behind the meter, which can help to manage, for example, peak demand on the electric grid and decrease source GHG emissions.

Transaction-based controls are those control solutions that interact with each other (including whole-building systems) and the electric grid to maximize the efficiency of building energy systems. Continuous, real-time information on building components and systems will allow building owners, managers, and occupants to manage buildings in the most efficient manner possible and increase energy savings through across-the-meter transactions. Transaction-based services can inherently be integrated into the work of other programs and augment other technologies that EERE engages, including renewable energy technologies like photovoltaics (PV) and end uses like electric vehicles, to balance building assets with distributed generation assets. The Sub-Program's developed technology solutions include whole-building operations, independent equipment, and consumer devices or appliances, which provide value to all participants in a transaction-based energy ecosystem. Furthermore, sensors and controls can increase or enhance the hosting capacity of energy-efficient and renewable energy technologies at scale within the distribution system.

As clean energy and energy-efficient technologies become more prevalent on the customer side of the meter, the distribution system must evolve to accommodate these technologies. Seamlessly integrating multiple EERE technologies into the electrical grid is critical to ensure that utilities can continue to operate the grid in a safe, reliable, and cost-effective manner. Sensors and controls technologies are key solutions to accomplishing this integration, while also improving energy efficiency and comfort for building occupants.

Sensors and Controls Sub-Program Market Overview

Sensors and Controls Market and Opportunity: Commercial buildings use more energy than they should simply because their systems drift away from optimum performance over time. As these buildings use more energy, they cannot maintain adequate comfort for occupants because they lack the ability to sense, monitor, and control themselves in a coordinated manner. Only about 5% of commercial buildings use energy management and control systems;[63] other buildings still rely on

[63] Kiliccote et al., 2014, "Buildings-to-Grid Technical Opportunities: From the Buildings Perspective," DOE/EE-1052

simple time clocks, thermostats, and manual switches to operate. Even those buildings that have sophisticated building automation systems rarely use the full capabilities of the system, leading to many operational problems and ultimately energy waste.

An Intelligent Software Framework for Transactive Energy (VOLTTRON)

BTO support, in collaboration with DOE's Office of Electricity and the Pacific Northwest National Laboratory (PNNL), has enabled the development of the open-source VOLTTRON platform for distributed control and sensing. VOLTTRON is designed to support modern control strategies, including use of agent- and transaction-based controls. It enables mobile and stationary software agents to perform information gathering, processing, and control actions. VOLTTRON is a secure, extensible, and modular technology that supports a wide range of applications, such as managing end-use loads, increasing building efficiency, integrating renewable energy, accessing storage, or improving electric vehicle charging. It is equipped to communicate with building systems (e.g., MODBUS or BACnet devices) and external services, has a built-in data historian and weather service, supports OpenADR 1.2., has a flexible messaging system (publish/subscribe), as well as utility and supporting classes to simplify application development, and a logging service for saving application results and logging information. More broadly, it is a highly interoperable reference platform for transactive energy applications, enabling the integration of buildings and the grid.

Significant opportunities exist to improve energy efficiency of the existing commercial building stock; up to 30% reduction in energy consumption is possible by improving building operations through sensors and controls, without the need to upgrade the existing appliances, devices, and equipment.[64] A recent study on the use of advanced occupancy sensors compared with conventional occupancy sensors revealed that advanced sensors yielded average energy savings of 17.8%, compared with only 5.9%, relative to a base-case commercial building.[65] A Department of Defense project that incorporated advanced controls for lighting demonstrated energy savings greater than 40%.[66] Siemens Corporation estimates that energy savings of 30% are possible in buildings with improved climate, air quality, and occupancy sensors.[67]

Sensors and controls that can automatically respond to and even anticipate changing conditions enable buildings to use energy optimally and help building owners and managers better manage energy use with minimal input. Sensors can measure pre-defined variables and communicate with a building's control system to make predetermined decisions related to a building's energy use. The controls then respond to those inputs to make real-

[64] TIAX LLC, 2005, "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential," NTIS PB2006-100567

[65] Zhang et al., 2013, "Energy Savings for Occupancy-Based Control of Variable-Air-Volume Systems," PNNL-22072

[66] Mukherjee, S., 2013, "Advanced Lighting Controls for Reducing Energy Use and Costs at DoD Installations," EW-201012, https://www.serdp-estcp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201012

[67] OECD, 2009, "Smart Sensor Networks: Technologies and Applications for Green Growth," OECD Digital Economy Papers, No. 167

time changes to the building's energy consumption. For example, an occupancy sensor that measures when a room has remained empty for a predetermined amount of time could send a signal to the lighting control system to turn the lights off in that room. Other lighting sensors can automatically adjust the amount of overhead light based on the level of daylight coming in through windows, giving occupants a consistent indoor light level. Sensors and controls are at the core of realizing continuous and responsive load response, which directly benefits the tenants, building owners, and grid operators.

Sensors and controls technologies can extend the life cycle of major building appliances and systems by allowing them to run consistently at optimal efficiency levels or detect and respond to faults. Automatic fault detection and diagnostics can therefore reduce maintenance time and costs—a core focus of the Sensors and Controls Sub-Program. For example, advanced sensors using cloud-based analytical software can track changes in appliances and systems and provide real-time information on when equipment maintenance is necessary and cost-effective, so that periodic checks by services contractors are not needed and occupancy comfort and energy use are not compromised.

Market Barriers: Many of these aforementioned technologies are currently available in the market but are cost-prohibitive due to first cost and installation costs. Furthermore, sensors and controls are limited in terms of ease of use and interoperability between building devices and equipment, making it difficult for buyers to understand the benefits. Often, vendor solutions are closed and remain proprietary (i.e., vendors lock in customers through their selection and installation of proprietary hardware), thereby inhibiting growth, market competitiveness, and the incorporation of new solutions by different vendors.

Furthermore, despite their potential, advanced sensors and controls technologies are not yet attracting private service providers or manufacturers due to a high level of perceived risk, high costs, and certain performance deficiencies that limit investment, including the following:

- Lack of awareness of the benefits (i.e., the benefits from increased energy efficiency, decreased maintenance costs, and increased occupancy comfort have not been monetized)
- Long-standing privacy and security concerns (i.e., cyber security)
- Proliferation of competing standards and proprietary vendor solutions (i.e., lack of interoperability)

Opportunities for Future Savings: Low-cost sensors and controls can provide options for reducing energy costs and more effectively managing energy loads by maintaining energy systems at peak performance because they represent new opportunities for buildings. Building energy systems can be managed according to weather forecasts (e.g., to aid in balancing distributed generation), or could respond to pricing signals from the larger energy system and contribute to its needs.

For example, NETL found that more than one-fourth of the 713 gigawatts (GW) of U.S. electricity demand in 2010 could be dispatchable,[68] offsetting new generation and transmission build for years—if only loads such as residential and commercial buildings could respond to that dispatch. Additional building opportunities can be accrued from smart grid applications. McKinsey found that these customer applications, deployed largely in residential and commercial buildings, could potentially be worth $59 billion (in 2009 dollars) in smart grid benefits annually by 2019, including packages of pricing, in-home displays, smart appliances, and information portals that would serve to reduce both demand and overall use.[69]

Other studies are needed to evaluate the energy market and end-user benefits of sensors and controls (including monetizing comfort). As demonstrated in Figure 25, a diagram of the NIST Smart Grid Interoperability Panel, low-cost sensors and controls can provide options for reducing energy costs. This figure shows all the actors and devices that the evolving smart grid entails and illustrates the opportunity for commingling energy, information, and controls. The NIST Framework lays out a plan for transforming the nation's aging electric power system into an interoperable smart grid—a network that will integrate information and communication technologies with the power delivery infrastructure, enabling two-way flows of energy and communication. The final version reflects input from a wide range of stakeholder groups, including representatives from trade associations, standards organizations, utilities, and industry associated with the power grid. More effectively managing energy loads is central to increasing and enhancing the hosting capacity of energy efficiency and renewable energy technologies.

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[68] National Energy Technology Laboratory. *Demand Dispatch – Intelligent Demand for a More Efficient Grid*. DOE/NETL- DE-FE0004001.Washington, DC: U.S. Department of Energy, 2011; p.31. Accessed April 20, 2013: http://www.smartgrid.gov/document/demand_dispatch_intelligent_demand_more_efficient_grid.

[69] Booth, A.; Greene, M.; Tai, H. "US Smart Grid Value at Stake: the $130 Billion Question." *McKinsey on Smart Grid: Can the smart grid live up to its expectations?* New York City, NY: McKinsey & Co. Accessed February 14, 2014: http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/mckinsey_on_smart_grid.

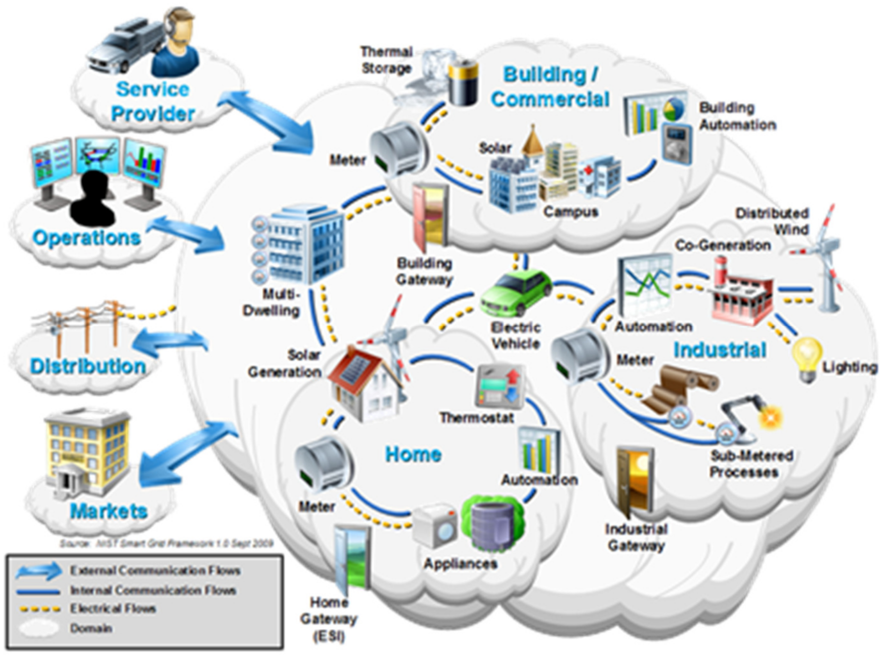

Figure 25. Low-cost sensors and controls can provide options for reducing energy costs

Source: National Institute of Standards and Technology. *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0*. NIST Special Publication 1108. Washington, DC: U.S. Department of Commerce, 2010; http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf.

Our current energy system does not fully leverage or utilize buildings, leading to billions of dollars in efficiency, energy, and infrastructure savings left untapped. A better understanding of the entire spectrum of energy use from generation to end-user, as well as the future opportunities that exist, will provide a business case and value proposition to building use cases. To illustrate the implications of this opportunity for integration, the California Independent System Operator plotted the expected daily average load shape in California as PV solar penetration increases to 30%, as shown in Figure 26. The figure shows that the demand seen by the bulk grid can increase by 32% (8,000 MW) in a single hour as solar output drops just as demand is peaking, and illustrates how energy efficiency and renewable energy technologies, when implemented at scale, can change the entrenched understanding of electricity needs.

The electric industry focuses on engaging major electric loads in both efficiency and demand-side management programs (e.g., HVAC, lights, and water heaters), while buildings automation focuses on comfort and energy efficiency. Providing buildings' systems with a DR signal that respects the facility's internal decisions is a broadly held tenet. DR is only one of many transactive energy grid services that the market could deliver. As grid flexibility demands increase, so does the value of DR.

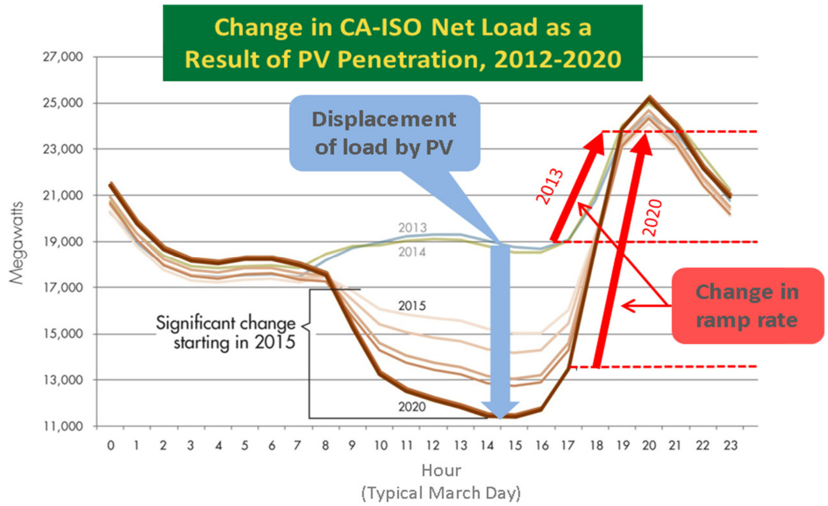

Figure 26. Rapid PV penetration increasingly displaces midday loads over time

Source: Meeusen, K. *Flexible Resource Adequacy Criteria and Must-Offer Obligation*. California: California ISO, 2014. Accessed September 15, 2015: http://www.caiso.com/Documents/Presentation-FlexibleResourceAdequacyCriteriaMustOfferObligationStrawProposalDec20_2012.pdf

These types of changes in load patterns with increased penetration of energy efficiency and renewable energy technologies will require new operating strategies to ensure continued grid reliability, resiliency, and affordability. Energy can be managed effectively by controlling the physical, logical, and financial components across different temporal scales so that they settle into an efficient system that does not waste resources from any one of those components. Energy utilization within a building can be realized as a commodity, thereby allowing outside markets as financial or service providers (or both) to enter the business of building operations, energy markets, and grid services for profit in a structured, open way. Transactive energy systems will open up new financial opportunities from energy savings and trades, efficiency gains, and in-depth understanding of buildings' energy use.

Sensors and Controls Goals

The goal of the Sensors and Controls Sub-Program is to develop low-cost, self-powered wireless sensor platforms and self-configuring, self-commissioning, self-optimizing controls that will allow optimization of building performance, enable integration of buildings with the rest of the electrical grid (e.g., electric vehicles, other buildings, PV) and automatic energy transactions with the grid, making both buildings and the electric grid more reliable and energy-efficient. Improved sensors and controls will reduce building energy consumption and costs even for building owners that do not want two-way transactions with the grid.

BTO is currently working with researchers and other stakeholders to develop a sensors and controls technology roadmap (as of September 2015), including R&D metrics and cost and performance targets.

Sensors and Controls Technology Challenges

There are outstanding technology challenges that impede widespread deployment of sensors and controls. Solutions need to self-configure or self-optimize. Solutions need to offer self-diagnostics, automatic fault detection, and automatic response to faults that do not erode efficiency savings. Finally, solutions need to seamlessly interoperate and connect with each other.[70]

Defining the characteristics of the technology: In order to make it easier to communicate the benefits of sensors and controls systems to owners and operators, the characteristics of those systems must be defined. Improving the calibration, reliability, accuracy, and diagnostics of sensors and controls systems is needed for these transaction-based networks to function properly. This physical characterization will also improve performance measurement and fault diagnostics for the systems.

Interoperability: One of the greatest challenges that sensors and controls technologies face is that building devices and equipment cannot communicate with each other. This lack of interoperability leads to high implementation costs to get it right, system inefficiencies due to vendor lock-out of features, and uncertainty from building owners as to the selection of a technology that is future-proof. For example, two-way communication with IT and system operators is necessary for these diverse systems to function. A lack of standard communications protocols can affect the accuracy and effectiveness of sensor and controls systems. In addition, coordination and knowledge exchange within the IT community must improve. Furthermore, consumers have lingering concerns with wireless technologies, their benefits, and security/privacy.

Lack of control applications: The sensors and controls industry lacks the proper algorithms and models on a standardized control platform that will enable it to characterize physical devices. Developing these fundamental algorithms will enable researchers to write transactive energy applications that characterize and utilize the physical devices to deliver services. These applications will be in the form of control solutions that will enable owners and operators to realize scalable solutions that enable long-standing sensor and controls goals, including self-mapping sensors and controls and plug-and-play.

Sensors and Controls Strategies, Current and Planned Activities

The Sensors and Controls Sub-Program will focus on two key strategies:

Strategies

- *Develop cost-effective, accurate, long-lasting interoperable sensor platforms that are able to sense multiple parameters, including temperature, humidity, occupancy, and indoor air quality.*
- *Develop controls that are self-aware, self-calibrating, and self-discovering, and which can communicate with each other on a transactional network.*

[70] Hagerman, J. *Buildings-to-Grid Technical Opportunities*. Washington, DC: U.S. Department of Energy, 2014. Accessed August 22, 2014: http://energy.gov/sites/prod/files/2014/03/f14/B2G_Tech_Opps--Intro_and_Vision.pdf.

In addition to R&D, the Sub-Program will work with the Residential and Commercial Buildings Integration Programs to develop and deploy solutions and implementation models in the buildings marketplace that provide building owners and managers, as well as service providers, with the capability to easily and efficiently manage energy-consuming assets and systems. In all cases, sensors and controls efforts will adhere to DOE's larger interoperability strategies and goals as outlined in the Quadrennial Energy Review (QER).[71]

The Sub-Program actively engages with industry through public technical meetings and requests for information, which includes discussions on progress, potential projects, and opportunities.

Strategy 1: Develop cost-effective, accurate, long-lasting interoperable sensor platforms that are able to sense multiple parameters, including temperature, humidity, occupancy, and indoor air quality.

BTO is developing sensors and sensor systems that are able to easily share data that enables building operators and owners to capture energy and cost savings through the use of new and existing control system applications. The objective is to make new sensors and configurations available in the marketplace that make it easy to adapt building operations, collect data from an open-access platform, and apply that data to building management systems. The Sub-Program is particularly interested in innovative approaches that reduce the cost and energy needs of data collection for common building operation variables such as temperature, pressure, and relative humidity. Specifically, the Sub-Program is interested in sensor packages that allow for data acquisition and transmission that require fewer manual calibrations, as well as virtual sensors enabled by innovative combinations of hardware and software that can be easily installed. Additionally, the Sub-Program is interested in plug-and-play sensor packages that are automatically recognized by building energy management systems, similar to how printers are easily recognized by an existing computer network.

Further, the Sub-Program will develop hardware-sensing solutions for buildings, particularly those tailored to small- and medium-size buildings. BTO solutions should allow for the application of new sensor nodes from differing technology sectors to be applied to building applications for solutions in sensing and monitoring. Sensor packages are comprised of combinations of sensor nodes, power, logic, and communication configurations that sense building system states, energy usage, and environmental conditions, and which then communicate the data. These packages should have peel-and-stick or plug-and-play solutions, meaning they can be easily installed, commissioned, and operated to communicate with a centralized system. They should have secure, nonproprietary communications protocols that have self-calibrating and auto-mapping features, as well as fault-tolerant characteristics.

Virtual, proxy, or other inferential sensing and monitoring solutions for building applications have to generate an equivalent value to traditional sensors and yield a value that is actionable for building operations. BTO is working to develop sensors for categories that are difficult or costly to sense with a direct physical measurement, such as occupancy, as well as nonintrusive sensors. BTO is also working to find a way to utilize sensors that are already in use; for example, using

[71] http://energy.gov/epsa/quadrennial-energy-review-qer

temperature sensors to determine equipment state. In general, BTO encourages equipment that can report its own energy consumption and related variables. Sensors should be able to measure energy, flow, temperature, pressure, and light level. They should be installed, configured, and calibrated to meet lower life cycle costs than traditional sensors. Finally, they should not require complicated calibration and should provide continuous measurements over time.

All solutions that BTO develops need to address key requirements for sensing and monitoring in commercial and residential buildings across BTO's five sensor and controls unifying criteria: interoperability, scalability, ease of deployment, availability, and affordability. In order for a solution to be considered interoperable, it must work within existing control solutions from a diverse set of vendors. Solutions must be self-starting and not require ongoing commissioning, maintenance, or calibration by third parties. Solutions must be "open" in terms of their communications standards. Finally, they must be affordable and low-cost in terms of manufacturing, installation, and ongoing operation.

Strategy 2: Develop controls that are self-aware, self-calibrating, and self-discovering, and can communicate with each other on a transactional network.

There is an immense opportunity to invest in the development of common, shareable components and tools that allow building operators and owners to achieve efficiency at the lowest possible cost to their businesses, stemming from an untapped need facing the building energy management sector. BTO focuses on strategies that enable simplified applications for building operation, open and easily accessible data from sensors, and novel applications of sensor data to building management systems. These solutions offer new services to building assets.

Along with enabling significant building energy savings, a long-term goal of this activity is to enable transaction-based controls decisions, which are solutions allowing operational decisions to be based on market signals, including commodity prices or service demand. These decisions can be direct (i.e., time-of-day electricity price) or indirect (i.e., price given the fuel and carbon impact of the existing electricity mix) and are financially based. For example, transaction-based control decisions can be deployed alongside smart grid investments to allow consumers to easily interact with the electricity system to capture previously shielded value streams. These systems have proven a more economically efficient method of managing a complex system because end-use control with connectivity is less expensive to deploy than traditional, stationary storage solutions or other ancillary service solutions.

The information collected from sensors and controls systems themselves are the most basic requirements for traditional building operations. The information enables transactive energy and "smart buildings". As buildings and the grid become increasingly integrated, systems and devices must automatically communicate their identity, status, and availability to facilitate and optimize energy management at the grid, utility, and building levels. Additionally, sensors and controls will improve traditional building energy management and result in reduced energy use and building systems maintenance costs, simultaneously ensuring more competitive energy pricing and utilization. If properly developed, these systems can deliver a plug-and-play solution, lowering the cost of implementation so that all buildings, regardless of size, can benefit from grid optimization and related strategies that have historically only been available in large, highly sophisticated buildings.

To date, little work has been completed by utilities or other market participants to integrate these concepts in a holistic way. This integration can happen behind the meter or in dispersed equipment installed and operated in buildings, such as in lighting systems in a building or throughout a campus. BTO will integrate the concepts and strategies by working with the relevant manufacturers, market actors, and system integrators on solutions and implementation tools for end-use equipment, building automation systems, and onsite renewable energy systems.

Activities in this focus area include developing the fundamental economic and control theories needed to support transaction-based control in different classes of equipment, as well as advancing sensors and controls to communicate and respond to outside signals by secure, reliable, and robust means. BTO is also focused on establishing communications, measurement, and verification requirements and conducting field measurements of transactive deployments to assess the feasibility, merits, and implementation protocols for transactive energy systems.

The new transactive energy ecosystem is a seamless, cost-effective electricity system, from generation to end use, capable of meeting all clean energy demands and capacity requirements, with the following characteristics and capabilities:

- Significant scale-up of clean energy, including renewables
- Universal access to consumer participation and choice with distributed generation, demand-side management, electrification of transportation, and energy efficiency
- Holistically designed solutions exhibiting regional diversity, including AC-DC transmission and distribution solutions, microgrids, and energy storage
- Two-way flows of energy and information
- Reliable, resilient, and secure information and energy throughout the cyber-physical environment

Enabling efficient energy utilization through open markets and across-the-meter transactions will encourage the innovation and new investments necessary to enable the grid of the future and fully realize the benefits of clean energy technology. A number of recent and ongoing projects are working to achieve these benefits. For example, Virginia Tech University is developing an open-source controls platform for small- and medium-size buildings.[72] ORNL is integrating local solar PV generation with a packaged RTU and weather forecasting to provide an efficient, cost-effective DR strategy.[73] PNNL, in collaboration with several other national labs, is developing applications for VOLTTRON,[74] an open-source software platform that enables building equipment and entire buildings, distributed generation sources, and the grid to transact in a secure and efficient

[72] http://energy.gov/eere/buildings/downloads/building-energy-management-open-source-software-development-bemoss
[73] Starke, M. et al., 2014, "Integration of Photovoltaics into Building Energy Usage through Advanced Control of Rooftop Unit," Paper 3623, 3rd International High Performance Buildings Conference at Purdue, July 14-17.
[74] http://gridoptics.pnnl.gov/VOLTTRON/

environment. NREL has developed an image-processing based virtual sensor with broad applications (including occupancy, HVAC and lighting controls) that is based on low-cost embedded processing platforms and commodity hardware, open-source computer vision libraries, and standard building communications protocols.[75] Finally, ORNL and CRADA partner Molex are developing wireless peel-and-stick sensor platforms for building applications with a targeted cost of $1–$3 per sensor at full-scale deployment, compared with the costs of existing commercially available sensors at $150–$300 per sensor.[76]

[75] Brackney, L.J. et al., 2012, "Design and Performance of an Image Processing Occupancy Sensor," Proceedings. The Second International Conference on Buildings and the Environment, pp. 987 – 994, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.401.4541&rep=rep1&type=pdf

[76] http://energy.gov/eere/buildings/downloads/low-cost-wireless-sensors-building-applications

2.5 Building Energy Modeling

Whole-building energy modeling, or software calculations of building energy use given a description of the building's physical assets, operations, and weather conditions, is an enabling technology for increasing building energy efficiency. Energy modeling supports system-level integrative design that simultaneously optimizes the building's envelope and systems to match its anticipated use profile and local conditions. A recent study of more than 1,000 design projects submitted to the AIA 2030 Commitment program shows that buildings designed using energy modeling have an energy consumption rate that is 44% lower than Commercial Buildings Energy Consumption Survey (CBECS) 2003 national sample survey stock. Buildings designed using prescriptive rules that typically address building systems individually rather than optimizing them globally outperform stock by only 29%.[77]

In addition to design, energy modeling supports the creation and updating of building energy codes like ASHRAE 90.1 and California's Title 24. These codes' prescriptive requirements are developed by analyzing the results of many building energy models of alternate configurations in different climate zones and for different building types. Similar analysis underpins beyond-code prescriptive guides and "deemed savings" calculations. Energy modeling is also the basis of performance path code compliance—model-based comparison of the actual building to a code-minimum version of the same building—and beyond-code programs such as green certification.

Increasingly, energy modeling is used to maintain, diagnose, and improve building energy performance during occupancy. Comparing modeled operations to actual operations can help building owners and operators detect and diagnose equipment and control faults, as well as other divergences from the building's intended design. Model-predictive control uses energy modeling, real-time weather forecasts, and price signals from the grid to tailor short-term control strategies to reduce energy demand, particularly at peak times, or meet other energy objectives.

DOE's Building Energy Modeling (BEM) Sub-Program aims to increase the use of modeling tools in building design and operation. Mirroring the layered structure of other computer systems, DOE is developing and promoting a three-tiered structure for energy modeling. The bottom layer includes physics engines like the detailed energy modeling engine EnergyPlus™ and its predecessor, DOE-2™, as well as the detailed lighting engine Radiance™. Lighting, both natural and electric is a major component of building energy consumption and visual comfort an important constraint. The top layer includes applications that target specific end uses, from design to auditing to operations to large- scale analysis. These layers are mediated by an operating system, which provides common abstractions and services—interoperability, model articulation from high-level descriptions, management of large simulation batches for sensitivity analysis, calibration, or optimization, etc.—and reduces the cost of application development. DOE's operating system is OpenStudio®. DOE's role is to develop the EnergyPlus engine and the OpenStudio operating system, both under permissive open-source licenses and in collaboration with industry and users. Applications

[77] Pickard, Kelly. *2030 Commitment Measuring Industry Progress Toward 2030.* Washington, DC: The American Institute of Architects, 2013. Accessed August 13, 2014: http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab100374.pdf

targeting specific use cases and the corresponding customer relationships are left to market actors. For example, DOE prefers to serve 50 application vendors rather than 50,000 application users. With OpenStudio improving the value proposition of developing energy simulation applications, this vision is finally being realized.

Energy modeling is an important cross-cutting Sub-Program within BTO. BTO's Building Energy Codes Program uses energy modeling—and specifically EnergyPlus—to support development of building energy codes through ASHRAE and the International Code Council (ICC). The Commercial Buildings Integration (CBI) Program uses energy modeling to develop the Advanced Energy Design Guides (AEDGs) and Advanced Energy Retrofit Guides (AERGs), which are 30–50% more stringent than building energy codes. CBI also used EnergyPlus simulation to create a qualification calculator for the 179D whole-building energy efficiency tax credit. EnergyPlus and OpenStudio form the computational basis for the Commercial Asset Score. BTO's Residential Buildings Integration (RBI) Program uses EnergyPlus in BEopt™—a residential energy optimization software tool used by Building America teams. Energy modeling helps to push technologies developed by BTO's ET Program into building projects by providing quantitative estimates of energy savings relative to alternative technologies. For example, BTO developed a model of the advanced "challenge" RTU for EnergyPlus, and plans to develop models for IHPs that combine WH with space conditioning. Finally, energy modeling is helping with strategic prioritization, BTO is using OpenStudio's cloud-based analysis framework to generate energy savings estimates by end use for its strategic P-Tool.[78]

[78] Farese, P.; Gelman, R.; Hendron, R. *A Tool to Prioritize Energy Efficiency Investments*. NREL/TP-6A20-54799. Golden, CO: National Renewable Energy Laboratory. Accessed August 22, 2014: http://www.nrel.gov/docs/fy12osti/54799.pdf

Building Energy Modeling Market Overview

Success Story: Concept3D Simuwatt®
In 2012, the Denver startup Concept3D won an award from the Department of Defense to develop a mobile application for performing investment grade audits on commercial buildings. Using the OpenStudio SDK, Concept3D built Simuwatt, a tablet application that facilitates geometry capture, intelligently guides an auditor through onsite data collection, sends the data to the cloud where it builds an EnergyPlus energy model and then uses OpenStudio to evaluate measures on that model. Pilot tests at several army bases show that Simuwatt reduces audit time by 75%. Simuwatt is now conducting a public beta.

Source: "Simuwatt." National Renewable Energy Laboratory. Accessed August 28, 2014: http://www.simuwatt.com/.

Building Energy Modeling Market: The building energy modeling marketplace consists of about a dozen engines. Some like EnergyPlus and ESP-r (from Strathclyde University) are open-source. Many others like DOE-2 or TRACE™ (from Trane Corporation) are proprietary. Some, like EnergyPlus, are actively updated, whereas others are not. Among all these engines, EnergyPlus is both the most comprehensive and the only one that is available under a commercial-friendly, "non-viral" open-source license.

This combination of characteristics allows EnergyPlus to act simultaneously as the basis for standards development and compliance, for commercial tools, and as an open reference for other engines. Analysis of the projects submitted to the AIA 2030 Commitment program in 2013 shows that EnergyPlus is the third most popular engine for design, capturing 7% of the total market. Within projects that achieved the AIA 2030 Commitment performance target of 60% below CBECS 2003, EnergyPlus was used 20% of the time.

Several hundred applications are built based on these engines. They vary greatly in use case (design, equipment sizing, code compliance, and auditing), target audience (architects, engineers, and educators), underlying modeling features exposed to the end user (full exposure with few defaults, or many defaults and few user inputs), and platform (desktop vs. web). EnergyPlus specifically has a number of desktop design interfaces (including DesignBuilder© from DesignBuilder-UK, AECOSim Energy Simulator™ from Bentley, N++ from ExpertApp, ArchSim from ArchSim, Simergy™ from Digital Alchemy, and Sefaira Systems™ from Sefaira), a tablet-based auditing application (Simuwatt from Concept3D), several web-based large-scale simulation and analysis frameworks (gEnergy from GreenSpaceLive, EnergyPlus-Cloud from Autodesk, Apidae from BUILDlab, and JESS from EnSimS), a performance path code compliance application (CBECC-Com from Architectural Energy Corporation), a design assistance program management tool (Energy Design Assistance Program Tracker [EDAPT] from Xcel Energy), a stock modeling and incentive customization tool (COFEE from National Grid), and an asset rating tool (Commercial Asset Score from DOE).

In the larger computing ecosystem, a small number of operating systems—such as Windows, MAC OS, and Linux for traditional personal computing devices and iOS and Android for smart phones—mediate a larger number of engines and a much larger number of applications. In building energy modeling, a similar situation is emerging. OpenStudio is the only building energy modeling operating system thus far, and it is not clear whether proprietary operating systems or additional open-source operating systems will emerge. Both Linux and Android emerged after their proprietary counterparts and no dominant operating system—open-source or otherwise—emerged after them. OpenStudio serves the same functions as a traditional operating system, providing common abstractions that facilitate application development. The more recently developed applications like Concept, CBECC-Com, Simuwatt, EDAPT, COFEE, and the Asset Score all access EnergyPlus via the OpenStudio software development kit, and as a result, they have been developed quicker and with less effort. OpenStudio also supports multiple engines. In addition to EnergyPlus, it supports the energy simulation engines ESP-r and EE-Calc (i.e., the CEN/ISO 13790 algebraic annual and hourly energy consumption calculations), the lighting engine Radiance, and the airflow engine CONTAM. Figure 27 shows the OpenStudio ecosystem of engines and applications.

The lighting simulation software world is significantly smaller than the energy simulation world. Still, Radiance is the most widely used and commercially influential lighting simulation tool due to its status as a prime mover and its open-source license. Like EnergyPlus, Radiance is embedded in a number of free and commercial products, including façade design tools (COMFEN from LBNL), daylighting and electric lighting design tools (DAYSIM from MIT and Penn State and IDEAKit from NREL), lighting control design tools (Sensor Placement Optimization Tool from AEC), and energy analysis tools (Sefaira Architecture from Sefaira, DesignBuilder, and Virtual Environment from IES to name several).

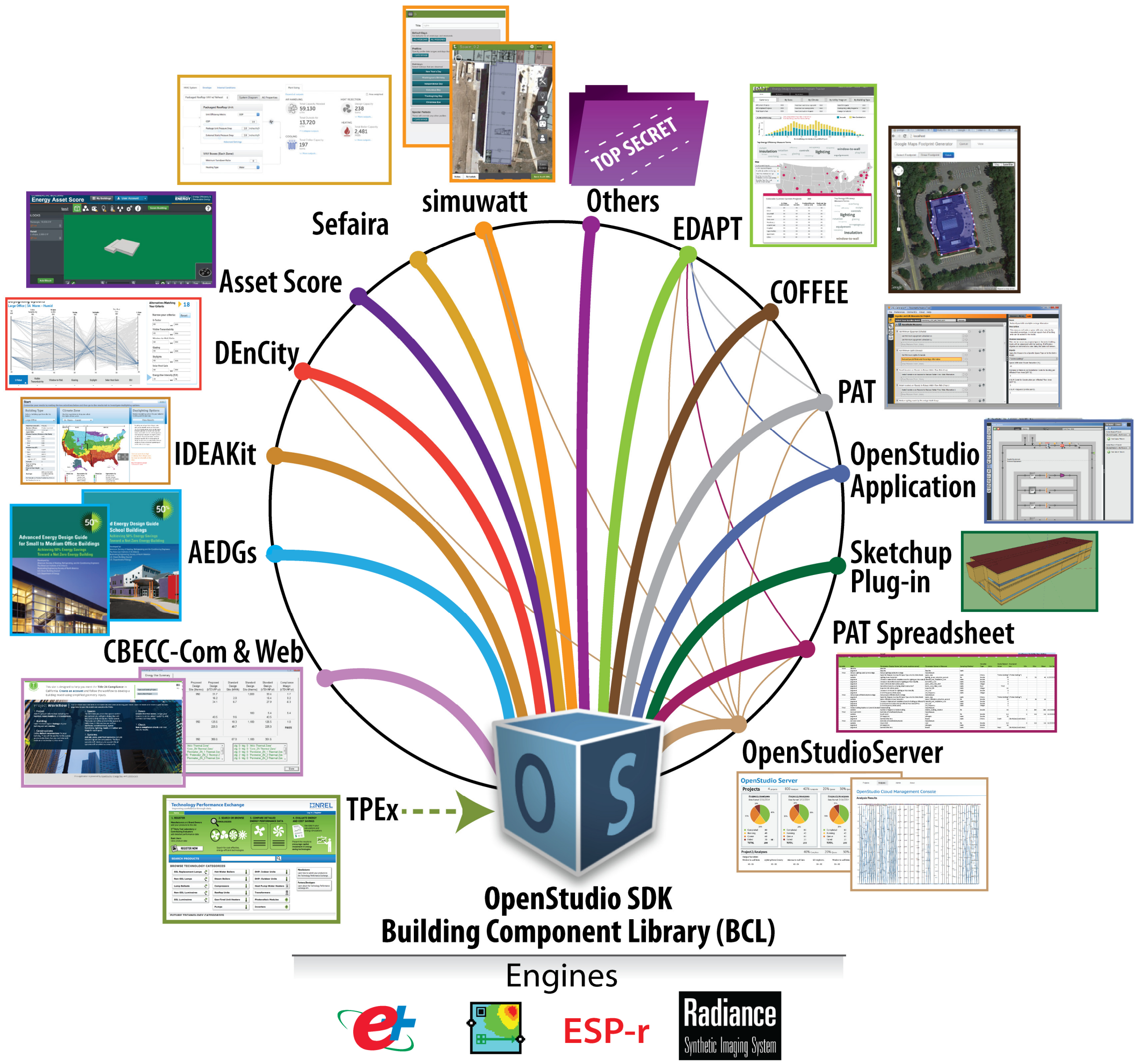

Figure 27. OpenStudio energy modeling ecosystem. OpenStudio serves as the operating system or middleware for a number of engines—including EnergyPlus—and a large number of applications, both public and commercial.

Whereas the "offline" uses of energy modeling like design and certification are relatively established, the "online," or "real-time" uses are just starting to emerge. These operational use cases include design of low-energy building control algorithms, continuous commissioning of building mechanical systems, and model-predictive dynamic building control for energy optimization or DR. One EnergyPlus-based application in this space is the building control and DR engine QCoefficient.

BTO recently started tracking the use of simulation in design via the AIA 2030 Commitment Reporting Program.[79] BTO also has utility partners that could facilitate tracking of other use cases. As operational uses of energy simulation become more established, use could be tracked through utility incentive programs.

Market Barriers: Although a variety of energy modeling tools are currently available, their use for energy reduction lags compared to their use for code compliance and LEED certification. For instance, of the more than 1,000 completed projects submitted to the AIA 2030 Commitment, fewer than 55% used energy modeling at any point during design. Reasons for the lag include lack of awareness of the benefits of energy modeling, lack of confidence in those benefits, gaps in building physics education and training, and poor integration of energy modeling tools into existing design workflows and data sources. In general, factors that suppress demand for energy efficiency also stifle use of energy modeling.

For energy modeling to be predictive (i.e., to accurately predict a building's energy consumption) it needs accurate descriptions of the building's physical characteristics and operations. Unfortunately, many key inputs to building energy models, such as air infiltration rates, occupancy schedules, plug loads and their schedules, equipment schedules, degraded equipment efficiencies, internal thermal mass, and even specific weather conditions, are often difficult to obtain. This leads to estimates that differ from measured values by 30% and more. In recognition of this limitation, most uses of energy modeling are set up as comparative, where the results of two simulations are compared to one another, canceling out the effects of parameters that are the same in both, including potential uncertainties. Code compliance and green certification use energy modeling in this way. However, despite this setup, which provides accurate answers to comparative questions, many people mistrust energy modeling because of its inability to provide accurate predictive estimates under ordinary circumstances. The fact that most simulation tools provide point answers rather than ranges or distributions and do not account for uncertainty in key inputs adds to this lack of confidence by giving the impression that energy modeling provides authoritative answers independently of inputs.

Another issue is that quantitative absolute statements about the accuracy and sensitivity of various aspects of energy simulation are largely missing. Although there is a framework and extensive suite of tests for validating energy modeling engines, namely ASHRAE Standard 140, the reference results for the large majority of the tests are themselves by consensus among various simulation engines. This is a valid approach, especially given the difficulty and cost of empirical validation, but it gives the impression that energy modeling does not have a firm footing in reality. Inconsistent results across simulation tools also cause confusion; problems with one tool can erroneously reduce confidence in all energy modeling tools.

Inconsistencies across tools pale in comparison to inconsistencies across modelers. Energy modelers are sparsely distributed, undertrained, and often poorly supported. Few architecture and mechanical engineering programs include energy modeling in their curricula and do not produce professionals with adequate building physics and modeling knowledge. Although advances have

[79] See http://network.aia.org/2030commitment/home

recently been made, the infrastructure for training is sparse, and few modelers seek professional certification. Further, basic modeling procedures are not documented, and best practices are slow to spread to practitioners.

Inconsistency among modelers, modeling errors, and the cost of modeling are exacerbated by poor integration of energy modeling tools within existing architecture and engineering workflows. Lack of automation and interoperability increases the likelihood of human transcription errors, leads to differences in interpretation between modelers, and soaks up time and money that would be better spent analyzing results and exploring conservation opportunities. The cost of creating models initially suppresses the availability of those models for use later in the building life cycle, for applications like commissioning, retrofit planning, and control.

Building Energy Modeling History

DOE's involvement with and support for building energy modeling predates its status as a cabinet-level department. In the 1970s, the Energy Research and Development Administration (ERDA), along with the California Energy Commission (CEC), developed a whole-building energy modeling tool called CAL-ERDA based on the NASA Energy Cost Analysis Program (NECAP). In 1977, ERDA became the modern U.S. Department of Energy, and CAL-ERDA was renamed DOE-1. DOE continued developing DOE-1 and its successors DOE-2 and DOE-2.1 for the next decade and a half.

In the early 1990s, DOE, LBNL, the Electric Power Research Institute (EPRI), and J. J. Hirsch and Associates began a joint project to develop a follow-on to DOE-2.1, called DOE-2.2, which would include interactive capabilities. After a dispute and subsequent court case, J. J. Hirsch and Associates secured the rights to distribute DOE-2.2. Rather than continuing with overlapping development of DOE-2.1, DOE rebooted its energy modeling development efforts around the Building Loads and System Thermodynamics (BLAST) program developed at the Construction Engineering Research Lab (CERL) of the U.S. Army Corps of Engineers. DOE re-engineered many of the system modeling capabilities that had been developed for DOE-2, and the new engine, called EnergyPlus, was released for the first time in 2001. DOE has continued to develop EnergyPlus, releasing major updates about every 18 months.

In January 2012, DOE released EnergyPlus version 7.0 under a new permissive open-source license. This license allowed companies greater freedom to work with EnergyPlus, make modifications to it, hire subcontractors to work on it, and incorporate it into their products. In November 2013, Autodesk Corporation hired Objexx Inc. to translate EnergyPlus from the procedural programming language FORTRAN to the more modern and object-oriented C++ and donated the translated code back to DOE and LBNL. DOE released the first EnergyPlus version based on this code, EnergyPlus 8.2., in September 2014, and is now developing on this code base exclusively. DOE is planning a major upgrade to EnergyPlus' HVAC and controls modeling based on the modern equation-based simulation language Modelica. This upgrade targets rapid prototyping of components and system models, a better connection to building control design and implementation workflows, and simulation speedups of an order of magnitude and more.

EnergyPlus uses a text-based input/output scheme. DOE had planned to leave it to commercial interests to develop graphical interfaces for EnergyPlus, but that activity did not begin in earnest until 2007, when ASHRAE published a simulation-based method for beyond-code performance calculations, known as Appendix G of Standard 90.1, or "Performance Rating Method," and the U.S. Green Building Council adopted the method as the basis for its Energy and Atmosphere Credit 1. Even then, commercial activity was initially limited to a geometry interface from DesignBuilder-UK. Due to a lack of activity, in 2009, DOE entered a public-private partnership with the CEC and Infosys, Ltd. to develop a free, but not open-source, comprehensive user interface for EnergyPlus called Simergy. Around the same time, NREL began expanding its OpenStudio plug-in for the SketchUp 3D drawing program into more fully featured middleware architecture capable of supporting multiple engines and end-use applications.

DOE began funding OpenStudio in 2011, and in early 2013, exited the Simergy partnership to focus its energy modeling deployment activities through the OpenStudio platform. DOE has recommitted to its original stance of developing only open-source software and not developing end-user applications unless for programmatic purposes. OpenStudio has helped make this stance productive by improving the value proposition for commercial application development.

In addition to developing engines and middleware, DOE has supported the development of test methods for building energy simulation programs. These methods and the associated suites of tests were initially developed via International Energy Agency Annexes. They were subsequently codified by ASHRAE as Standard 140. DOE continues to support the development and expansion of Standard 140, expanding its validation activities to include tests and reference datasets acquired from well-characterized, highly instrumented test facilities such as LBNL's Facility for Low-Energy eXperiments (FLEXLAB and, potentially, ORNL's Flexible Research Platform (FRP).

DOE also has historically invested in the development of exchange standards for building energy modeling. DOE has funded energy modeling specific additions to the Industry Foundation Classes (IFC) international standard for building information modeling. More recently, DOE has funded work on importing both IFC and the gbXML energy model exchange format into OpenStudio.

DOE also has recently begun supporting the energy modeling community via education and training. Specifically, DOE is working to empower the U.S. chapter of the International Building Performance Simulation Association (IBPSA) to act as an education material resource hub, and is independently working to establish a training ecosystem for energy modeling. DOE also works with ASHRAE and IBPSA to support research projects and student involvement in research and conferences.

On the lighting side, DOE has supported Radiance at a low level since 2008. Radiance had been developed by LBNL and Anyhere Software using other funds since 1985. It has been distributed under a permissive open-source license since 2002.

Opportunities for Future Savings: Building energy modeling has many uses and just as many energy saving vectors. Energy modeling plays a large role in the development of energy conservation codes and standards, as well as in the development of design guides, which can result in energy performance that exceeds building code levels.

According to an analysis of 1,112 projects that are in the design development stage or later submitted to the AIA 2030 Commitment in 2013, 499 projects that did not use modeling achieved

29% energy savings over CBECS baseline. 613 projects that used modeling achieved 44% reduction. 76 projects that modeled using EnergyPlus achieved 49% energy reduction. 236 projects that used DOE-2 achieved 40% reduction.

Maximizing the benefit of integrative design requires increasing the number of projects that use modeling above the current 55%, which is already an over-estimate because the sample includes only data from firms signed on to the AIA 2030 Commitment, and presumably these are more energy-conscious firms than some others. It also potentially requires maximizing the use of advanced energy modeling engines like EnergyPlus rather than older engines such as DOE-2. Finally, there is the potential to increase the effectiveness of energy modeling beyond its current 15 percentage point difference compared to no usage of modeling, (20 percentage point difference with EnergyPlus) by expanding tool capabilities, making them easier to use, and training modelers.

According to the P-Tool, using energy modeling in design can yield annual savings of 442 tBtu for new construction and 230 tBtu for deep retrofits. If EnergyPlus or another advanced engine is used, the savings potential jumps to 590 tBtu for new construction and 306 tBtu for deep retrofits.

Building Energy Modeling Goals

The energy modeling Sub-Program's overarching goal is to increase the use of building energy modeling in design while improving modeling accuracy. There are separate goals for expanding modeling use cases. These goals were created through internal BTO discussion and with national laboratory researchers as well as representatives from AIA and IBPSA. There is virtually no data about the historical use of modeling. Therefore, benchmarks and trends are difficult to establish.

The use of building energy modeling in design is tracked using annual reports submitted by firms to the AIA 2030 Commitment. DOE is partnering with AIA to improve the 2030 Commitment reporting process and to tie it to other BTO tools such as the Building Performance Database and the Commercial Building Energy Asset Score.

Table 9 outlines the mid- and long-term goals for the use of building energy modeling tools in design and in building commissioning and control.

Table 9. Building energy modeling goals

Goals: Building Energy Modeling			
Metric	**Status**	**Mid-term (2020)**	**Long-term (2030)**
Use in Design of New Buildings and Deep Retrofits	Only 40% of 1.4bn gross square feet (gsf) submitted to the AIA 2030 Commitment in 2013 used energy simulation*; only 14% achieved the 2030 goal.	Widespread use of advanced energy simulation (50% of gsf), achieving 20% reduction in design EUI over prescriptive design.	Pervasive use of advanced energy simulation (90% of gsf), achieving 20% reduction in design EUI over prescriptive design.
Use in Continuous Building Commissioning and Dynamic Building Control	These are emerging applications with new infrastructure and no reporting program—status is difficult track.	Preliminary use (2% of gsf) of advanced energy simulation, achieving and persisting designed savings.	Moderate use (20% of gsf) of advanced energy simulation, achieving and persisting designed savings.

*Note: *Includes cases where simulation was only used post-design for green certification purposes.*

Building Energy Modeling Challenges

The BEM Sub-Program has an opportunity to significantly affect the number of users applying building energy modeling in the design and operation of their buildings. In order to do that, the Sub-Program must address issues that hinder adoption and the consistent and effective use of energy modeling tools.

Lag of technology coverage in energy modeling engines: Energy modeling engines are typically behind in including technologies available on the market by 3–5 years. Simulation of technologies that are not directly available in an engine requires ad hoc workarounds that increase modeling effort and cost, introduce additional variability across modelers, and suppress installation of these new technologies.

Lack of support for modeling buildings under actual operation. Energy modeling engines model buildings under somewhat idealized operations—deterministic, repeating occupancy and use, perfect sensors, and equipment that does not foul, degrade, or outright break. Support for modeling more realistic conditions including sensor drift, equipment degradation and faults, and stochastic occupant behavior is needed to allow modeling to effectively deal with existing buildings.

Insufficient characterization of modeling engine accuracy: Error or degree of approximation associated with various aspects of energy modeling and various use cases of energy modeling is not well-characterized or well-attributed. This lack of clarity reduces confidence in energy modeling as a whole and suppresses the use of modeling in investment and decision-making.

Missing or brittle automation of common energy modeling tasks: Although the situation is improving with the help of OpenStudio, common energy modeling support tasks—such as transfer of information from 3D CAD models—are currently either not automated or poorly automated, and their use is not well-established. These tasks consume time that would be better spent analyzing model results and exploring design alternatives and generally degrade model quality.

Insufficient integration of energy modeling tools with existing design tools: Poor integration of energy modeling in existing design workflows increases the amount of effort needed to accurately model a building and leads to decreased use of modeling tools.

Insufficient integration of energy modeling tools with control design and implementation tools: Many challenges of developing and deploying control systems in large, complex buildings involve translation inconsistencies and errors between English descriptions of control strategies, modeling of those strategies in energy simulation engines for the purposes of energy optimization and testing, and final implementation in physical building controllers. Unifying the two software applications—energy simulation and physical implementation—using a single language and platform can essentially eliminate these problems and align simulation with actual building control to enable applications like continuous commissioning.

Lack of standardization of minimal requirements and best practices: Lack of standardization and established best practices introduces variability in model quality and model estimates and leads to a lack of quality assurance while reducing confidence in modeling.

Lack of primary and continuing education and support: There is a lack of continuing education for the already small number of modelers, many of whom do not have any professional credentials. Existing energy modelers are scarce and do not have access to proper institutional or grassroots-level training and support systems.

Addressing these challenges will help contribute to increased energy savings due to more robust building designs for new construction and retrofits because information gleaned from running simulation models and analyses better informs decision-making during the design and construction process.

Building Energy Modeling Strategies, Current and Planned Activities, and Key Targets

The BEM Sub-Program is designed to accelerate the use of energy modeling in established use cases and to develop new use cases. It also focuses on maintaining and supporting existing open-source tools like EnergyPlus and OpenStudio and updating them with models using recent building energy efficiency technologies so that users can make informed decisions about how to construct and operate buildings using available materials, equipment and known strategies.

During the next 5 years, the Sub-Program will focus on four key strategies related to software development, testing and validation, and external partnerships. These will address the R&D and market-related challenges identified above, as well as work toward meeting Sub-Program goals.

Strategies

- *Improve characterization of energy modeling engine accuracy and improve accuracy as necessary.*
- *Continue to improve open-source whole-building energy modeling engine EnergyPlus, lighting engine Radiance, and middleware OpenStudio.*
- *Expand partnerships with commercial software vendors to create end-user applications that use energy modeling.*
- *Develop and expand partnerships with professional and educational organizations to improve the level of service and support available to energy modelers and the state of common energy modeling practice.*

The R&D and market-based activities outlined below are necessary to fully realize energy savings through building energy modeling. Each strategy is comprised of planned activities and associated targets between now and 2020. These are outlined in Table 10, which summarize how the Sub-Program intends to reach its goals. Included with the activities are key targets; these are updated each year to reflect progress or changes in course.

The targets are based on the area of commercial building space designed using building energy modeling and the marginal design energy performance achieved, the number of third-party applications developed using DOE supplied tools, and the number of reference datasets for engine validation. Targets focus on commercial buildings because the cost of modeling has historically been too high for wide use in the residential sector. In addition, homes are much more uniform than commercial buildings in terms of size and energy use, and are therefore more amenable to packaged design guide approaches.

Strategy 1: Improve characterization of energy modeling engine accuracy and improve accuracy as necessary.

The Sub-Program plans to ramp up its activities in the area of energy modeling engine testing and validation. Specifically, the Sub-Program will use new, well-characterized, finely instrumented test facilities in the United States and around the world, such as FLEXLAB at LBNL and potentially FRP at ORNL, to create modeling engine tests with reference data sets generated from measurement. These tests will enable definitive statements about the accuracy of specific calculations in individual engines, which will help reduce confusion and misinformation about energy modeling accuracy, as well as point to areas needing upgrade and refinement.

Strategy 2: Continue to improve open-source whole-building energy modeling engine EnergyPlus, lighting engine Radiance, and energy modeling middleware OpenStudio.

The Sub-Program will continue to develop, maintain, distribute, and support the EnergyPlus whole-building energy modeling engine, the Radiance lighting engine, and the OpenStudio energy modeling middleware. EnergyPlus will be enhanced to incorporate models for new construction and fenestration technologies, HVAC and refrigeration equipment and system configuration, and control strategies. BTO will also improve EnergyPlus' execution speed. One initiative involves moving the HVAC and controls modules part of EnergyPlus to the Modelica declarative modeling platform, which will allow component models to be developed outside of EnergyPlus and then plugged in to the system solver and simulation master. This transition should help reduce the delay between the development of a technology and the development of models of that technology suitable for whole-building energy simulation. It will also unify control simulation and implementation.

OpenStudio will be maintained, supported, and enhanced to encapsulate new EnergyPlus features and to incorporate new general-purpose energy modeling support functions. As OpenStudio is increasingly driven by client applications, new features will be added according to client needs.

Radiance will also be maintained, supported and enhanced in recognition of the fact that increasingly stringent codes—and the beyond-code efficiency programs that build upon them—place greater emphasis and onus on deep savings from system-level measures like daylighting and lighting controls. DOE will emphasize integration between Radiance and EnergyPlus—as opposed to duplication of replicating Radiance's detailed lighting calculations within EnergyPlus—and support of Radiance within the OpenStudio platform to both facilitate single-model energy and lighting analysis and to encapsulate EnergyPlus-Radiance interaction.

The Sub-Program will capitalize on its open-source code base investments by accelerating recruitment of voluntary open-source code contributions from firms, educational organizations, and individual users of EnergyPlus and OpenStudio to enrich the software distributions with new functionalities and capabilities of general user interest.

Strategy 3: Expand partnerships with commercial software vendors to create end-user applications that use energy modeling.

The Sub-Program will continue to recruit both public and private partners to develop end-user applications on top of EnergyPlus, Radiance, and the OpenStudio platform. Existing partners include state organizations like the CEC, utilities like Xcel Energy National Grid, and Bonneville Power, large companies like Trane and Autodesk, and small ones like Concept3D and Sefaira. The Sub-Program will continue supporting these partners and will attempt to recruit new partners to serve new markets and constituencies and to provide new products and services. The Sub-Program is working with three Small Business Innovation Research awardees to develop tools and services that enhance EnergyPlus and OpenStudio.

Success Story: Xcel Energy's Energy Design Assistance Program Tracker (EDAPT)

Many utilities operate energy design assistance (EDA) programs that fund energy modeling services for new construction projects with the goal of limiting new demand. Xcel Energy, a utility operating in eight Midwestern states, was facing financial problems with its Colorado EDA program.

Recent code changes made achieving beyond-code savings more costly, while energy-savings regulatory requirements mandated expanding the program to include smaller buildings for which energy modeling is typically less cost-effective. Working with NREL, Xcel Energy developed an EDA Program Tracker (EDAPT) tool using OpenStudio to automate the design review and administration process. Xcel certified eight new consulting firms to work in its EDA program, with OpenStudio giving these firms access to EnergyPlus—an engine capable of modeling advanced energy-efficiency measures—and a way of automating the application of those measures.

Launched in July 2013, EDAPT saved Xcel $500,000 in program administration costs and allowed its EDA program to turn those savings into additional projects that helped Xcel meet its goals. DOE is working with Xcel to open up EDAPT to other utilities.

Source: "Welcome to EDAPT." National Renewable Energy Laboratory. Accessed August 28, 2014: http://www.eda-pt.org/.

Strategy 4: Develop and expand partnerships with professional and educational organizations to improve the level of service and support available to energy modelers and the state of common energy modeling practice.

The Sub-Program also will work on developing and expanding partnerships with professional and educational organizations as well as private interests to standardize and codify minimum and best practices for energy modeling. It will also help to develop and share educational and support materials for energy modeling, and to establish training and tool support infrastructure for energy modeling professionals.

Table 10. Building energy modeling metrics and targets for 2020

Metrics and Targets: Building Energy Modeling			
Activity	**Project Area**	**Metric**	**2020**
Accuracy characterization	*ASHRAE140* *FLEXlab*	Measured reference data sets	20
World-class open-source modeling software	*EnergyPlus* *OpenStudio*	Commercial gsf designed beyond AIA 2030 Commitment	200%
Vendor partnerships	*EnergyPlus* *OpenStudio*	3rd-party products	12

3.0 Residential Buildings Integration

The U.S. residential housing market is comprised of more than 114 million households[80] and represents more than 223 billion square feet of floor space.[81] In 2014, approximately 1 million new residential housing units were built.[82] Existing residential buildings account for approximately 21% of total U.S. energy consumption, with the average annual household energy bill amounting to approximately $2,000, or about 3% of annual household income.[83] Residential energy use and energy bills use can be reduced through a variety of existing and emerging energy-efficient technologies and installation techniques while enhancing the comfort and services they provide to building occupants. The greatest opportunity for reducing residential energy consumption is in heating, cooling, and water heating, as these end uses contribute almost 50% of residential energy consumption and offer more cost-effective energy savings than all other end uses combined.[81]

The Residential Buildings Integration (RBI) Program's mission is to accelerate energy performance improvements in existing and new residential buildings using an integrated building systems approach to achieve peak energy performance.

The RBI Program accelerates energy performance improvements in existing and new homes by integrating energy-efficient technologies and practices to optimize energy performance in homes; providing data, design, and decision support tools; and partnering with building professionals, energy service providers, and other stakeholders on a national scale. The Program addresses technology integration and installation issues that can affect total home performance, including energy efficiency, especially issues related to water heating and heating and cooling loads, durability, comfort, and indoor air quality and moisture control, and ultimately prepares homes for renewable energy options.

By proving the viability and energy saving capabilities of energy saving technologies, techniques, and systems, RBI helps to accelerate their use across all housing types and diverse climates, and to move U.S. homes toward higher efficiency industry standards and building energy codes. RBI enables stakeholders to make informed decisions and reduce their risk in the implementation of energy saving solutions. Engaging with industry such as building professionals, manufacturers, educators, utilities, state and local energy offices, and non-governmental organizations to promote tools and successful approaches for constructing high-performing new homes and upgrading

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[83] U.S. Energy Information Administration, "Lower residential energy use reduces home energy expenditures as share of household income." *Today in Energy*. Washington, DC: U.S. Department of Energy, 2013. Accessed Aug 2014: http://www.eia.gov/todayinenergy/detail.cfm?id=10891#
U.S. Bureau of Labor Statistics, Consumer Expenditure Survey, 2012.

homes also helps to increase market adoption and the resulting benefits such as energy and cost savings.

> ***Focus Areas for Residential Energy Efficiency Markets***
>
> ***New Homes Design***
> *Work with building designers and builders to:*
> - *Demonstrate and validate new, integrated design options to create homes that are ready for renewable energy systems*
> - *Prove and document viable new construction technologies and practices and energy savings in a variety of homes and climate zones*
> - *Increase partnerships to scale more energy efficient newly constructed homes*
>
> ***Existing Building Upgrades***
> *Work with general and trade contractors, utilities, non-governmental organizations, states and local governments to:*
> - *Demonstrate and validate integrated energy efficiency technologies and practices across a variety of climate zones.*
> - *Prove and document successful business models for energy service providers to increase homeowner investment in energy efficiency upgrades*
> - *Develop and promote widely recognized tools and resources help homeowners understand the value of energy efficiency*

RBI collaborates with the Emerging Technologies (ET) Program to demonstrate recently commercialized technologies and address technology integration challenges. RBI works with the Building Energy Codes (BEC) Program to address issues that may impede the adoption of more rigorous model energy codes. The Program also collaborates with the Appliance and Equipment Standards Program to increase market exposure of innovative, high-performing technologies and advance energy conservation standards. RBI and the Commercial Buildings Integration (CBI) Programs share lessons learned, resources such as standardized databases and measurement and valuation methods, and strategies to reduce market barriers.

RBI engages with other federal programs to reduce residential energy use on a national scale. Within the Office of Energy Efficiency and Renewable Energy (EERE), RBI collaborates closely with the Weatherization Assistance Program, which addresses buildings in the low-income residential sector, to share best practices and to support the creation of workforce guidelines. Outside of the Department of Energy (DOE), RBI collaborates with the Environmental Protection Agency (EPA) on ENERGY STAR®[84] new and existing home programs, and with the Department of Housing and Urban Development to promote financing opportunities, such as the FHA PowerSaver loan program,[85] to increase energy efficiency in residential buildings.

Residential Buildings Integration Market Overview

Residential Housing Market and Energy Use: Residential buildings in the United States consume more than 20 quads of primary energy annually.[86] Of the more than 114 million homes in 2012, about 80 million are single-family households; 28 million are multi-family households; and 6

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[84] See https://www.energystar.gov/ for more information on ENERGY STAR.
[85] See http://energy.gov/savings/fha-powersaver-loan-program for more information on the FHA PowerSaver loan program.
[86] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

million are mobile homes. Single-family homes represent over 80% of the residential building floor area[87] and are projected to continue to remain the dominant type of residential building.[86] The average home consumes more than 176 million Btu. Energy use varies based on such factors as building structure, vintage, and climate.[88] According to the U.S. Energy Information Administration's (EIA's) *Annual Energy Outlook 2014*, delivered energy use is expected to increase by 5% due to the increasing number of residential homes during that period, but the energy intensity of residential buildings or the annual energy use per household is predicted to decline by 16% between 2012 and 2040 due to increased efficiencies in lighting, space heating, and water heating.

For decades, space heating and cooling accounted for the majority of residential energy use and almost 60% of residential energy use in 1993.[89] However, recent estimates from the EIA Residential Energy Consumption Survey show that less than 40% of consumption is now attributed to space heating and cooling.[90] In contrast, energy use for appliances, electronics and lighting has risen, up from 24% in 1993[89] to almost 35% in 2009. Energy use for home appliances, electronics, and lighting now make up almost half of total consumption.[90] Factors contributing to this shift include the use of more electronic devices, lighting fixtures, and appliances in homes, and the increased adoption of more efficient space heating and cooling equipment and building envelope components.

New homes built in the 2000s accounted for about 14% of all occupied housing units in 2009. These new homes used 21% less energy for space heating on average than older homes. This is due to advancements in building technologies, including increased efficiency of heating and cooling equipment and better windows and envelopes built to more stringent energy codes. However, newer homes used about 18% more energy on average than older homes for appliances, electronics and lighting, due to increased use of dishwashers, clothes washers, clothes dryers. New homes are also more likely to have two or more refrigerators / freezers, and more computers, TVs, and TV peripherals such as digital video recorders and video game systems. [91]

New home construction offers opportunities for optimal building design and technologies with significant potential to influence energy use and optimize the operations of the building by the

[87] U.S. Energy Information Administration. "2009 RECS Survey Data." *Residential Energy Consumption Survey*. Washington, DC: U.S. Department of Energy, 2012. Accessed July 18, 2014: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics

[88] U.S. Energy Information Administration. "RECS data show decreased energy consumption per household." *Analysis and Projections*. Washington, DC: U.S. Department of Energy, 2013. Accessed Aug 14, 2014: http://www.eia.gov/consumption/residential/reports/2009/consumption-down.cfm?src=%E2%80%B9%20Consumption%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-b5#fig-1.

[89] U.S. Energy Information Administration. "1993 RECS Survey Data." *Residential Energy Consumption Survey*. Washington, DC: U.S. Department of Energy, 1993. Accessed July 18, 2014: http://www.eia.gov/consumption/residential/data/1993/

[90] U.S. Energy Information Administration. "2009 RECS Survey Data." *Residential Energy Consumption Survey*. Washington, DC: U.S. Department of Energy, 2012. Accessed July 18, 2014: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=characteristics

[91] U.S. Energy Information Administration. "Newer U.S. homes are 30% larger but consume about as much energy as older homes." *Today in Energy*. Washington, DC: U.S. Department of Energy, 2013. Accessed July 18, 2014: http://www.eia.gov/todayinenergy/detail.cfm?id=9951&src=%E2%80%B9%20Consumption%20%20%20%20%20Residential%20Energy%20Consumption%20Survey%20(RECS)-b3#.

homeowner. Reducing energy use in existing homes requires that homeowners invest in energy-efficient appliance and equipment upgrades. The recent rise in home sales volume, prices, and improvement investments demonstrate a return of consumer confidence that is expected to continue to strengthen the residential home industry in the coming years. [92]

Market Barriers: The key barriers to development of advanced residential energy systems include the large number and fragmented nature of market players, and the lack of information available to consumers and builders. Additional barriers to market acceptance are perceptions about incremental costs and reliability of new or advanced technologies, and the large number of technical performance requirements that must be met before building professionals will implement solutions on a production basis.

The value of energy efficiency in residential buildings is not completely recognized or understood by many stakeholders in the marketplace and is not often prioritized by consumers. This lack of awareness hinders the growth of the residential energy efficiency market. There is also a general lack of information regarding proven reliability of energy and cost savings, particularly related to projects with long payback periods. For example, construction of high-performance homes or implementation of energy efficiency upgrades that require a large upfront investment can appear risky due to uncertainty of life cycle payback. The lack of information on expected savings or a common standard for measuring and verifying energy and cost savings, estimating financial risk, and tracking performance of efficiency projects makes it difficult to convince consumers to prioritize these types of investments. In addition, consumers often do not have the proper understanding of home energy performance or enough information on potential solutions to effectively address high utility bills. Lastly, homeowners do not easily make the connection between energy efficiency and comfort. In many cases, comfort problems within a home are attributable to poor efficiency performance.

Building professionals may also lack knowledge of how to profitably deliver cost-effective, whole-home energy efficiency services for new or existing homes. Further, the market lacks the framework to identify knowledgeable home energy performance contractors to install the improved equipment. Standardization of workforce training and credentialing focused on energy efficiency in buildings is only beginning, and the complex and siloed nature of the trades involved in the buildings workforce hinders a recognizable or unified marketplace of residential energy efficiency professionals. This leads to consumer uncertainty and makes it difficult for builders or contractors to differentiate their business based on building science expertise.

The RBI Program addresses these market barriers by providing reliable information on building science and promoting energy efficiency in home improvements and building design to reduce overall building energy consumption, improve comfort, and reduce costs.

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[92] "Emerging Trends in Real Estate 2013," Census Bureau Construction Spending Data and PWC; National Association of Realtors February 2013 Commercial Real Estate Survey and PWC; Census Bureau 2012 Statistical Abstract.

Residential Buildings Integration Program History

DOE launched the Building America program in the early 1990s to fill the critical research and development (R&D) gaps in the new home construction industry and help reduce energy use in residential buildings. DOE initially piloted a project with a housing products unit at General Electric (GE) that was tasked to market its engineering plastics for home construction applications. The pilot ultimately led DOE to formalize grants to help introduce systems engineering concepts into the home building industry as a way to integrate high-performance technologies in construction. This program was the seed to RBI's now keystone program, Building America.

During the first 10 years of the Building America effort, DOE competitively funded building science teams to develop, demonstrate, and prove the business case for whole-house, integrated building innovations and to transfer knowledge to the building industry and to universities. These innovations are based on building science or the interdisciplinary study of building physics (e.g., heat, air, and moisture transfer) and the interaction between the various building construction materials, assemblies, and technology sub-systems that make up the whole-building system. Early innovations and guidance in the 1990s and 2000s enabled hundreds of homebuilders to voluntarily adopt advanced new technologies and building science best practices, including whole-house technology upgrade and design packages by climate and innovations related to thermal enclosures; heating, ventilation, and air conditioning (HVAC) components; ventilation; and health and safety.[93] During this time, Building America also worked with the EPA's ENERGY STAR New Homes program to accelerate adoption of the innovations in new home construction and provide infrastructure development for use with the early Home Energy Rating System (HERS) to verify performance.

> ***Advancing Residential Building Energy Codes through Building America***
>
> *Building America's field demonstrations have helped to advance building energy codes, for example:*
>
> - *Climate-specific guidance on cost-effectively building to above model energy code insulation levels supported an increase in insulation levels in International Energy Conservation Code (IECC) 2009.*
> - *Demonstrating vapor barrier techniques that reduced the risk of moisture failures due to higher insulation levels allowed Building America to provide climate-specific guidance on vapor control for IECC and International Residential Code (IRC).*
> - *Techniques and specifications for eliminating thermal bypass helped to inform ASHRAE Standard 62.2 ventilation and air-tightness requirement proposals and led to increased air-tightness requirements in IECC 2012/2015.*
> - *Field data and best practices related to exterior insulation overcame IRC structural and fire code issues associated with added insulation and enabled more insulation in IECC 2012/2015.*

Since then, the Building America program has evolved through several generations of building science teams, industry partners, and program strategies, which now includes a focus on both new and existing homes. By considering system interactions in the home. Building America and ENERGY

[93] See http://energy.gov/eere/buildings/building-america-top-innovations for more information on Building America Top Innovations from 1995 to the present.

STAR results were instrumental in increasing the stringency of model building energy codes. Since 1994, the rigor of the national building energy code has increased by more than 40% by incorporating innovations validated through Building America.

In 2008, RBI created the Builders Challenge, which recognizes builders who construct new homes beyond the ENERGY STAR requirements to 30% or more efficient than the 2006 International Energy Conservation code (IECC) model code. The Builders Challenge led to the construction of more than 14,000 energy-efficient homes and millions of dollars in energy savings. In 2014, this effort evolved into the DOE Zero Energy Ready Home, which requires that homes are durable, healthy, ready for renewable energy systems, and are 40%–50% percent more energy-efficient than a typical new home.

RBI launched the Home Performance with ENERGY STAR (HPwES) effort to improve energy performance of existing homes using a whole-house approach in the early 2000s. In this effort, RBI partners with energy efficiency programs run by utilities and state and local energy offices and provides specifications and practices. In the late 2000s, RBI further increased its focus on existing homes. For example, Building America's efforts shifted to also addressing issues specific to integrating energy-efficient technologies and practices as part of home improvements. In 2009, RBI initiated the Better Buildings Neighborhood Program (BBNP), which helped state and local governments to improve energy efficiency in existing buildings through innovative energy efficiency programs, grants, rebates, tax credits, and loans for homeowners and building professionals. The HPwES as well as BBNP efforts have helped to improve the energy efficiency of more than 400,000 homes by more than an estimated 25% per home, on average.[94,95]

American Recovery and Reinvestment Act: Response to an Economic Crisis

The American Recovery and Reinvestment Act (ARRA) provided more than $500 million in grants funds to create the RBI BBNP. Through Energy Efficiency and Conservation Block Grants and State Energy Programs, these funds helped 41 state and local government and non-government organization (NGO) recipients to improve energy efficiency in existing buildings through innovative energy efficiency programs, grants, rebates, tax credits, and loans for homeowners and building professionals. These efforts expanded the workforce to implement these improvement projects. BBNP led to improvements in more than 100,000 residential and commercial buildings, with homes averaging energy savings of 22%–26%. These activities also resulted in more than $770 million leveraged in funds that drove energy efficiency upgrades. An online Better Buildings solution center provides access to all lessons learned, case studies, data, and documentation collected.

[94] ENERGY STAR. "Home Performance with ENERGY STAR." Washington, D.C.: Environmental Protection Agency, U.S. Department of Energy, 2015. Accessed September 10, 2015: https://www.energystar.gov/index.cfm?c=home_improvement.hpwes_for_homeowners

[95] Research Into Action, Inc., Evergreen Economics, Nexant, Inc., NMR Group, Inc. *Savings and Economic Impacts of the Better Buildings Neighborhood Program Final Evaluation Volume 2.* Portland, OR: Research Into Action, 2015. Accessed September 10, 2015: http://energy.gov/sites/prod/files/2015/08/f26/bbnp_volume_2_savings_and_economic_impacts_072215.pdf

Opportunities for Future Savings: The more than 100 million existing homes across the country offer a significant opportunity for reducing building energy consumption, and the capability to construct highly efficient or zero energy ready new homes today offers the opportunity to reduce energy use from the outset. New housing construction reached a low in 2009 but has been rebounding since then, offering significant opportunity to increase the number of highly energy-efficient designed homes. By 2013, the number of new housing starts increased by an estimated 65% compared to the number in 2009.[96,97] EIA forecasts that new housing starts will continue to increase at a rate of 2.5 per year,[96]and by 2030, homes built after 2015 are expected to represent 25% of total residential floor area,[98] representing a major opportunity for savings in the residential sector. In the existing homes market, DOE estimates that if just one of every 10 U.S. homes cut its energy use by 25%, Americans could save a total of more than $5 billion per year on their energy bills and eliminate greenhouse gas (GHG) emissions equivalent to taking 225 million cars off the road.[99]

Residential Buildings Integration Program Impact

If the energy performance of today's existing residential buildings was improved by 25%, the estimated savings would be:

- *5 quads of total annual energy*
- *$60 billion in consumer costs*
- *278 million metric tons of carbon dioxide emissions, assuming current mix of generating power stations.*

Sources: U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014; Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

Energy improvements in a wide variety of building components, systems, and appliances can benefit both new and existing homes. Despite the recent and sustained declines in energy use intensity for heating and cooling and water heating loads, these three end uses still represent the best and most substantial opportunity for future savings in homes. These end uses currently account for almost half of residential total energy use today and are projected to account for 70% of the total energy savings available in the residential sector in 2030. Typical upgrades that address these end uses and provide the most benefit include insulation, ventilation, heating and cooling systems, windows, water heating systems and more wholly integrated buildings systems. EIA forecasts that overall residential energy intensity will decrease; RBI is working to accelerate this decline in residential energy intensity by focusing on end uses with the greatest potential for energy savings.

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96 U.S. Energy Information Administration. Annual Energy Outlook 2014 with projections to 2040. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

97 U.S. Energy Information Administration. Annual Energy Outlook 2012 with projections to 2035. DOE/EIA-0383(2012). Washington, DC: U.S. Department of Energy, June 2012. Accessed September 11, 2015: http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf

98 U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

99 "About Residential." (2014). U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Accessed: July 18, 2014: http://energy.gov/eere/buildings/about-residential.

Residential Buildings Integration Goals

The RBI Program's goal is to reduce, by 2025, the energy used for space conditioning and water heating in single-family homes by 40% from 2010 levels. RBI's focus on space conditioning and water heating offers the best opportunities for influencing residential energy use. This market outcome goal is comprised of two 2025 goals for the existing and new homes market:

- A 35% energy use intensity reduction in the heating, cooling, and water heating end uses in **existing** single-family homes.
- Cost-effective design and construction of **new** single-family homes that will consume 50% less energy per square foot for heating, cooling, and water heating relative to typical homes in 2010.

In 2010, the energy use intensity for heating and cooling and water heating in the residential sector was 59 kBtu per square foot. RBI's interim market outcome target is 35 kBtu per square foot, a nearly 20% reduction in total residential energy use intensity. Said another way, the achievement of this RBI goal accounts for nearly half of the overall BTO goal of a 40% reduction in energy use intensity (EUI) for the residential sector by 2030. BTO's 2030 residential sector goal will be achieved by further reductions to heating, cooling, and water heating loads, as well as reductions in lighting, appliances, and other end uses.

Five program performance goals will enable RBI to affect the market for energy-efficient heating, cooling, and water heating equipment and create the transformation necessary to achieve the 2025 goal. The resulting outcomes along with the work of BTO's other Programs and RBI's partners will put the residential sector on a path to achieving the 40% reduction in EUI by 2030, as illustrated in Figure 28.

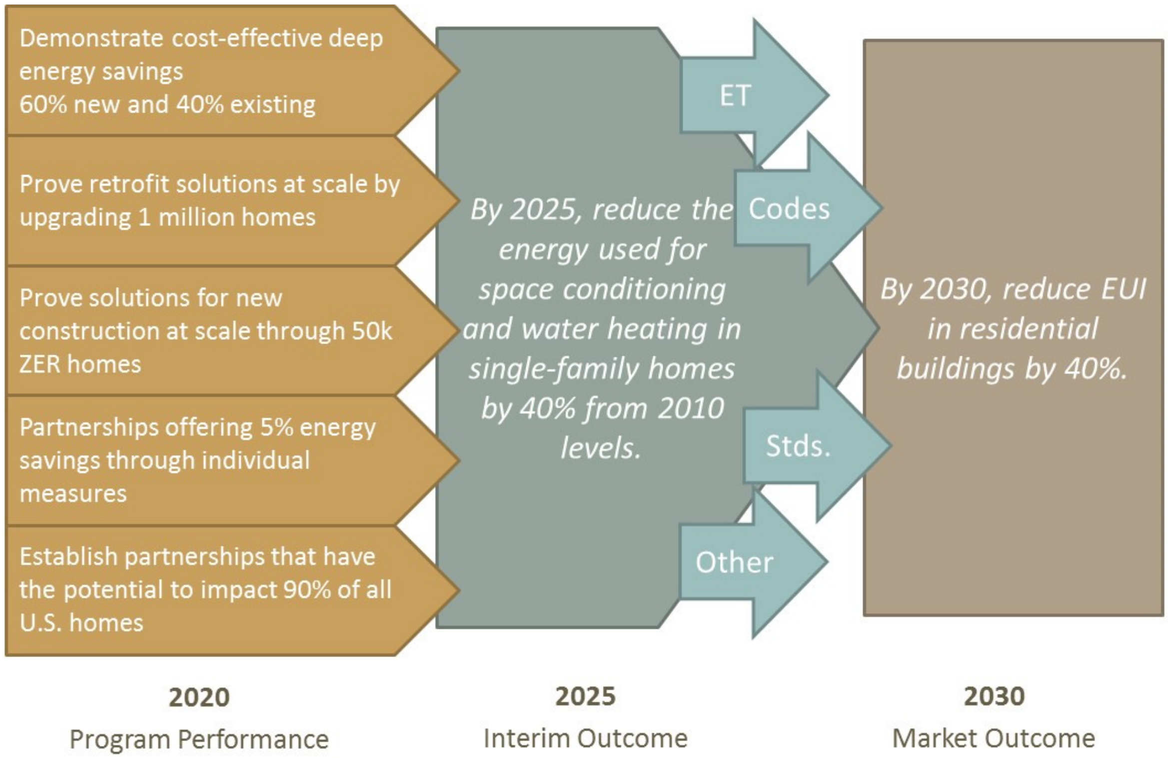

Figure 28. Residential Buildings Integration Program's goals hierarchy

In more detail, the RBI Program's performance goals are:

1. **Demonstrating and Integrating Technologies**: By 2020, develop and demonstrate cost-effective bundles of technologies and practices in each of the seven climate zones that can reduce the energy use intensity of new single-family homes by at least 60% and existing single-family homes by at least 40%, relative to the average homes in each of the seven climate zones in 2010 with a focus on reducing heating, cooling, and water heating loads. Additionally, by 2020, demonstrate performance of individual technologies and solutions that provide at least 10% energy savings (relative to 2010 levels).
2. **Proving Whole-House Solutions at Scale for Existing Homes**: Prove to homeowners and energy efficiency programs that it is possible to cost-effectively reduce the average energy use intensity of homes by at least 25% by 2020 by enabling upgrades of at least 1 million single-family homes with a focus on heating, cooling and water heating loads.
3. **Proving Whole-House Solutions at Scale for New Homes**: Prove to the building industry and market leading programs (e.g., ENERGY STAR for new homes, Leadership in Energy & Environmental Design [LEED]) across all climate zones that it is possible to cost-effectively reduce the average energy use intensity of new homes by at least 40% by 2020, relative to the average EUI of new homes in 2010 (103 kBtu per square foot) with no decline in performance. One indicator of success is certifying at least 50,000 single-family homes under Zero Energy Ready Home specifications across every climate zone.

4. **Establishing Market Partnerships to Deploy Individual Measures**: Establish targeted partnerships with states, utilities, manufacturers, retailers, distributors, and installers, serving at least 50% of U.S. households across all climate zones to overcome current market barriers and expand the purchase of high-efficiency technologies and services capable of cost-effectively reducing the EUI of existing homes by at least 5% by 2020 (from 2010 levels).
5. **Sharing Solutions through Market Partnerships:** Partner with a variety of energy efficiency programs and other market actors that have the ability to reach at least 90% of single-family homes by 2020, and establish strong working relationships with partners covering at least 50% of single-family homes by 2020.

The RBI Program will track progress toward these performance goals by regularly collecting information from the various activities the Program implements. Each program performance goal has a unique set of metrics which are identified below.

Residential Buildings Integration Strategies, Current and Planned Activities, and Key Targets

RBI's strategies, outlined below, are designed to increase market adoption of advanced energy-efficient technologies and practices in both existing and newly constructed homes and to gain enough market penetration to become incorporated in new building energy codes and industry standards. These strategies address the technical and market barriers faced by a wide array of stakeholders in the fragmented residential market, and to motivate homeowners and builders to invest in more energy-efficient homes. The activities focus on increasing the number of constructed homes that are highly efficient and ready for renewable energy systems, and spurring significant improvements in the energy efficiency of existing homes across various housing types and climates.

Strategies for New and Existing Home Markets

- *Demonstrate and integrate cost-effective, energy-efficient technologies and practices in representative homes, which significantly reduce EUI and optimize home performance.*
- *Prove energy savings solutions in new and existing buildings with market partners that can greatly reduce EUI of homes through demonstrating the market viability of energy efficiency and service models that stakeholders can use to engage customers.*
- *Accelerate market wide adoption of energy saving solutions and the resulting benefits by addressing market barriers and expanding a skilled workforce to successfully increase energy efficiency in homes.*

Figure 29 illustrates RBI's strategic pathway, which is intended to follow market diffusion processes. First, new technologies and solutions focused on heating and cooling are demonstrated in a small number of representative homes across climate regions. Although highly energy-efficient equipment may be available on the market, building professionals who install the measures may have little experience with the installation and integration of the technologies. This lack of experience can often lead to less-than-optimal performance of the technologies when installed in a home. As a result, building professionals are often reluctant to install a more efficient technology and instead choose to install more conventional, less efficient options. By integrating energy saving technologies and practices, RBI identifies potential problems and documents solutions for building professionals. Once a solution has been sufficiently demonstrated, market priming activities can increase adoption. Working with market partners, RBI implements activities to demonstrate that energy efficiency solutions and service models are replicable and that solutions exist for every major climate zone. By working with a geographically diverse set of partners, RBI ensures that the vast majority of Americans have access to cost-effective energy efficiency solutions and programs. Ultimately, RBI can leverage these market partners to further embed energy efficiency in standard practice.

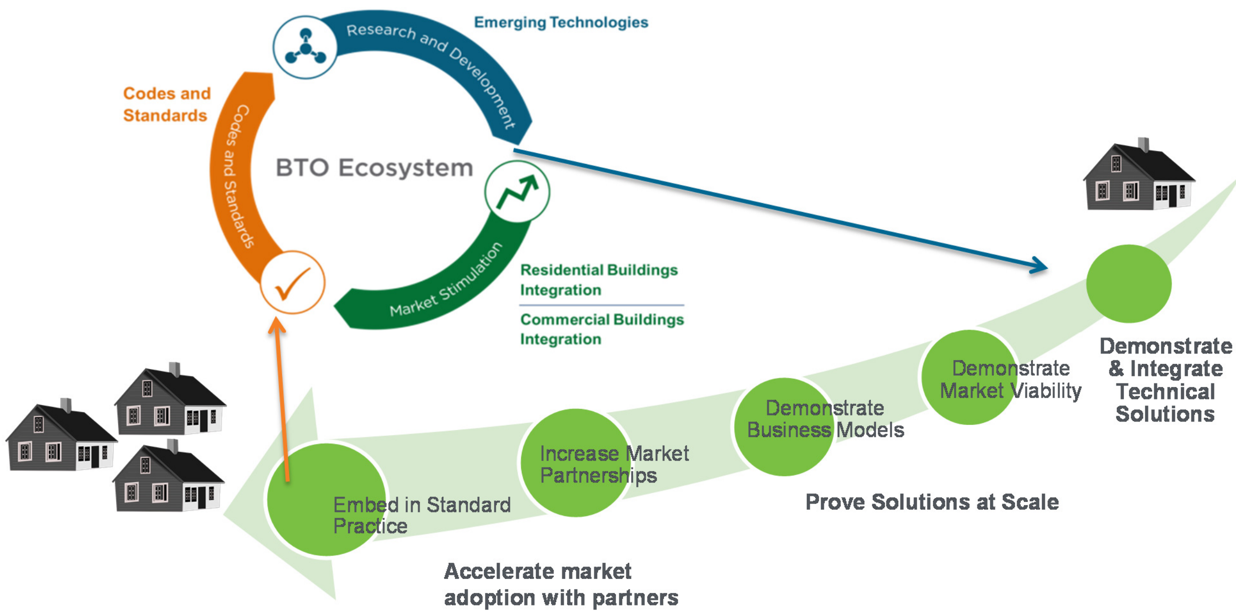

Figure 29. Summary of RBI strategies to accelerate energy saving solutions from demonstrations in individual home types and climates to standard practice in the housing market

Figure 30 shows a summary of the three strategies and the primary activities, some of which were mentioned in the Program History section, that serve as platforms to implement multiple projects. Each strategy area includes multiple activities that directly support RBI's performance goals, but these activities also can indirectly support other strategy areas. For example, Building America is focused on demonstrating advanced technologies and building systems and overcoming integration issues that can impact whole-building performance. (See RBI Strategy 1.) Building America projects also provide technical support to the Zero Energy Ready Home activity and the Building America Solution Center by creating curricula content for training the skilled workforce needed to implement energy saving solutions at scale. (See RBI Strategies 2 and 3.)

RBI Primary Activities		Home Type	Demo & Integrate Technical Solutions	Prove Solutions at Scale	Accelerate Market Adoption with Partners
Building America	Validate & demonstrate new technologies & practices to builders and contractors Solutions in real homes.	New and Existing	X	O	O
Building America Solution Center	Provides technical solutions to contractors and builders on a web-based platform	New and Existing	O	X	O
Better Buildings Solution Center	Better Buildings Solution Center provide resources for energy efficiency service providers	Existing		X	O
Home Energy Score	HEScore compares the energy efficiency of one home to another	Existing		X	
Zero Energy Ready Homes	Promote zero energy homes using technologies from Building America	New	O	X	O
Home Perf. with ENERGY STAR	Whole house retrofit program with over 51 sponsors nationally	Existing		X	O
Staged Upgrade Initiative	Effort to encourage incremental energy efficiency improvements	Existing		O	X
Better Building Network	National network of over 200 organizations to discuss innovations and programs	Existing		O	X
Building Science Education Task Force	National effort led by DOE to develop curriculum for tech schools and colleges on energy efficiency	New and Existing	O		X
Race to Zero Competition	Competition to seed the future energy efficiency workforce by inspiring innovation in students	New and Existing	O		X

Figure 30. Summary of RBI's primary activities and the supported strategies (X signifies direct support and O indirect support)

RBI's current and planned activities are described below for each strategy and for the new and existing home markets. Key targets or success indicators toward reaching RBI's performance goals are outlined for each strategy.

Strategy 1: Demonstrate and integrate cost-effective, energy-efficient technologies and practices in representative homes, which significantly reduce EUI and optimize home performance.

Demonstrating the performance of cost-effective, advanced energy-efficient technologies and practices and properly integrating them is essential to reducing market risk to home builders, contractors, and homeowners. Building America is the principal platform through which RBI proves energy saving solutions for both new and existing homes and addresses issues that affect indoor air quality and moisture control and the advancement of building energy codes. These activities produce innovative and integrated real-world solutions that enable significant energy and cost savings for a variety of housing types and climates.

Building America is composed of teams of building scientists and national laboratory researchers working collaboratively to validate the performance, reliability, cost-effectiveness, and marketability of energy-efficient technologies and systems for existing and newly constructed homes by demonstrating prototype technologies and systems, test houses, and community scale housing. DOE national laboratories provide technical assistance to the teams, with the National

Renewable Energy Laboratory (NREL) serving as the lead lab. Through Building America, RBI works with the building scientist teams to develop and bring innovations to the building industry, and with leading builders to demonstrate the value of those innovations in real-world environments. These demonstrations help builders and contractors to confidently try new technologies, systems, and installation techniques.

For the new homes market, Building America works to reduce the EUI of single-family homes by addressing specific technical and integration challenges that can impede construction of high-performance homes and the advancement of more efficient building energy codes. Projects currently underway focus on cost-effective, high-performance envelopes that work in all climates; solutions for homes with a high latent load (high moisture) to prevent material degradation and mold growth and enable an environment that is comfortable and healthy; and efficient, safe ventilation and indoor air quality solutions that decrease air leakage into and out of homes. From BTO's ET Program, RBI is currently demonstrating cold climate heat pumps and integrated heat pumps.

To reduce total EUI in existing single-family homes, Building America focuses on the same technical issues faced in new home construction as well as issues specific to the home improvement industry. Building America addresses technical challenges that slow the adoption of high-performance envelopes and HVAC systems in home upgrades. Projects focus on identifying opportunities to easily implement individual energy-efficient technologies in typical home improvement transactions and the following home improvement sectors: building envelope (i.e., roofing, siding, window replacements, and foundation repairs) and mechanical systems (i.e., HVAC replacement and maintenance). See the Staged Upgrade section in RBI Strategy 3 for more detail. To further reduce risk to building professionals and to homeowners, Building America also works to improve or reduce costs of methods and technologies for assessing home performance during inspections or real-time operation.

Through Building America activities, RBI also helps to ensure quality work in new home construction and energy efficiency improvements by influencing the development of model specifications and best practices. There are layers of specifications for home systems, including specifications for individual components like ventilation fans, sub-systems like HVAC duct systems, whole-house performance such as the DOE Zero Energy Ready Home label; and also testing specifications like home air tightness testing (blower door), duct leakage testing (duct blaster) and combustion safety testing (Combustion Appliance Zone test). RBI collects and analyzes performance data and identifies improvements for higher efficiency to improve specifications. The best practices and improved specifications are then used in the EPA's ENERGY STAR New Homes program and activities outlined in RBI Strategy 2 (e.g., DOE Zero Energy Ready Homes, HPwES) to accelerate usage by the building industry. When enough stakeholders use the model specifications, RBI can promote incorporation of the specifications into industry standards and building energy codes. To do this, RBI collaborates with organizations like ASHRAE, the Residential Energy Services Network, and the Building Performance Institute.[100] The Program is also exploring ways to increase

[100] Through joint funding with EPA and HUD, DOE established the Buildings Performance Institute (BPI), to develop technical standards built on sound building science. BPI is approved by the American National Standards

the number of industry organizations that adopt the specifications and accelerate the introduction of new technologies into building energy codes.

Building America recently drafted three Technology-to-Market Roadmap strategy documents[101] that are primarily focused on solving three technical challenges in the next 5 years: high-performance, moisture-managed envelope systems; optimal comfort systems for low-load homes; and optimal ventilation systems and indoor air quality solutions for low-load homes. These documents, along with other prioritization processes, will serve as a guide for selecting future projects. In 2015, RBI selected four new building science teams and projects, and three to five new teams and projects are expected in 2016. These teams will carry out the demonstration and integration activities described above.

Table 11 shows the metrics and targets to reach RBI's performance goals for Strategy 1, which are associated with Building America's activities. To determine current status and annual milestones for each metric, Building America is currently conducting analyses related to the number of new and existing single-family demonstration homes built or upgraded that have reduced EUI by at least 60% for new construction or 40% for existing homes relative to 2010 baselines based on each of the seven climate zones. RBI will also assess the current status of and appropriate targets for individual technologies and solutions that provide at least 10% energy savings relative to the average EUI of a single-family home in 2010.

Institute as an accredited developer of American National standards and as a certifying body for personnel credentials.

[101] Feedback was solicited in early 2015 via a Request for Information (RFI), (DE-FOA-0001326), related to these draft technology-to-market roadmaps. The feedback will be used in part to help plan and develop future Building America FOAs. See http://energy.gov/eere/buildings/building-america-bringing-building-innovations-market for more information.

Table 11. Technology demonstration & integration, metrics, statuses and 2020 target

Metrics and Targets: RBI Technology Demonstration & Integration			
Activities contributing to the goal	**Metric**	**Status Relative to 2010***	**2020**
Building America	New single-family homes relative EUI reduction	Based on preliminary analysis, 5 demonstration homes across a variety of climate zones meet a 20-70% reduction relative to 2010.†	5 homes per climate zone (7) that meet a 60% reduction relative to climate specific 2010 baselines
	Existing single-family homes relative EUI reduction		5 homes per climate zone (7) that meet a 40% reduction relative to climate specific 2010 baselines
	Individual technologies and solutions for existing homes that provide 10% energy savings relative to a 2010 baseline	Analysis underway to determine the status and target	

** Analysis will be conducted with available data to begin tracking targets in terms of EUI reduction that meet the 60% and 40% savings improvement levels for new and existing homes. Building America has information for 40 demonstration homes, and expects to build 100 more demonstration homes by 2020.*
†This initial analysis examined less than 10% of Building America's total portfolio of projects.

Strategy 2: Prove energy savings solutions in new and existing buildings with market partners that can greatly reduce EUI of homes through demonstrating the market viability of energy efficiency and service models that stakeholders can use to engage customers.

For builders, building owners, and homeowners to improve the energy efficiency of their homes, they must have the confidence that energy saving improvements are viable, cost-effective, and add value. RBI addresses this need by providing informational resources and technical support that are tailored to the new and existing home markets and to specific audiences within those markets, including building professionals who design homes and install the technologies; utilities, state and local governments, and non-governmental organizations that manage energy efficiency programs; and homeowners who invest in energy efficiency upgrades. Utilities, for example, invested approximately $3.5 billion in 2014 on energy efficiency programs targeted at residential customers.[102] RBI assists utility programs by providing tools and resources that decrease the cost of energy efficiency programs and reduce the risks for homeowners and the building industry.

[102] Consortium for Energy Efficiency (2015). CEE Annual Industry Report—2014 State of the Efficiency Program Industry: Budgets, Expenditures, and Impacts. Boston, MA. http://library.cee1.org/sites/default/files/library/12193/CEE_2014_Annual_Industry_Report.pdf

Activities such as HPwES and Zero Energy Ready Home (ZER Home) demonstrate business models that help service providers and building professionals be more successful in their efforts to upgrade existing homes and construct highly efficient new homes that can easily be integrated with renewable energy systems.

Informational Resources: RBI develops and maintains a range of tools and resources that support the growing residential energy efficiency market and accelerate investment in energy-efficient homes. The Program provides access to reliable, consistent, and data-driven tools through industry networks; disseminates information on best practices and lessons learned; and promotes sharing of successful solutions and benchmarks. These informational resources ensure that stakeholders understand the value of high-performance homes and energy efficiency upgrades.

For the new homes market, RBI's web-based Building America Solution Center[103] provides building professionals with access to expert building science information on technical aspects associated with installation of highly energy-efficient technologies and state-of-the-art construction practices. These solutions are collected from Building America projects and demonstrations. The interactive solution center provides information on hundreds of topics related to building specifications, installation guidance, case studies and more, and also provides a forum for building professionals to add content based on their own successes and to share issues and get comments from peers and experts. In addition, the repository shares information with the building codes community.

For the existing homes market, RBI's Better Buildings Residential Solution Center[104] provides resources to utilities, state and local governments, and NGOs to assist their energy efficiency programs, including information on lessons learned, benchmarking data, and financing options. This interactive, web-based solution center makes these resources available in a living repository that provides information from the BBNP, [105] HPwES, and other activities related to energy efficiency programs operated across the country. The solution center includes case studies, templates for program administration, and topical webcasts and videos that are designed to help

Success with the Better Buildings Neighborhood Program (BBNP)

BBNP grants, initiated in 2009, provided the opportunity for 41 state and local government and NGO recipients to demonstrate sustainable program delivery approaches to increase comprehensive energy upgrades. Home upgrades completed under BBNP averaged 22%–26% in energy savings and occurred across the seven major climate zones and 43 states. The majority of the grant recipients continue to upgrade homes after the grant period and participate in the Better Buildings Residential Network. RBI utilizes the information and lessons learned gathered during BBNP in the Better Buildings Residential Solution Center and continues to engage these programs, providing them with access to tools, information and peer-to-peer sharing networks.

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[103] https://basc.pnnl.gov/

[104] http://energy.gov/rpsc

[105] BBNP was a three-year grant program that provided funds to 40 competitively selected state and local governments to develop sustainable energy-efficiency programs that test innovative program models, create jobs, leverage private- sector funds, and improve the efficiency of existing buildings. See the Program History section.

utilities, local governments and NGOs to more quickly adopt innovations, and to plan, implement, and evaluate their own programs.

RBI's Benchmarking Guide[106] provides information to assist program administrators in planning and creating data-driven progress targets and allows them to compare their operational metrics to national averages based on BBNP data. In coordination with the CBI Program, RBI will further standardize data collection efforts to increase availability and consistency of data related to building characteristics, estimated and actual energy savings, and specific packages of energy efficiency improvements.

Peer-to-Peer Networking: RBI also supports a national network of residential energy efficiency programs to improve their effectiveness and to reach a wider geographic area. The Program implements activities, such as the Better Buildings Residential Network (BBRN), to recruit and engage energy efficiency program partners. For example, BBRN convenes a group of energy efficiency program administrators and partners to share best practices and solutions to market barriers for existing homes. This network engages BBNP stakeholders, HPwES program sponsors, and other industry partners to learn from one another through meetings, conference calls, and webinars. BBRN partners are required to annually report energy upgrade data to inform program benchmarks and effective program delivery approaches and to help assess RBI impacts.

DOE and EPA also convene a working group of market actors as part of the State and Local Energy Efficiency Action Network (SEE Action) to provide support to state and local governments and energy efficiency program administrators interested in proven and demonstrated energy efficiency policies. RBI leads the Residential Retrofit Working Group, which is working on the Policymakers' Guide to Home Energy Upgrades. This guide will help state and local policy makers understand home energy upgrade policy options, considerations for design and implementation approaches, and frameworks for measuring progress.

In the new homes market, RBI partners primarily with builders and contractors to incorporate solutions demonstrated by Building America and Zero Energy Ready Home in home construction across climates and building types. These partnerships help builders and contractors to incorporate energy efficiency and home performance into their standard practices, leading to homes with superior indoor air quality, comfort, durability, and overall quality of construction. RBI formally recognizes partners that continually raise the bar for energy efficiency and seek their partners' feedback to ensure the Program is providing the necessary level of support and guidance.

Proving Successful Solutions: Through Zero Energy Ready Home, RBI targets the new homes market and partners with leading builders and contractors to drive the home building industry to design and construct homes to energy-efficient specifications that are far more energy-efficient than most homes on the market today. Building America teams work with Zero Energy Ready Home builder partners to apply recent innovations and technology integration solutions in actual homes.

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[106] The Benchmarking Guide can be found within the Better Buildings Residential Solution Center or here: https://bbnp.pnnl.gov/sites/default/files/publication/c-971_BBR%20Benchmarking%20Guide%204-27-15%20(FINAL)_508_0.pdf

To achieve the Zero Energy Ready Home label, builders must construct homes that meet rigorous technical specifications. This is done through one of two pathways. The prescriptive path requires a registered verifier to inspect the house and submit a compliance report that the home meets requirements, and the performance path requires a verifier to use approved rating tools to qualify that home against performance requirements. The homes must be durable, 40%–50% more energy-efficient than IECC 2006 model energy codes, and ready for installation of renewable energy systems. Zero Energy Ready Home builds on the long-standing ENERGY STAR New Homes label, which requires new homes to be 30% more efficient than the typical home. DOE recognizes the top Zero Energy Ready Home builders with its Housing Innovation Awards. Such recognition communicates the value of high-performance homes and spurs further wide scale adoption of innovative energy-efficient technologies and practices.

In the existing homes market, RBI works with organizations that implement energy efficiency programs across the country, challenging them to test and demonstrate successful and sustainable business approaches and meet a high bar for improving the energy efficiency of homes. This includes new approaches to increase the market for investment in energy efficiency, the quality of the home upgrades, and the effectiveness of energy efficiency program implementation.

RBI's HPwES activity proves and promotes energy saving solutions for existing homes. HPwES is a public-private partnership that is coordinated with the EPA's ENERGY STAR program and uses a comprehensive, whole-house approach to systematically improve a home's energy performance, reduce energy costs, enhance structural durability, and enable a healthier and more comfortable living environment. The whole-house approach considers the house as an energy system that has interdependent parts, each of which affects the performance of the entire system. Changes in any individual component of the home's energy system affect the performance of other parts and the whole home. For example, if a homeowner adds adequate insulation, a direct result is a reduction in the heating and cooling costs for the home, but an indirect impact is a reduction in the furnace size needed when a replacement is necessary.[107] A whole-house approach to improving energy efficiency typically involves an energy assessment by a professional that concludes with recommended and prioritized improvements and can result in total energy and cost savings of at least 20%. HPwES requires independent quality verification of the participating contractors' installation work, which provides homeowners with confidence to invest in improvements.

HPwES partners are utility, state, or local government-run energy efficiency programs that promote upgrades through a qualified workforce, approved analytical techniques, and outreach activities that provide incentives or information on financing. HPwES's 48 partners completed nearly 85,000 whole-house energy upgrades in the 12-month period ending June 30, 2014, up 12% from the previous year. RBI released a revised HPwES guide for partners that includes resources for more business-friendly program approaches, including flexibility on how home assessments are completed; workforce credentialing guidance; cost-cutting and performance-improving quality management systems; and program administration tools such as HPXML-compliant software.

[107] Weiner, C. (2013). The Whole House Approach to Energy Efficiency. Retrieved November 12, 2013 from http://www.ext.colostate.edu/pubs/consumer/10629.html

Table 12 and Table 13 show the performance metrics and annual targets associated with Strategy 2. This includes metrics for the existing home activities that target a 25% reduction in energy use intensity (HPwES, BBNP, and BBRN), and the new home activity, Zero Energy Ready Home, which supports a 40% EUI reduction per home. RBI currently collects the necessary information to track these targets and will require any future activities to also report this data.

Table 12. Proving solutions at scale in existing homes, metrics, statuses and annual targets

Metrics and Targets: RBI Proving Solutions at Scale in Existing Homes								
Activities contributing to the goal	**Metric**	**Status Relative to 2010**	**Annual Targets**					
			2015	**2016**	**2017**	**2018**	**2019**	**2020**
Home Performance with ENERGY STAR	Number of upgraded homes exhibiting 25% reduction in EUI	300,000	88,000	95,000	103,000	112,000	123,000	136,000
Better Buildings Residential Network		27,500	16,000	18,000	20,000	22,000	24,000	26,000

**Energy efficiency program partners upgraded approximately 105,000 homes through BBNP grants from 2010 to present. These homes are encompassed in RBI's overall progress toward targets. Many of these partners are now engaged as part of the Better Buildings Residential Network.*

Table 13. Proving solutions at scale in new homes, metrics, statuses, and annual targets

Metrics and Targets: RBI Proving Solutions at Scale in New Homes								
Activities contributing to the goal	**Metric**	**Status Relative to 2010**	**Annual Targets**					
			2015	**2016**	**2017**	**2018**	**2019**	**2020**
Zero Energy Ready Homes	Number of new homes built to Zero Energy Ready Home specs, exhibiting 40% reduction in EUI	8,000	1,200	2,500	5,000	8,000	12,000	25,000

Strategy 3: Accelerate market wide adoption of energy saving solutions and the resulting benefits by addressing market barriers and expanding a skilled workforce to successfully increase energy efficiency in homes.

RBI works with a wide variety of market partners across the United States to speed the adoption of energy-efficient technologies and practices in new and existing buildings. Increasing these partnerships and providing resources and forums for peer-to-peer sharing enables RBI to improve residential energy efficiency on a national scale.

Scaling Successful Solutions: RBI recently implemented a new activity focused on existing homes, known as the Staged Upgrade Initiative, through which the Program will partner with states, utilities, manufacturers, retailers, distributors and installers across the United States to increase the overall volume of energy-efficient technologies and services purchased and to address market-related barriers. Complementing the comprehensive whole-house approach encouraged through HPwES, the Staged Upgrade Initiative addresses small, more incremental market opportunities that increase energy efficiency without the significant first cost of a whole-house upgrade. This approach intends to capture energy efficiency through manageable action steps for homeowners at a higher volume and at key transactional moments such as replacement of heating and cooling equipment or during routine equipment maintenance, home purchase or remodel, or multiple improvement projects (e.g., windows, siding, roofing, and installation of solar panels). The Staged Upgrade Initiative will conduct analyses, national and regional forums, and other engagement activities to leverage the expertise of existing networks necessary to design and implement an effective and efficient program. RBI utilizes information from Building America to develop incremental upgrade packages and demonstrate them with market partners. In addition, the Program creates tools and resources to aid in implementation of the approach, such as through a field guide for contractors that will recommend measure packages and the optimal sequencing of measures. RBI will also leverage its other activities to inform single trade companies (e.g., an HVAC contractor) and the homeowner of what they can do to improve the performance of different home components and mechanical systems when the homeowner already intends to make an investment.

RBI is currently refining the work plan for these efforts and convening working groups to increase stakeholder involvement and feedback. The Program will conduct demonstrations of the delivery model in the market beginning in 2015 with current DOE partners, trade groups, and manufacturers, and will utilize the initial demonstration sites to refine the approach and enable implementation on a national scale. In 2016 and 2017, RBI will scale staged upgrade approaches nationally by engaging key stakeholders in the home improvement industry to incorporate energy-efficient technologies and installation practices more widely in target industries and markets. RBI will also leverage new technologies and solutions information from Building America and the ET Program to determine the staged upgrade approaches.

Data Exchange Tools: RBI also supports activities to help contractors and energy efficiency programs more easily communicate building energy performance data at a reduced cost. For example, RBI supported the development of a data transfer protocol for industry, informally known as Home Performance XML or HPXML, which facilitates communication and the consistent exchange of data between energy analysis software and project tracking systems used by building professionals and energy efficiency program administrators. HPXML helps stakeholders to aggregate empirical data on energy improvement projects and energy savings at the local, regional, and national levels. Many different software platforms are available on the market for tracking the results of home energy assessments and energy efficiency upgrades and for analyzing home energy performance, making it difficult for building professionals to report information and for energy efficiency program administrators to receive information. The common HPXML data transfer protocol helps to reduce the overhead costs of energy efficiency programs and contractor businesses by an estimated 20%.[108] RBI will create an HPXML implementation guide to help software vendors easily incorporate the data transfer protocol into analysis tools and to inform energy efficiency program administrators and building professionals how to utilize the protocol. RBI recently launched the Home Upgrade Program Accelerator to help home energy upgrade programs bring services to more homes by leveraging data management strategies such as HPXML that minimize program costs and improve effectiveness. In collaboration with stakeholders such as developers of program management and home energy assessment software, the 3-year accelerator will deploy HPXML in programs representing at least 25% of home upgrades nationally and will document time and cost reductions and other ways to streamline energy efficiency program administration and reduce costs.[109]

RBI is also launching the Home Energy Information Accelerator to facilitate the widespread use of reliable home energy information at all relevant points in real estate transactions, enabling fair value at sale for energy-efficient homes. This accelerator is a collaborative effort among national organizations; federal agencies; and regional, state, and local leaders in real estate and energy efficiency to expand availability and use of reliable home energy information in five pilot markets. The accelerator partners will demonstrate replicable models of automated, linked systems to make energy-related information easily available to home buyers and sellers through multiple listing services and reports, influencing home sales.

FHA PowerSaver Loans: Opportunities to Increase Homeowner Investment in Energy Efficiency

RBI provided FHA PowerSaver loan information to stakeholders to create partnerships between PowerSaver lenders, energy efficiency program administrators, and building contractors. PowerSaver offered loans, insured by the Federal Housing Administration, to homeowners for energy saving improvements and renewable energy additions to their homes. RBI recently completed an evaluation of these activities to determine the most effective approaches for increasing the number of loans made through such partnerships, which will help inform increasing investments in future energy efficiency financing programs.

RBI's Home Energy Score (HES) provides homeowners with a low-cost way to measure and understand the energy efficiency of their home. HES is a data-driven resource tool that measures a home's energy performance, similar to a vehicle's mile-per-gallon fuel consumption rating. The tool

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[108] BTO analysis

[109] See http://www1.eere.energy.gov/buildings/betterbuildings/accelerators/index.html for more information on Better Buildings Accelerators.

allows homeowners to compare the energy performance of their homes to other homes nationwide using a 10-point scale (10 being the most efficient) and also gives homeowners suggestions for improving their home's energy efficiency. RBI is currently working to increase awareness and usability of the tool. Through the use of an application programming interface (API), RBI also allows software vendors and programs to incorporate the HES interface on top of their own customized computer software packages that model home energy usage and suggest energy-efficient home improvements. To date, there are already five software packages that include HES through an API.

Building the Energy Efficient Buildings Workforce: Accelerating the adoption of energy efficiency technologies and practices in the buildings sector requires a knowledgeable and skilled workforce. RBI pursues a number of activities to address this need. The Program's Building America Building Science Education Task Force develops building science curriculum and core competency guidelines and facilitates the incorporation of building science into secondary and post-secondary education and degree programs. RBI is working to complete guidelines for key housing industry workforce classifications by 2016 and will work with building science organizations to utilize the guidelines. The Program is partnering with stakeholders to integrate these building science guidelines into high school physics text books and in architecture, engineering, and construction management degree curricula and licensing exams by 2020.

For the new homes market, RBI seeds the future energy efficiency workforce by inspiring innovation in students through home design and construction competitions. These collegiate competitions educate students in building science within a number of disciplines (e.g., architecture, engineering, business, and interior design). The Program recently launched the DOE Race to Zero Student Design Competition, which will take place biannually and engage students to design and build real homes that meet or exceed specifications of Zero Energy Ready Homes. RBI plans to engage 40 teams and 400 students in the competition by 2016, and 60 teams and 600 students in the future.

Table 14 shows the metrics and targets associated with Strategy 3. Increasing the number and geographic coverage of partners are indicators of RBI's success in having a national impact on accelerating adoption of energy saving solutions. All of RBI's major activities that involve partnerships contribute to these performance goals (e.g., BBRN, Building America, HES, HPwES, Zero Energy Ready Homes). Many other activities indirectly contribute to these goals by providing informational resources to support partnerships. RBI requests partners to report on the size of their service territory; this information will be compared to census records regarding the location of houses to track progress against the targets.

Table 14. Accelerate market adoption with partners in new and existing homes, metrics, statuses and annual targets

Metrics and Targets: RBI Accelerate Market Adoption with Partners				
Activities contributing to the goal	**Metric**	**Status**	**Targets**	
			2018	**2020**
Staged Upgrade Initiative	% of U.S. single-family households served by RBI's market partners that support installation of individual energy efficiency measures that can reduce EUI by at least 5%	Analysis currently underway	Analysis currently underway	50% across all climate zones
BBRN, Building America, Home Energy Score, HPwES, Zero Energy Ready Homes	% of U.S. single-family households served by energy efficiency programs	71%	80%	90%; 50% are partners that have relationships with RBI & participate in at least 2 RBI activities

4.0 Commercial Buildings Integration

The U.S. commercial buildings market is comprised of 87 billion square feet of floor space.[110] These are buildings of all sizes, ages, and construction, located in all climate zones, and used for a variety of purposes. Commercial buildings account for approximately 18% of total U.S. energy consumption, 35% of U.S. electricity consumption, and 18% of the nation's carbon dioxide emissions.[111] In 2013, the United States spent nearly $180 billion to provide energy services to these existing commercial buildings.[111] From 2008 to 2012, over 300,000 new buildings were constructed, comprising over 5.7 billion square feet.[112] There is immense potential to improve the energy efficiency of commercial buildings, which would allow their occupants and owners to spend more of their resources on other aspects of their business. Commercial buildings can be made much more energy efficient, which can also improve the resilience of our communities, create jobs, and build a stronger economy.

The Commercial Buildings Integration Program's mission is to accelerate voluntary adoption of significant energy performance improvements in existing and new commercial buildings.

The Commercial Buildings Integration (CBI) Program accelerates the adoption of energy saving technologies and solutions in commercial buildings by helping to overcome specific technical and market barriers. CBI's activities are targeted toward two market segments characterized as efficiency leaders and early adopters on the curve illustrated in Figure 31, or henceforth as market leaders. The market leaders represent the segment of the market with the most energy-efficient buildings, and are the most willing to push the boundary of energy efficiency. Their actions pave the way for those stakeholders further down the technology diffusion curve to adopt energy saving technologies. CBI's strategies are intended to engage market leaders to demonstrate that significant building energy use reductions are possible and cost-effective. The Program works to disseminate and enable the replication of best practices by market leaders to drive the adoption of energy efficiency solutions on a larger scale. CBI also develops tools and resources that help building owners monetize the value of their energy saving investments.

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[110] U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed June 25, 2014: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm .

[111] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[112] "U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed September 23, 2014: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm?src=Consumption-b1.

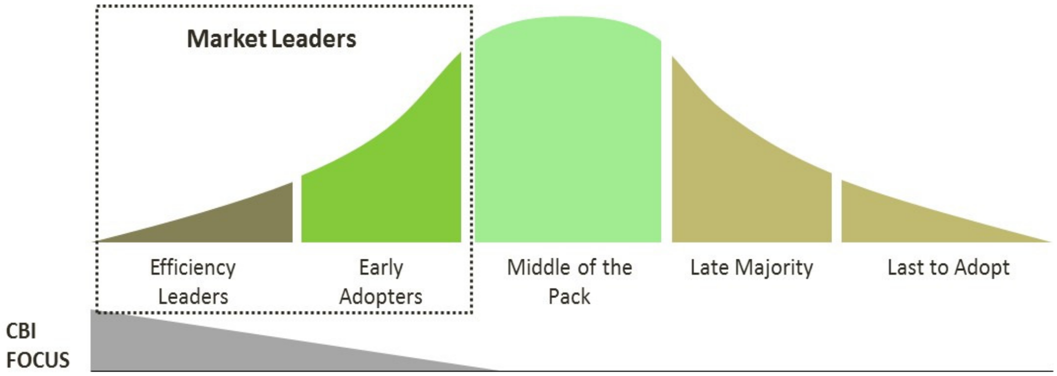

Figure 31. CBI's diffusion of innovation (based on Rogers, 1983)

> ***Focus Areas for Commercial Energy Efficiency Markets***
>
> ***New Buildings Design***
>
> *Work with building designers, architects, building owners and builders to:*
>
> - *Demonstrate and validate new, highly energy efficient and integrated design solutions*
> - *Incorporate building energy performance information in real estate transactions*
> - *Improve design and decision data and modeling tools to verify building performance*
> - *Prepare the clean energy buildings workforce*
>
> ***Existing Building Upgrades***
>
> *Work with market leaders (including building owners, engineers, and operators):*
>
> - *Demonstrate and validate energy efficient technologies and practices in a variety of buildings types and climate zones*
> - *Increase partnerships with market leaders to scale adoption of energy efficiency solutions*
> - *Develop data-driven decision support tools to measure and verify building energy performance as a result of upgrades*

CBI works with decision makers who are concerned with maintaining occupant comfort while improving their buildings' performance and reducing energy consumption. Additionally, CBI engages groups such as manufacturers, state and local governments, utilities, and financial institutions that play important roles in overcoming the barriers necessary to broadly deploy building energy efficiency best practices. CBI develops activities with an understanding of the constraints and opportunities faced by these decision makers, and focuses on creating meaningful impact throughout the commercial building life cycle, from design through construction, occupancy, and renovation.

To accomplish its goals, CBI builds on the results of the Building Technologies Office's (BTO's) Emerging Technologies (ET) Program to help bring new technologies and solutions to market more quickly and to demonstrate and facilitate the deployment of recently commercialized but underutilized technologies. CBI also works with BTO's Building Energy Codes and Appliance and Equipment Standards Programs to address market barriers and bring high impact technologies more quickly to market acceptance. CBI's efforts serve as a critical "market stimulation" link between the Emerging

Technologies Program and the Building Energy Codes and Appliance and Equipment Standards Programs.

Outside BTO, CBI regularly engages with other DOE and federal programs to lead by example and increase energy efficiency in federally owned and leased spaces. CBI also works closely with state and utility programs to focus national attention on specific high impact technologies and energy reduction strategies. One example is CBI and the General Services Administration's (GSA's) Green Proving Grounds partnership to demonstrate technologies that are appropriate for federal and privately owned commercial buildings. The collaboration provides a win-win for both agencies.

Commercial Buildings Integration Market Overview

Commercial Buildings Market and Energy Use: There are more than 5.5 million commercial buildings in the United States.[113] These buildings consume roughly 18 quads of energy per year.[113] Commercial buildings – the nation's offices, schools, hospitals, and other building types – represent a huge opportunity to save tens of billions of dollars each year by reducing energy waste. This waste is due to inefficient design, installation, and operation of equipment, lack of understanding of the benefits of equipment upgrades, and underinvestment in efficiency because of systemic barriers in the commercial real estate market. Energy savings of 20% or more are possible in commercial buildings if a variety of systemic and persistent market barriers to energy efficiency are overcome, especially in the commercial real estate market. [114]

The market's most pronounced feature is the diversity of building size and types, with an equally varied set of energy end-uses, including lighting systems; large-scale appliances and cooking equipment; many types of heating, ventilation, and air conditioning (HVAC) systems; elevators and escalators; controls and building management systems; and more. For example, the average EUI of a healthcare facility can be as much as three times greater than a public assembly building.[115]

Most U.S. commercial buildings are small. The average building size is 15,700 square feet. In fact, more than 90% of all commercial building properties are small buildings (defined as structures of 50,000 square feet and below), accounting for roughly half of U.S. commercial floor space and more than half of the sector's energy use. Small buildings, especially in small portfolios, are particularly difficult to reach, as the market is fragmented, and these buildings are typically owned, leased, and operated by small businesses that often do not have staff to focus on energy use and efficiency.

On the other hand, large commercial buildings—those with more than 100,000 square feet of floor space—are small in number but account for more than one-third of total commercial building floor

[113] U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed June 25, 2014: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm .

[114] Better Buildings Alliance. *2013 Annual Report*. U.S. Department of Energy: Washington, DC. DOE EE 0993. http://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/better-buildings-alliance-annual-report-2013.pdf.

[115] Calculated from *AEO 2014*—U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

space,[113] and more than 40% of the sector's energy consumption.[116] Large buildings with multiple tenants are also particularly difficult to reach due to market fragmentation.

Considering that most commercial buildings operate for decades, energy saving opportunities in existing buildings are critical to obtain future energy savings. Approximately half of today's existing commercial building stock was built before 1980. By 2030, more than 60% of commercial floor space will have been built before 2014.[117] The existing buildings market holds many of the most difficult and persistent challenges, due to the market's own distinct financial and structural barriers to operational improvements or equipment and systems retrofits. New construction has similar challenges, but offers opportunities for optimal building design, with the potential to influence energy consumption from the outset.

Market Barriers: A variety of informational, structural, and other market barriers impede the adoption of energy-efficient technologies and practices in commercial buildings. By understanding, developing, and deploying solutions that overcome these barriers, CBI helps unlock energy efficiency opportunities and empowers stakeholders to reduce energy use in new and existing commercial buildings.

Some of the market barriers that lead to underinvestment in building energy efficiency are informational. Building owners and operators often have inadequate information about the performance of high-efficiency technologies and energy-efficient operations. Stakeholders lack robust ways to assess, compare, and validate building energy performance. This leads to the perception that investing in efficiency is too expensive, complicated, or risky, making it difficult to gain access to internal or external capital. Without the appropriate information, tools, and platforms, building owners and managers are not able to accurately track their energy consumption, assess and compare their buildings, make timely decisions on upgrades and maintenance, or properly value their investments.

Inadequate information also leads to uncertainty in valuation of energy-efficient commercial buildings by the real estate community. The design, construction, appraisal, and underwriting processes do not fully account for the value that increased energy efficiency can bring to a building. When building owners are uncertain about their ability to recoup their energy efficiency investment through rent or resale, they are more hesitant to make energy efficiency investments.

Insufficient training or experience and a lack of standard quality metrics in the building services workforce hinder a well-developed and reliable marketplace of commercial building energy efficiency workers. This can also translate to improperly designed, installed, maintained, and operated commercial building systems and technologies, which affects energy performance.

CBI activities address these barriers to improve the market conditions for energy efficiency investment. CBI works to demonstrate and validate technology performance, improve the

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[116] U.S. Energy Information Administration, Commercial Buildings Energy Consumption Survey 2003, Table C1A
[117] Calculated from *AEO 2014*—U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

integration of energy efficiency into market transactions, and raise the bar for quality workforce training and certification programs.

Commercial Buildings Integration Program History

The Energy Policy Act of 2005[118] requires DOE to establish programs to support the development of voluntary consensus-based standards for high-performance buildings. DOE implements this requirement through stakeholder partnerships like the Better Buildings Initiative, which provides a conduit for DOE and subject matter experts to document and share best practices for increasing the energy performance of commercial buildings.

With the passage of the Energy Independence and Security Act (EISA) of 2007,[119] DOE was charged with playing a leading role in realizing energy efficiency opportunities for the nation's commercial buildings stock. EISA requires DOE to increase energy efficiency in commercial buildings and focus on the construction and establishment of net-zero energy commercial buildings so that by 2050, the entire commercial building stock in the United States will be net-zero energy.[120] CBI implements this requirement through several initiatives, including the development of data, tools, and resources supporting the adoption of high-performance green buildings and various resources and tools that enable designers and owners to move toward net-zero building energy use.

Building on these legislative mandates, CBI continues to play a catalyzing role in driving energy-efficient commercial buildings throughout the country. To date, CBI activities have led to the following:

- **Improved building design**. CBI has supported the development of guidance tools for deeper energy savings, such as the Advanced Energy Design Guides (AEDG) and the Advanced Energy Retrofit Guides (AERG). These guides provide simple, proven recommendations that engineers and architects can incorporate in their development efforts to ensure high performance building efficiencies in a wide variety of building types and climates zones. AEDGs represent a pathway to zero-energy commercial building construction. In 2006, CBI completed the first AEDGs. Available for free in 2008, the original series showed pathways to obtain 30% energy savings over ASHRAE Standard 90.1-1999. The next series, initiated in 2011, addressed pathways to achieve 50% energy savings over ASHRAE Standard 90.1-2004. CBI produced these in partnership with ASHRAE, the American Institute of Architects, the U.S. Green Building Council, and the Illuminating Engineering Society of North America. These guides provide critical guidance for how to design buildings that use significantly less energy than those buildings built to the requirements of minimum building energy codes. In addition, these guides help influence

[118] Energy Policy Act of 2005, Title IX Sec. 914 (c), http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/html/PLAW-109publ58.htm

[119] Energy Independence and Security Act of 2007, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf.

[120] See EISA Title IV Sec. 422(c), which requires DOE "*to develop and disseminate technologies, practices, and policies for the development and establishment of zero net energy commercial buildings for 50% of commercial building stock of the United States by 2040 and all commercial buildings in the United States by 2050*."

energy code development and stringency. Modeled after AEDG success, AERGs were then developed beginning in 2013 to cost-effectively improve commercial buildings while maintaining and improving occupant comfort and safety through multiple approaches.[121] The AERGs were developed in partnership with E-Source, Rocky Mountain Institute, National Association of Energy Service Companies (NAESCO), and PECI. In addition, CBI supports OpenStudio®, a user-friendly access point for EnergyPlus™, the nation's most sophisticated energy modeling software. Energy modeling during construction and retrofit design can greatly improve energy performance, systems performance, and comfort.

- **Faster adoption of market-ready high-efficiency technologies**. CBI has developed a strategy to accelerate the adoption of high-impact technologies (HIT) through the "HIT Catalyst." For example, the Lighting Energy Efficiency in Parking (LEEP) Campaign is an example of how CBI builds on several years of BTO technology research, development, and demonstration activities. Participation in the LEEP Campaign provides information, access, and tools to help building owners reduce energy costs. Participants have committed to retrofit 475 million square feet of parking real estate, representing 1.4 million parking spots and saving 120 million kWh per year, or $10 million annually. LEEP has kick-started the adoption of high performance outdoor lighting systems broadly across the country.
- **Collaboration with market partners to increase commitment to energy efficiency**. In 2008 CBI initiated with industry a series of partnerships to increase the speed and scale of the adoption of energy savings solutions. Since then, membership has continually increased and the number of industry sectors involved has grown. This has allowed CBI and its partners to promote innovative and replicable solutions and best practices to improve energy efficiency. Currently, CBI has two flagship initiatives that emphasize industry collaboration: the Better Buildings Alliance and the Better Buildings Challenge. Better Buildings Alliance partners represent 10 billion square feet in commercial floor space and work together to share best practices on energy efficiency. The Better Buildings Challenge partners collectively maintain approximately 3.5 billion square feet and have committed to reduce energy use by 20% by 2020 across their respective commercial buildings portfolios. Both the Better Buildings Alliance and the Better Buildings Challenge are critical parts of CBI's strategy.
- **Better decisions through better data**. CBI has developed the Building Performance Database (BPD) to provide quick public access to a wide spectrum of data about the energy performance of commercial buildings. BPD users can access data for more than 800,000 commercial and residential buildings nationwide through an easy online interface. Businesses are mining the BPD for insights on market trends and opportunities and using it to support a new wave of innovative products to help customers reduce their energy bills.

[121] For more information, see http://energy.gov/eere/buildings/advanced-energy-design-guides and http://energy.gov/eere/buildings/advanced-energy-retrofit-guides

As of 2015, over 9,000 users have accessed the dataset to understand trends in building performance.[122]

Opportunities for Future Savings: Significant opportunity remains to reduce energy use in commercial buildings. CBI's work is focused on accelerating the use of energy-efficient technologies and solutions in the marketplace. While the energy intensity of commercial buildings is forecasted to modestly decrease, the U.S. Energy Information Administration (EIA) estimates that total commercial building energy consumption will continue to grow at an average annual rate of 0.6% due to continued growth in the new construction market.[123]

CBI Program Energy Savings Potential

If today's existing commercial buildings were improved by 20%, the savings would be approximately:

- *3.5 quads of total energy*
- *$35 billion in costs*
- *188 million metric tons of carbon dioxide emissions, assuming current mix of generating power stations*

Sources: U.S. Energy Information Administration. *Annual Energy Outlook 2014* with projections to 2040. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014; Table A5, p. 162. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf

Overall, the motives behind investment in more sustainable buildings, especially in commercial buildings, have shifted from regulation-based drivers to desire to reduce costs and use of energy and market differentiation. According to a 2013 study, 83% of leaders in the largest U.S. companies view overall sustainability practices as consistent with their profit mission. This is up from only 58% in 2006.[124] High performance buildings are increasingly factoring into tenants' decisions about leasing space and into buyers' decisions about purchasing properties.

Future opportunities to reduce energy in existing buildings require improvements in building operations, equipment, and systems. Through CBI's Better Buildings Challenge efforts, market partners representing 4% of total U.S. commercial floor space,[125] have committed to reducing energy consumption in their buildings by 20% over the next 10 years. In addition, Better Buildings

[122] U.S. Department of Energy. Better Buildings Progress Report 2015. Washington, DC: U.S. Department of Energy, 2015. Accessed September 11, 2015: http://betterbuildingssolutioncenter.energy.gov/sites/default/files/news/attachments/DOE_BB_2015_Progress_Report_Solution_Center.pdf

[123] U.S. Energy Information Administration. *Annual Energy Outlook 2014 with projections to 2040*. DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, April 2014. Accessed June 12, 2014: http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[124] McGraw Hill Construction. Green Outlook 2011: Green Trends Driving Growth. New York, NY, 2010: http://aiacc.org/wp-content/uploads/2011/06/greenoutlook2011.pdf

[125] U.S. Department of Energy. Better Buildings Progress Report 2015. Washington, DC: U.S. Department of Energy, 2015. Accessed September 11, 2015: http://betterbuildingssolutioncenter.energy.gov/sites/default/files/news/attachments/DOE_BB_2015_Progress_Report_Solution_Center.pdf

Alliance members representing 11% of commercial buildings floor space,[126] have committed to addressing energy efficiency needs in their buildings.

For new construction, growth in awareness and use of labeling programs for commercial buildings—such as ENERGY STAR®[127] and Leadership in Energy & Environmental Design (LEED)—as well as an interest in integrated and sustainable design and zero-energy operations are helping to drive interest in low-energy equipment and designs. As of April 2014, the U.S. Green Buildings Council cited that more than 4.3 million people already live and work in LEED-certified buildings The percentage of new construction starts for green buildings has seen significant growth. In the U.S., the green buildings market share grew from 2% of new construction starts in 2005 to 44% in 2012. According to a survey of U.S. building professionals, 40% of respondents reported heavy engagement in green projects in 2012 (more than 60% of total projects undertaken), and 53% of respondents projected heavy engagement in green projects for 2015. The top reported planned sectors for green projects are new commercial buildings, retrofits of existing buildings, and new institutional buildings. Fifty-seven percent of U.S. building firms reported green projects for new commercial buildings for 2012 through 2015. [128]

Commercial Buildings Integration Goals

CBI is transforming the market transformation by working with market leaders to improve the design, construction, retrofit, and operation of commercial buildings. [129] The market leaders set an example for the rest of the commercial buildings market and thereby accelerate broader adoption of energy saving solutions. CBI's goal is for market leaders in the commercial buildings sector to reduce, by 2025, EUI by 35% than that of an average commercial building in 2010.[130] This market outcome goal is comprised of two goals for the existing and new commercial buildings markets in the market leader segment:

- Achieve a 30% reduction in EUI improvement in existing buildings of market leaders.
- Cost-effectively design and construct new buildings that consume 50% less energy per square foot relative to the average commercial buildings in 2010.

These outcomes, along with the work of BTO's other Programs and CBI's partners, will position the commercial sector to achieve the BTO outcome goal of a 25% reduction in EUI by 2030, as illustrated in Figure 32. Five program performance goals will enable CBI to affect the energy used in

[126] U.S. Department of Energy. Better Buildings Alliance Winter 2015 Progress Report. Washington, DC: U.S. Department of Energy, 2015. Accessed September 11. 2015: https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/better-buildings-alliance-progress-update-winter-2015.pdf
[127] See https://www.energystar.gov/ for more information on ENERGY STAR.
[128] McGraw Hill Construction. World Green Building Trends: Business Benefits Driving New and Retrofit Market Opportunities in Over 60 Countries. Bedford, MA: McGraw Hill Construction, 2013.
[129] Market Leaders represent the top 20% of the market based on floor area, i.e. the most efficient 20% of buildings weighted by floor area.
[130] The baseline energy use intensity in 2010 for the commercial buildings sector was 224 kBtu CBI's interim market outcome target is to reduce this to 143 kBtu

the nation's commercial space and create the transformation necessary to achieve the 2025 and 2030 market outcome goals.

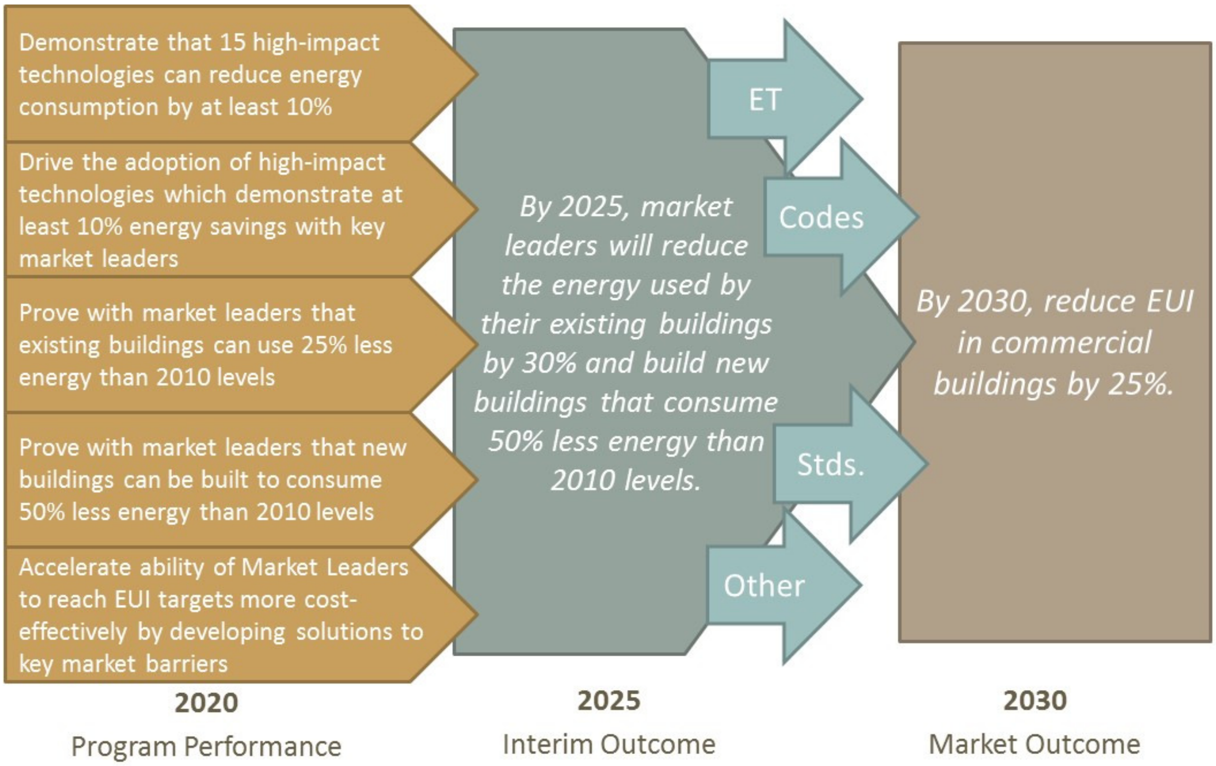

Figure 32. Commercial Buildings Integration Program's goals hierarchy

CBI's program performance goals equip market leaders with the energy saving solutions necessary to lead the way in transforming the commercial market:

1. **Demonstrating Technologies:** By 2020, demonstrate performance of at least 15 targeted HITs and solutions that each provide at least 10% average reduction in real building energy consumption as validated by third-party monitoring and verification.
2. **Driving Adoption of Technology Solutions:** Partner with market leaders to drive the adoption of HIT applications capable of reducing building energy consumption by 10%. The indicator of success would be if at least 10% of market leaders adopted HIT or solutions by 2020.
3. **Proving Solutions via Market Partnerships in Existing Buildings:** Prove with market leaders that, by 2020, it is possible to cost-effectively reduce average commercial buildings by at least 25% relative to 2010 levels. The indicator of success is achieving this level of

energy savings in at least 10 billion square feet and covering every climate zone and major building type.

4. **Proving Solutions via Market Partnerships in New Construction:** Demonstrate with key market leaders that it is possible to cost-effectively construct new commercial buildings that consume 50% less energy than 2010 levels by 2020 in every climate zone and for every major building type.
5. **Accelerating Energy Efficiency by Addressing Market Barriers:** Develop, demonstrate, and deploy a full suite of tools and strategies that enable market leaders to achieve a 30% reduction in existing commercial buildings and a 50% reduction in new commercial buildings by 2020.

The CBI Program will track progress toward these performance goals by regularly collecting information from various activities the Program implements. Each program performance goal has a unique set of metrics which are identified below.

Commercial Buildings Integration Strategies, Current and Planned Activities, and Key Targets

Advances in energy-efficient commercial building technologies and practices can significantly lower building-related energy consumption on a national scale. CBI focuses on overcoming these technical, market, and informational barriers through a spectrum of market-relevant strategies designed to drive significant improvements in the energy performance of existing and new commercial buildings.

Strategies

- *Demonstrate the performance of highly energy-efficient technologies in commercial buildings and drive adoption with market leaders.*
- *Prove energy saving solutions in new and existing buildings that can greatly reduce EUI of commercial buildings through market partnerships on a national scale.*
- *Accelerate adoption of energy saving solutions by developing the market infrastructure to enable markets to deliver greater investment in energy efficiency.*

Figure 33 illustrates CBI's strategic pathway. Market leaders play a formative role in setting best practices for investment in energy-efficient solutions. CBI's work with market leaders begins with demonstrating and validating relatively new but underutilized energy-efficient technologies and solutions and developing procurement specifications and installation guides, thereby mitigating the risk for other adopters. Once technologies have been demonstrated, CBI expands its reach through formalized market partnerships in which members commit to reduce energy use to target levels, provide data, and document best practices. CBI also develops and maintains tools and resources that reduce key marketwide barriers to assist early adopters to cost-effectively implement energy-efficient technologies and solutions. By providing transparent and reliable information and data that accurately communicates the value of energy efficiency, CBI further assists market leaders to provide an example to follow for the rest of the market.

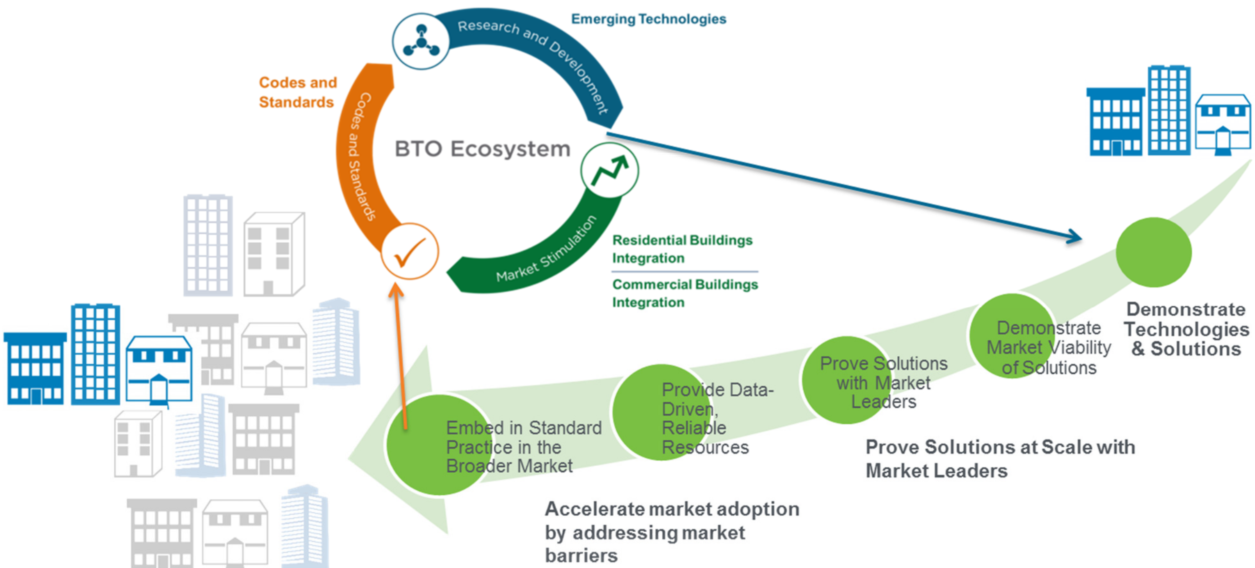

Figure 33. CBI's strategic pathway

Below are CBI's current and planned activities for new and existing commercial buildings. Metrics and targets that indicate success toward CBI's performance goals are identified for each strategy. Status is tracked on an ongoing basis, and targets are updated to reflect progress or changes in course as appropriate.

Strategy 1: Demonstrate the performance of highly energy-efficient technologies in commercial buildings and drive adoption with market leaders.

Demonstrating technologies in operational, occupied buildings provides the performance and cost data needed to inform decision makers. Each year, CBI conducts a research, identification, and evaluation exercise to develop deployment strategies for those technologies that can make the most impact in achieving BTO's energy savings goals. CBI refers to the technologies that offer the greatest impact as high impact technologies or HITs. HITs are prioritized based on key quantitative and market criteria to generate a HIT List. Figure 34 shows an example of the prioritization and screening process through which HITs are identified and evaluated. Adoption of HITs are then catalyzed using the most effective deployment channels such as real-building demonstrations. Each of these channels and how HITs will move from one to another are described in the following text.[131]

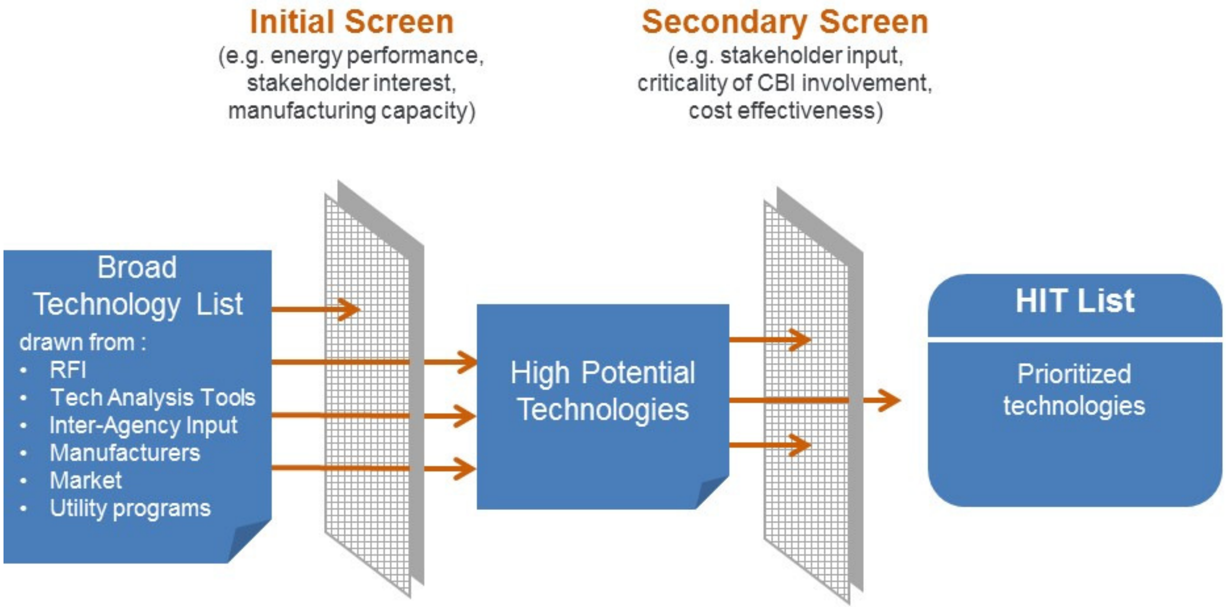

Figure 34. Example HIT Catalyst screening process

The key question for each technology on the HIT List is: "Which of the HIT core activities can most effectively improve the market adoption of this technology?" Five core activities reflect proven and successful market stimulation work. Core activities are selected using decision criteria that relies on an assessment of the technology landscape and the most significant market barriers. The core HIT market stimulation activities function as follows:

- **Innovation Challenge**: Triggers product development where the market has not met building owner and designer demands for more efficient products.
- **Real Building Demonstration:** Overcomes building owner uncertainty about how the technology will perform in real-world settings.
- **Performance Specification:** Answers the need for technical and functional guidance on the selection of the highest performing technologies.
- **Application Guidance:** Highlights best practices in design, installation, and ongoing maintenance of HITs.
- **Adoption Campaign:** Provides incentive for building owners and operators to choose and implement HITs. Adoption campaigns provide assistance and recognition for participants,

[131] See the following document for more information on the HIT catalyst, http://www.energy.gov/eere/buildings/downloads/high-impact-technology-catalyst-technology-deployment-strategies

help drive down costs, and enable CBI to share best practices and energy savings results from real projects that achieve significant energy savings.

CBI's understanding of the market landscape and barriers for each HIT allows for the appropriate identification of activities that have the greatest likelihood of significantly affecting the markets for the chosen technologies. The HIT Catalyst process allows CBI to tailor activities and market transformation plans for each HIT and ensures that resources will be allocated in the most effective manner for the greatest market impact.

The HIT Catalyst process operates cyclically. Each year, new technologies are added to the Program, and existing HITs are reevaluated. Then, new activities are initiated to build off of existing work or handed off to external organizations to maintain energy efficiency efforts. Table 15 outlines the annual efforts.

Table 15: HIT Catalyst annual cycle

<table>
<tr><th>Quarter</th><th>Quarterly Action Steps</th><th>Ongoing Activities (Year-Round)</th></tr>
<tr><td>Spring</td><td>• Initiate request for information (RFI) to gather suggestions on new candidate HITs
• Conduct literature and market review on possible new HITs, including new Prioritization Tool measures and "graduates" of other technology R&D programs (Tech Sweep)
• New inputs are added to the HIT Matrix
• Use BTO Peer Review and Better Buildings Summit to review HIT Matrix program feedback</td><td rowspan="4">• Catalog data and suggestions on possible HITs for next cycle
• Initiate new market transformation activities
• Reevaluate deployment plans for existing HITs and move to next step upon activity completion
• Hand off HITs once CBI work is complete</td></tr>
<tr><td>Summer</td><td>• Conduct workshop to answer qualitative questions, understand changing market conditions and uncover work by others
• Refresh HIT selection matrix with workshop feedback</td></tr>
<tr><td>Fall</td><td>• Revisit HIT priority list based on HIT Matrix updates
• Develop HIT Watchlist based on emerging high-potential technologies</td></tr>
<tr><td>Winter</td><td>• Develop market transformation plans for new HITs (as applicable for new technologies)
• Update plans for existing HITs based on new market conditions</td></tr>
</table>

The culmination of the HIT activities is greater adoption of HIT products by energy efficiency leaders in the market. When this occurs, CBI hands off the HIT data to BTO's BEC and Appliance Standards Programs. These Programs may incorporate this data into their products so that the HIT's benefits may expand to the broader market.

Table 16 shows the metrics and 2020 target associated with Strategy 1 to reach CBI's program performance goals. The two metrics used to track success are the number of demonstrations performed and the commitment by market leaders to adopt HITs. These metrics measure progress at two critical points in the technology deployment process.

CBI often leverages the Better Buildings Alliance members and technology teams, as well as other market partners to participate in the HIT Catalyst activities, which helps to reach the target of 10% of market leaders and prove demonstrated technology solutions on a broader scale.

Table 16. Demonstration & adoption of technologies metrics, statuses and annual targets

<table>
<tr><th colspan="5">Metrics and Targets: CBI Demonstrates & Drives Adoption of Technologies</th></tr>
<tr><th>Activities contributing to the goal</th><th colspan="2">Metric</th><th>Status Relative to Inception of HIT Catalyst*</th><th>2020</th></tr>
<tr><td>HIT Catalyst: Demonstrations</td><td>Number of demonstrations</td><td rowspan="2">Involved technologies exhibit at least 10% average improvement in real building energy consumption</td><td>8</td><td>15</td></tr>
<tr><td>HIT Catalyst: Technology Campaigns</td><td>Commitments to adopt technologies supported by a campaign, as a percentage of the total market</td><td>Exterior Lighting: 475 million sq. ft.
Interior Lighting: 175,000 troffers
RTU retrofits or replacement: 45,000 units</td><td>10% of market leaders;
2% of the total market</td></tr>
</table>

**The metric used to describe the status is based on currently reported information. CBI will perform an analysis of available data to begin tracking targets in terms of percent of the market that have committed to adopt the technologies.*

Strategy 2: Prove energy saving solutions in new and existing buildings that can greatly reduce EUI of commercial buildings through market partnerships on a national scale.

Through market partnerships with industry leaders, CBI proves it is possible and cost-effective to reduce the EUI of new and existing commercial buildings across all geographic climate regions. CBI relies on these partners to test and refine design and retrofit resources that make solutions more market viable, and to facilitate the deployment of solutions to the market through exchange of information. CBI also recognizes business leaders for their progress and successes. These partnerships help CBI to reach increasingly diverse building efficiency audiences.

The Better Buildings Alliance consists of building owners, operators, and managers that are energy efficiency leaders. Members work together to set energy savings goals, support CBI's development of innovative energy efficiency resources, and adopt cost-effective technologies and market solutions. These market leaders commit to track energy savings and participate annually in at least one Alliance activity, such as testing an implementation model or participating in a HIT Catalyst activity, or committing to implement an energy efficiency project in an adoption campaign. Alliance members work collaboratively with CBI's technical support teams to catalyze innovation and deploy proven efficiency technologies and solutions that lead to significant reductions in the EUI of commercial buildings.

The Better Buildings Challenge is DOE's highest level of partner recognition. Partners commit publicly to reduce the energy consumed in their portfolios by 20% over 10 years and to share their successful projects and business models with the market. As of September 2015, more than 250 organizations have committed to the Better Buildings Challenge. CBI is working continually to expand the number of partners that represent the top leaders in energy efficiency. DOE helps challenge partners to meet their goals by providing technical support and information on proven solutions to those committing to the challenge, as well as critical connections with a network of allies including financial institutions and utilities. CBI also encourages sharing of best practices, including successful implementation models and showcases. Once partners achieve their goal, DOE publicly recognizes their accomplishment.

CBI also works in the small buildings sector. Buildings less than 50,000 square feet make up more than 49% of the floor space[132] and about 44% of the energy consumed by commercial buildings in the United States.[133] CBI's activities in this sector target the barriers that small building owners, tenants, and service providers face. CBI works with market partners who are best able to reach the small buildings sector and help them to promote the utilization of proven technical resources and lessons learned from past successful pilots on a national scale.

CBI also maintains a range of other resources focused on new construction and design solutions that impact whole-building EUI. Advanced Energy Guides (AEDGs) offer information on how to vastly improve building energy efficiency above mandatory code levels during the initial design and construction of a new commercial building or a major retrofit of an existing building. CBI works with the BEC Program, the national labs, and industry experts to develop advanced energy building design guides for new construction and retrofits for a variety of commercial building types. These guides provide building professionals with vetted solutions, including both individual technology measures and whole-building performance-based measures. CBI develops this reliable information to help the industry identify and adopt market viable solutions to save energy across a range of building types.

The Program works with industry to track results and determine if the activities are having the intended impact. Table 17 shows the metrics associated with market partnerships described in Strategy 2. For existing buildings, the Better Buildings Alliance, Better Buildings Challenge, and other partnership activities directly contribute to CBI's performance goals. CBI uses reported data

[132] U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed June 25.
[133] U.S. Energy Information Administration, Commercial Buildings Energy Consumption Survey 2003, Table C1A

from these activities as an indicator that it is possible to cost-effectively reduce the average EUI of commercial buildings by at least 25% relative to buildings in 2010. The Better Buildings activities target a 20% reduction in portfolio-wide EUI, but many of these market leaders started with a more energy-efficient building portfolio than the average commercial buildings in 2010.

For new buildings, CBI is assessing the market and considering the most effective market partnership activities that can support the construction of highly efficient, above-model energy codes, zero energy ready commercial buildings. CBI will perform analysis to determine the appropriate targets for new construction within the 2015–2020 timeframe.

Table 17. Prove solutions at scale with market leaders, metrics, statuses and targets

Metrics and Targets: CBI Prove Solutions at Scale with Market Leaders			
Activities contributing to the goal	**Metric**	**Status Relative to Inception of Activities***	**2020**
Existing Buildings			
Better Building Challenge	Square footage of total buildings estimated to reduce average commercial building energy use by 25%	Since the Better Buildings Challenge's launch in 2011, partners have cumulatively saved 94 trillion Btu and >4,500 properties demonstrated energy savings of 20% or more across 50 states.	10 billion sq. ft. covering all major building types & multiple climate zones
Better Buildings Alliance		Better Buildings Alliance members, representing 10 billion sq. ft., have also reported more than 2% savings on an annual basis	
New Buildings			
Analysis underway to determine activities	Square footage of total buildings constructed that consume 50 percent less energy than the average commercial building energy use in 2010	Analysis currently underway	

** The metric used to describe the status is based on information reported in the Better Buildings Progress Report 2015 and the Better Buildings Alliance Winter 2015 Progress Update. Analysis will be conducted with available data to begin tracking targets in terms of square footage that meet the 25% and 50% savings improvement levels.*

Strategy 3: Accelerate adoption of energy saving solutions by developing the market infrastructure to enable markets to deliver greater investment in energy efficiency.

To reduce key market barriers on a broad scale, CBI uses two primary approaches:

1. **Harnessing the Power of Information:** Incorporate energy performance into organizational culture and real estate transaction points; this includes design and decision support tools, data access and analytics, and savings measurement and verification.
2. **Preparing a Clean Energy Workforce:** Ready the workforce to design, build, and operate buildings more efficiently.

CBI develops tools and resources that equip the market to properly value and implement energy efficiency in commercial buildings. These data-driven, consistent resources build confidence for the building design and construction, real estate, and financial markets.

Harnessing the Power of Information: CBI works with industry partners to show that energy performance data can be combined with financial performance data to inform real estate decisions such as building appraisal, underwriting, investment, and leasing. Energy performance information can be more fully incorporated into real estate transactions, leasing, and tenant fit-out decisions. This will help building owners and operators to better monetize their successes in saving energy. CBI is developing resources to make empirical data about the impacts of energy efficiency on building financial performance more accessible, usable, timely, and accurate.

CBI develops and maintains a suite of standardized platforms and tools for use in various phases of a building's life cycle, from design, operation, and renovation to resale. These tools address the information needs of a variety of stakeholders, including building designers, owners, and operators so they can better understand the potential for and impacts of improved efficiency. This allows them to manage and analyze their buildings' performance and make better-informed decisions about energy efficiency. CBI develops these tools to create a more consistent, transparent, performance-based commercial building market that results in less risk for stakeholders.

CBI created and maintains the BPD, which is an online platform that supports the anonymized sharing of building characteristics and energy performance data. The BPD is the largest publicly accessible data set of building performance information in the United States. Users can access BPD to perform statistical analysis on tens of thousands of commercial and residential buildings from across the country for a number of purposes, including comparing their building's performance to the rest of the market and making decisions related to investments in energy efficiency upgrades. The BPD has an application program interface (API), so applications can be designed by third-party software vendors or app developers using the underlying data set in different ways. These user applications and the addition of more and more data will allow for broader use of the performance information.

CBI maintains the Standard Energy Efficiency Data (SEED) Platform[134], an open-source software application that helps organizations easily manage data on the energy performance of large groups of buildings. Users can combine data from multiple sources, clean and validate it, and share the

[134] See http://energy.gov/eere/buildings/open-source-strategy for more information on SEED.

information with others. The software application provides an easy, flexible, and cost-effective method to improve the quality and availability of data to help demonstrate the economic and environmental benefits of energy efficiency, to implement programs, and to target investment activity. CBI is assisting a number of state and local governments across the United States in using SEED to manage their building energy performance data. This improves the ability of these jurisdictions to run cost-effective energy efficiency programs.

To give commercial building owners streamlined access to their own energy data, CBI implements Accelerators focused on recruiting utilities and local governments that will partner with DOE. When building owners have access to and can understand energy data, they are more likely to recognize the value of energy efficiency. Through CBI's Better Buildings Energy Data Accelerator, local governments are joining forces with their local utilities to make it easier for building owners to get access to whole-building energy usage data for the purposes of benchmarking their buildings. Partners agree to demonstrate streamlined, best-practice approaches for building owners to access whole-building energy usage data—with a specific focus on providing information for multi-tenant buildings. The recent High-Performance Outdoor Lighting Accelerator is focused on recruiting local governments that will partner with DOE to retrofit their street lighting and other outdoor lighting with energy saving technologies, such as high-efficiency lighting and advanced controls. DOE provides technical assistance to accelerator member cities in several key areas (such as technology specifications and education) and creates support documents, tools, and studies to help the partners achieve their goals as well as to disseminate solutions more broadly in the market.

To facilitate the use of building energy performance data, CBI leads the development and maintenance of the Building Energy Data Exchange Standard (BEDES). Consistent measurement and recognition of energy efficiency in buildings can improve the usefulness and interoperability of modeling and analysis tools, reduce costs, and unlock new business opportunities utilizing performance-based contracts, policies, and markets. BEDES is a dictionary of terms, definitions, and field formats that was created to help facilitate the exchange of information on building characteristics and energy use. DOE has already begun to use the BEDES data dictionary in its array of publicly available building energy efficiency tools. The dictionary can also be used by private-sector software tools and databases. As the number of public and private tools that utilize BEDES grows, they will contribute to an interoperable ecosystem of software that lowers the cost currently involved in sharing and aggregating data. The BuildingSync® file format is an example of BEDES at work—by defining a standard schema for transmitting data about building energy audits, it streamlines the process of storing and analyzing information from those audits. CBI is currently working with industry groups to improve interoperability of their data through BEDES. CBI is also working with the Federal Energy Management Program to streamline reporting of energy audits in federal facilities through the use of the BuildingSync file format.

CBI also supports the improvement, standardization, automation of the methods of measurement and verification (M&V) of energy efficiency projects and programs. CBI does this by developing a test protocol that vendors of automated M&V methods can use to analyze the accuracy of their algorithms. The goal of this effort is to reduce the cost of this type of analysis and increase the confidence in energy savings, while improving the comparability of different methods.

CBI develops and maintains OpenStudio, DOE's open-source operating system for building energy modeling. OpenStudio allows easy access to the powerful EnergyPlus and Radiance™ modeling engines, among others. OpenStudio can be used to assess energy performance and support performance-based design, decision-making, policy, and transactions. For more information on Building Energy Modeling, see Section 2.5.

Beyond its work on OpenStudio, CBI helps to develop and update Building Energy Modeling Guides for building energy modeling tools, which are used to inform and drive energy efficiency design; optimize building operations; and inform policy, codes, and standards. DOE's electronic library of best practices and building energy modeling knowledge is intended to improve modeling consistency and address training gaps.

The Commercial Building Asset Score is a national standardized tool for assessing the physical and structural energy efficiency of commercial and multi-family residential buildings. The Asset Score generates a simple energy efficiency rating that enables comparison among buildings, and identifies opportunities to invest in energy efficiency upgrades. The tool is available for voluntary use and is free to use. The Asset Score gives building owners a standardized way to analyze and communicate the efficiency of the systems in their buildings.

CBI also works with many stakeholders to overcome market barriers through the State and Local Energy Efficiency Action Network (SEE Action), convened by DOE and the Environmental Protection Agency (EPA). SEE Action provides support to state and local governments and energy efficiency program administrators interested in implementing proven energy efficiency programs and policies. DOE and EPA convene working groups and facilitate networking to help policymakers and program administrators develop effective policies and programs, and ensure that supporting resources address market barriers to energy efficiency in a consistent manner.

Preparing a Clean Energy Workforce: A highly skilled and qualified workforce is critical to allow for more of the market to successfully design, build, retrofit, operate, and appraise energy-efficient commercial buildings. Improving and maintaining the energy performance of the nation's offices, schools, hospitals, and other commercial buildings requires highly skilled workers, particularly as building technologies and systems become more advanced. CBI is working closely with the commercial buildings industry and other federal agencies to develop voluntary credentialing guidelines. A standardized framework for a high-quality commercial buildings workforce helps the market identify and utilize high-quality training and certification programs.

DOE works with industry partners such as the National Institute of Building Sciences to develop training and certification guidelines. These voluntary national Workforce Guidelines help improve the quality and consistency of the training and certification programs offered to the buildings workforce for four key energy-related jobs: building energy auditor, building commissioning professional, building operations professional, and energy manager. A high-quality workforce requires high-quality training. CBI developed the Building Re-Tuning Training to help building operators detect and fix problems in their buildings, keeping them running at peak performance, which can reduce energy usage in typical buildings by 15%. The Building Re-Tuning Training is being offered nationally by the Building Owners and Managers Association and APPA: Leadership in

Educational Facilities. CBI is also developing a federal facility manager skills assessment and training program in conjunction with the GSA.

CBI implements many activities to develop and demonstrate tools and strategies that help to reduce market barriers and will allow market leaders in the commercial buildings sector to reduce energy use intensity of existing buildings by 30% and new buildings by 50%.

CBI is currently performing analysis to determine the appropriate metrics and targets that will help track and identify market success indicators. Though CBI collects a great deal of information related to each of these activities, the Program develops targets that best represent the collective impact on the market toward the 2020 performance goals.

Table 18. Accelerates energy efficiency by addressing market barriers, metrics, statuses and targets

Metrics and Targets: CBI Accelerates Energy Efficiency By Addressing Market Barriers				
Activities contributing to the goal	**Metric**	**Status Relative to 2010**	**2018**	**2020**
Data Analytics, Tools & Modeling*	* Progress in the area of increased usage of energy modeling tools is largely tracked in the Building Energy Modeling Program (Section 2.5).			
Financial Value	Analysis currently underway			
Workforce	Number of certification / training programs accredited to meet Better Buildings Workforce Guidelines	1 certification program	At least 1 training/certification program in each of the 4 identified job categories	At least 2 training/certification program in each of the 4 identified job categories

5.0 Building Energy Codes

Today's building energy codes enable new buildings to use 30% less energy than the codes that were in place less than 10 years ago.[135] Building energy codes establish energy conservation requirements for new construction, additions, and substantial renovations of residential and commercial buildings, and represent an opportunity to incorporate successful energy-efficient technologies into standard design and construction practices. In addition to significantly reducing energy use, building energy codes also substantially reduce consumer utility expenditures and greenhouse gas emissions over the lifespan of buildings.

The Building Energy Codes Program's mission is to support U.S. building energy codes and standards development, adoption, implementation, and enforcement processes to achieve the maximum practicable improvements in energy efficiency while providing safe and healthy buildings for occupants.

BTO's Building Energy Codes (BEC) Program consists of an integrated portfolio of activities aimed at increasing building energy efficiency through participation in code development, adoption, and implementation processes. As the energy-related design elements of a building determine future operational and environmental impacts, energy codes present a unique opportunity to assure savings over the life of a building through more energy-efficient systems, technologies, and construction practices. BEC analyzes and develops potential code changes, which are reviewed through established public processes. BEC then contributes to code adoption and implementation by providing technical assistance to states and localities, including the development and distribution of tools, materials, and technical analysis.

Energy codes lock in savings by establishing energy efficiency requirements for the market after energy-efficient technologies have been developed by BTO's Emerging Technologies (ET) Program or by industry, and then accelerated into the market by BTO's Residential Buildings Integration (RBI) and Commercial Buildings Integration (CBI) Programs and utility incentive programs. As an example, Building America projects conducted as part of the RBI Program provided important evidence that increased insulation levels could be installed cost-effectively, paving the way for code changes that mandate higher energy efficiency on a national scale.

Building Energy Codes Process

Energy codes establish minimum energy efficiency requirements for new and renovated buildings and are a subset of building codes, which establish baseline requirements and govern building construction. Energy codes address the majority of elements within a building affecting energy consumption, often including wall, floor, and ceiling insulation levels; doors, windows, heating, ventilation, and cooling systems; lighting; and water heating systems.

[135] Livingston, O.V.; Cole, P.C.; Elliott, D.B.;Bartlett, R. *Building Energy Codes Program: National Benefits Assessment, 1992-2040.* Richland, WA: Pacific Northwest National Laboratory, 2014. Accessed August 22, 2014: http://www.energycodes.gov/sites/default/files/documents/BenefitsReport_Final_March20142.pdf.

The national model codes are identified in federal statute and administered by private non-profit organizations. ASHRAE Standard 90.1[136] and the International Energy Conservation code (IECC)[137] are the national model energy codes for commercial and residential buildings, respectively. They are developed through processes open to the general public, administered on a 3-year development cycle, and have full participation from building design & construction interests. Figure 35 below outlines a general overview of the building energy code cycle and BEC's involvement.

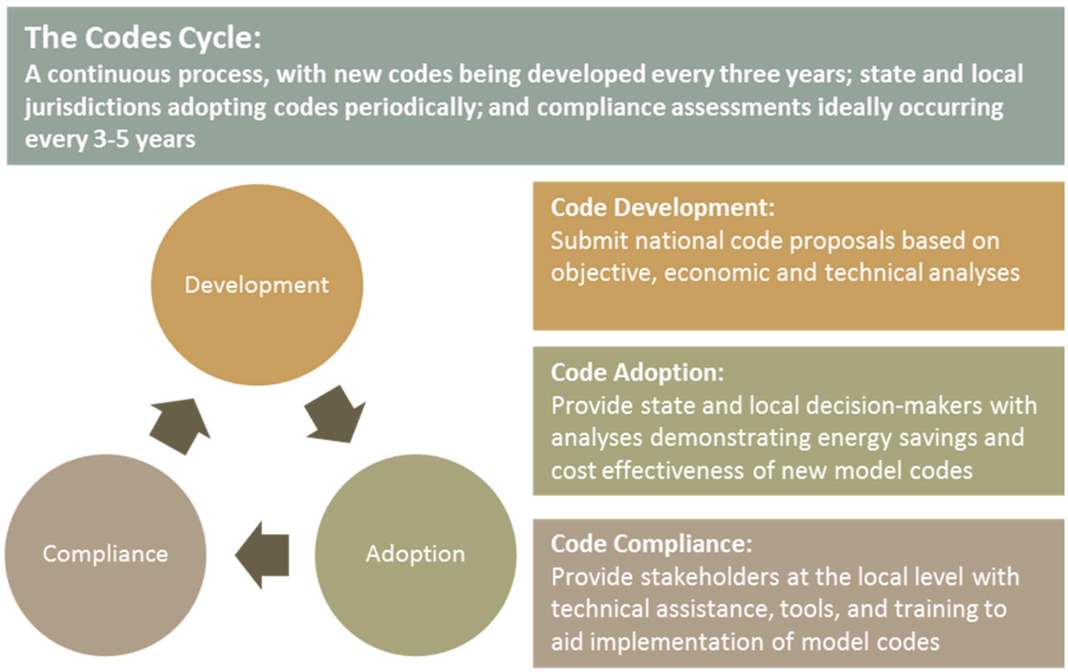

Figure 35. Building energy codes cycle

Once an updated edition of a model code has been developed, it is adopted by states and localities. States review the national model code and adopt it directly, or invite interested parties to submit amendments that are considered through an established public process. Where codes are adopted statewide, these processes are often run by state administrative agencies; in home rule states, they are run by local governments. The final result is a code which has the force of law in the adopting jurisdiction.

The majority of BEC Program support is focused on the implementation of building energy codes, as the intended energy savings are realized through achieving high levels of compliance. Design and construction professionals have the legal obligation to create code-compliant buildings, but city or county officials are responsible for enforcing the code, which they accomplish through plan reviews

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[136] ANSI/ASHRAE/IES Standard 90.1 is developed by the American National Standards Institute (ANSI), American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE), and the Illuminating Engineering Society (IES).

[137] The IECC is developed by the International Code Council (ICC)

and field inspections. Because the energy code is frequently one of the least understood building codes, the BEC Program plays a critical role by developing training curricula, funding instructors, and providing software resources like RES*check*™ and COM*check*™ to aid in demonstrating energy code compliance. Pacific Northwest National Laboratory (PNNL), supported by the Building Technologies Office (BTO), develops tools and resources for use across the nation, with additional technical assistance provided by national and regional energy efficiency organizations (REEOs) to ensure that activities and resources are tailored to the needs of regions and individual states.

Building Energy Codes Adoption Status

Forty-eight U.S. states and territories have adopted a building energy code as a means of ensuring energy efficiency in residential and commercial buildings. Figure 36 and Figure 37 illustrate the status of state code adoption as of August 2015. [138]

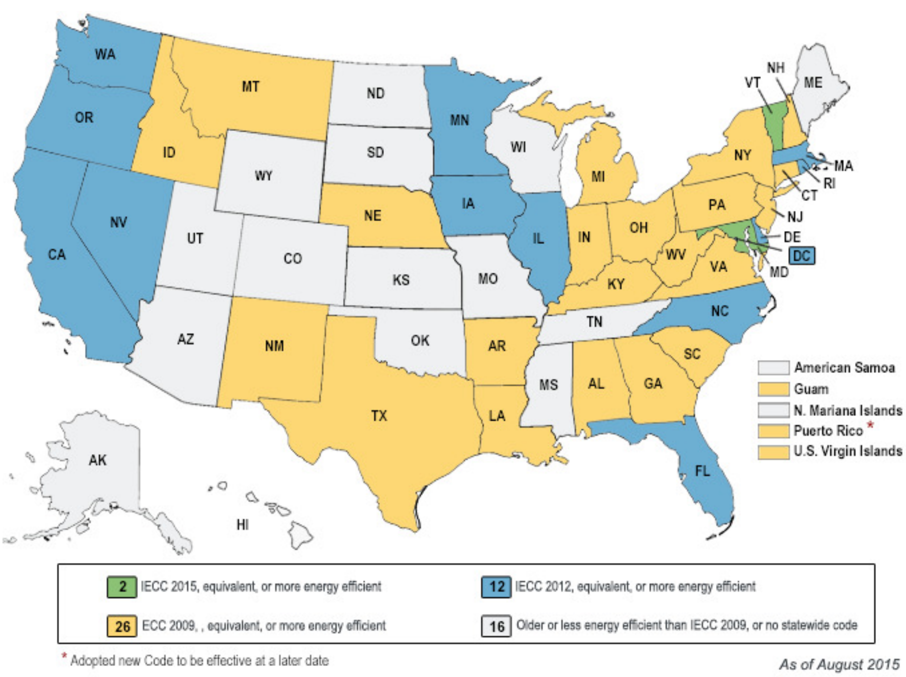

Figure 36. Current status of residential adoption

[138] See https://www.energycodes.gov/status-state-energy-code-adoption for the most up to date status.

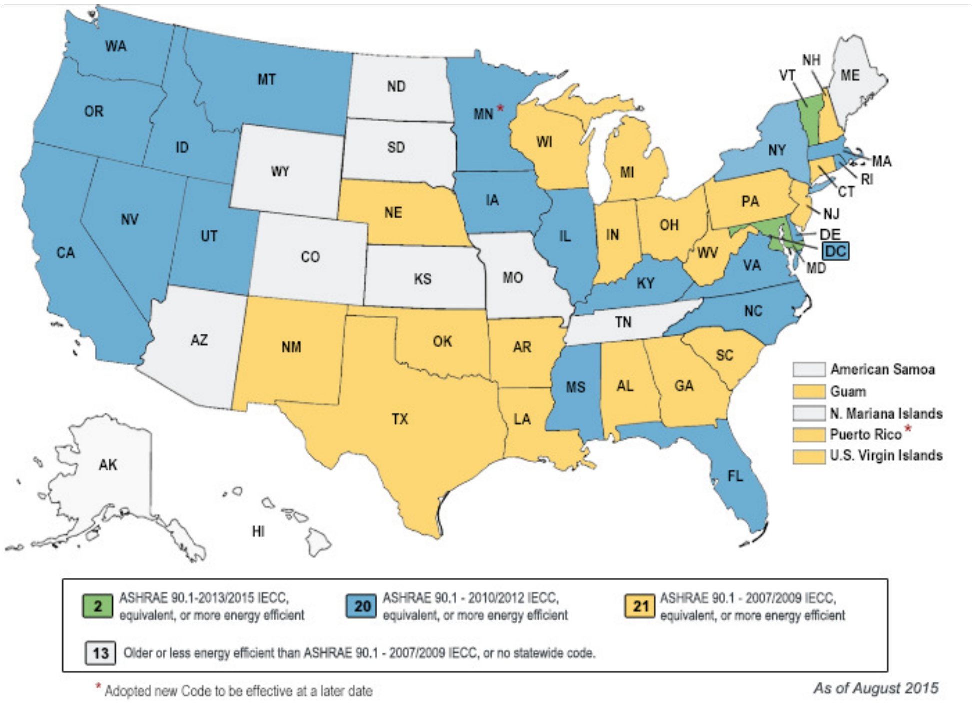

Figure 37. Current status of commercial code adoption

Another way to look at code status is through the advancement of the model energy codes over time. Figure 38 shows the percentage improvement in commercial buidlings based on ASHRAE Standard 90.1 (1975 to 2013), and Figure 39 shows the improvement in residential buildings based on the IECC (1975 to 2015).

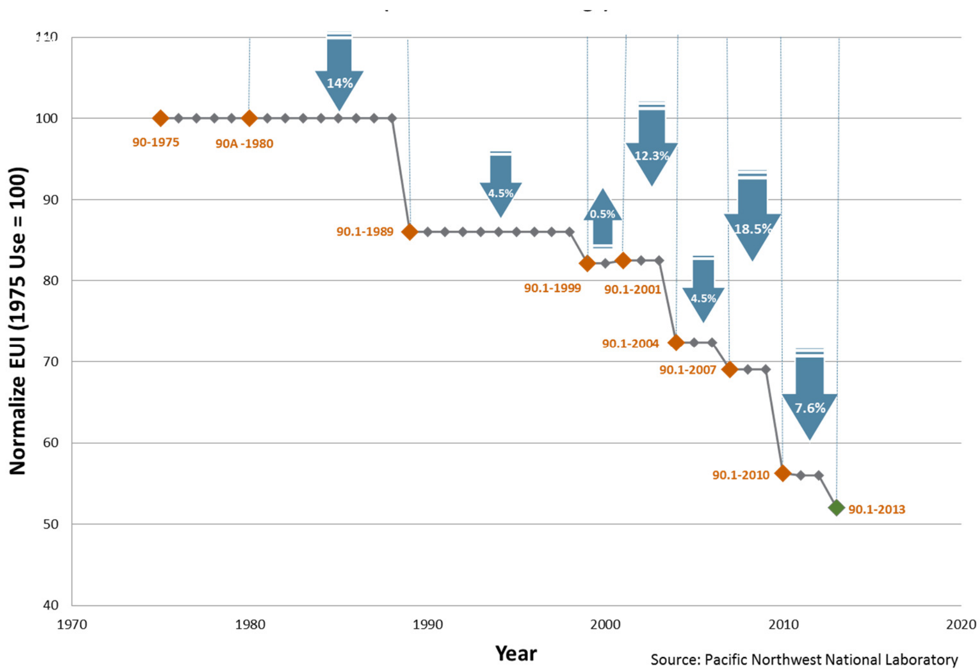

Figure 38. Improvements in Standard 90.1 (1975–2013)

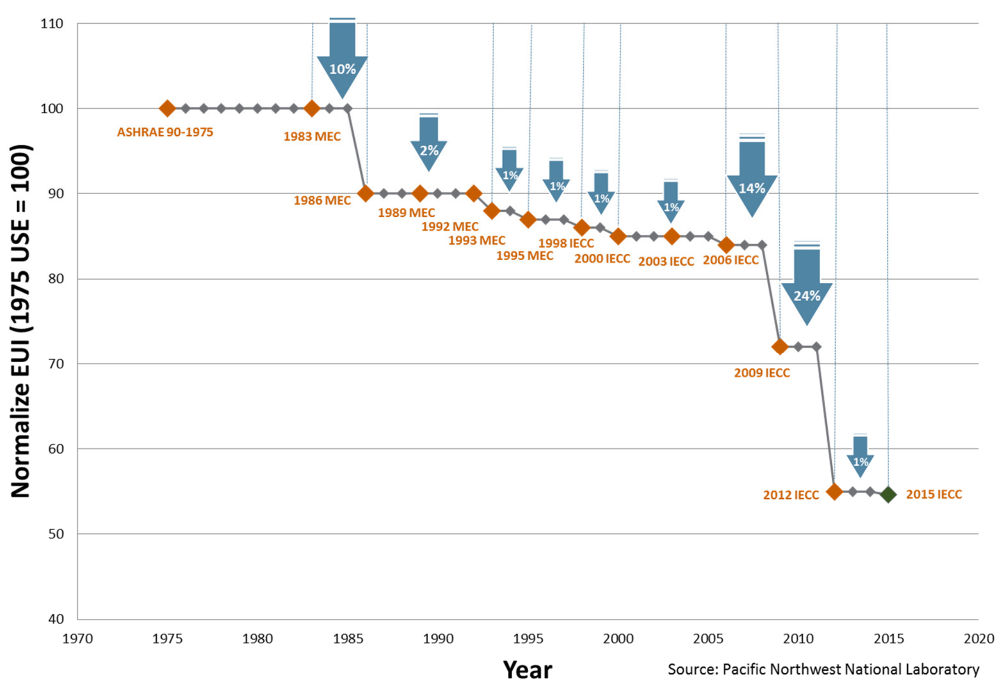

Figure 39. Improvement in the IECC residential provisions (1975–2015)

Building Energy Codes Market Overview

Market Barriers: Energy codes generate significant energy and cost savings over the life cycle of a building. These savings accrue to the owners and occupants of the buildings, but the cost to provide the benefits may fall on separate parties, such as developers and builders. This is the classic split incentive, which, except in the case of owner-occupied buildings, can reduce the motivation for developers and builders to invest in energy efficiency. Without energy conservation requirements established by the code, builders and consumers likely would not prioritize energy efficiency in buildings.

Another key barrier is that local building officials must address life and safety building codes (e.g., fire, electrical, structural). Therefore, fewer resources are often directed at the energy code, which ultimately results in lower-than-expected compliance rates and associated energy savings. Compounding this is that the benefits of energy efficiency have generally not been communicated in a way that adequately reflects the consumer savings and greater economic value resulting from building energy codes.

The improvements to the energy code itself can also be a barrier. As energy codes become more stringent, therequirements become more complex, which can challenge design and construction professionals' ability to understand and comply with them, as well as building officials' ability to properly enforce them. The 3-year code cycle also requires the market to quickly learn the new requirements and incorporate them into their building practices, which can be viewed as a challenge.

Economic and demographic shifts also affect the patterns and activity level of the construction industry. This can have a direct effect on building code adoption and compliance, as well as the amount of training and resources needed. For example, when the housing market collapsed in 2009, some jurisdictions were reluctant to adopt more stringent energy codes due to concerns over construction costs.

Building Energy Codes Program History

The BEC Program was established in response to the Energy Policy Act of 1992 (EPACT 1992).[139] The Department of Energy (DOE) is directed by statute to support the development and implementation of model building energy codes for residential and commercial buildings designed to achieve the maximum practicable improvements in energy efficiency. In addition, DOE encourages state and local governments to adopt and enforce such standards. DOE is required to:

- Participate in the development of residential and commercial model building energy codes, as administered by organizations such as the ICC and ASHRAE.
- Review the technical and economic basis of building energy codes.
- Determine whether updated editions of the model codes will improve energy efficiency in residential and commercial buildings.
- Promulgate assigned rules, such as those regulating energy efficiency in federal buildings and manufactured housing.
- Provide technical assistance to states implementing the model energy codes.

> **Building Energy Codes Program Impact**
>
> *The estimated cumulative benefits of the BEC Program through 2040:*
>
> - *Consumer utility savings of $230 billion*
> - *Almost 4 billion total tons of carbon saved*
> - *44 quads of primary energy saved*
>
> *These estimates are equivalent to almost an entire year's worth of primary energy consumption from the U.S. residential and commercial sectors at current consumption rates.*
>
> Sources: Livingston, Cole, Elliott, Bartlett. *Building Energy Codes Program: National Benefits Assessment, 1992-2040.* March 2014. http://www.energycodes.gov/sites/default/files/documents/BenefitsReport_Final_March20142.pdf.

The United States has realized significant energy savings through building energy codes. Since program conception (1992–2012), BEC Program activities have contributed to an estimated 4 quads of cumulative primary energy savings and cost savings to consumers of more than $44 billion.[140] Furthermore, this analysis estimates that federal investment in the Program over this same period was approximately $110 million, resulting in a return on investment of more than $400 in consumer cost savings for each taxpayer dollar spent.

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[139] The Energy Policy Act of 1992 (EPACT 1992) (Pub. L. No. 102-486) was amended from the Energy Conservation and Production Act (ECPA) (Pub. L. No. 94-385), which was further amended by the Energy Policy Act of 2005 (EPACT 2005) (Pub. L. No. 109-58) and the Energy Independence and Security Act of 2007 (EISA 2007) (Pub. L. No. 110-140). More information can be found at the following website: https://www.energycodes.gov/about/statutory-requirements

[140] Livingston, O.V.; Cole, P.C.; Elliott, D.B.;Bartlett, R. *Building Energy Codes Program: National Benefits Assessment, 1992-2040.* Richland, WA: Pacific Northwest National Laboratory, 2014. Accessed August 22, 2014: http://www.energycodes.gov/sites/default/files/documents/BenefitsReport_Final_March20142.pdf

Opportunities for Future Savings: Energy and cost savings benefits from energy codes are expected to grow in the coming years due to adoption of increasingly stringent building codes and higher implementation rates. Figure 40 shows estimated historical energy savings from 1992 through 2012 and forecasted savings from 2013 to 2040. Ensuring code compliance and the existence of adequate enforcement infrastructure is expected to be a continuing challenge for realizing predicted savings and will be a focus of the Program.

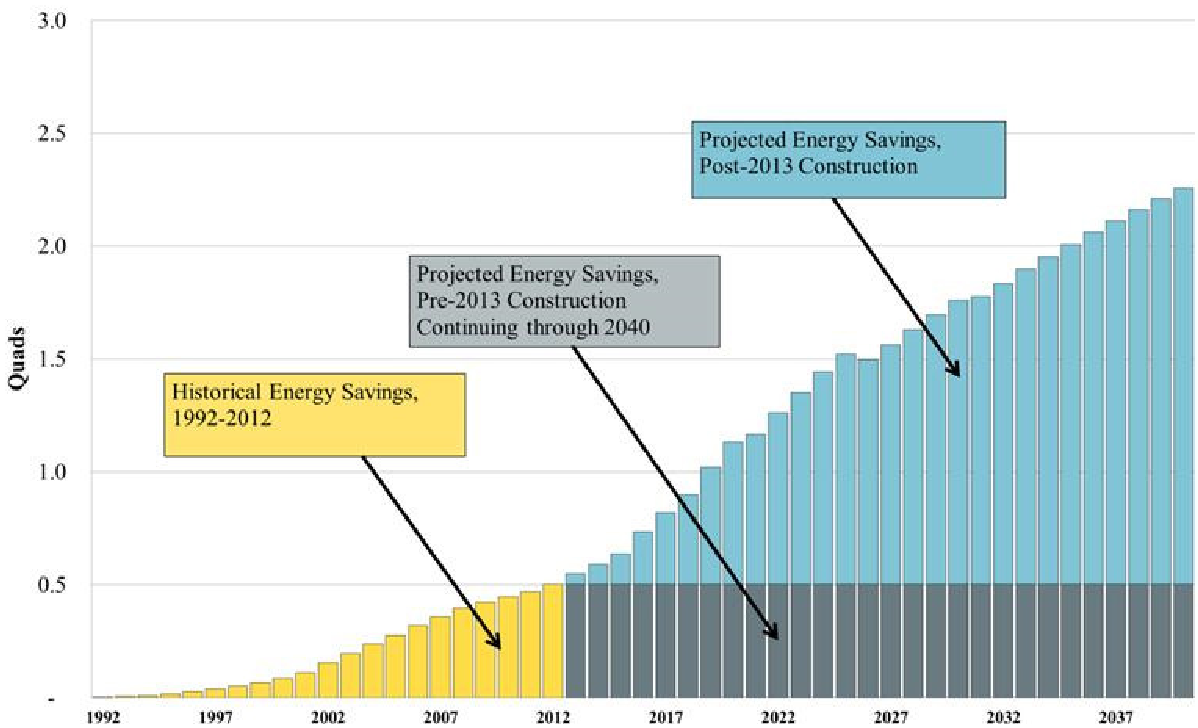

Figure 40. Annual full-fuel cycle energy savings from BEC Program activities (1992–2040)

Source: Livingston, O.V.; Cole, P.C.; Elliott, D.B.;Bartlett, R. *Building Energy Codes Program: National Benefits Assessment, 1992-2040.* Richland, WA: Pacific Northwest National Laboratory, 2014. Accessed August 22, 2014: http://www.energycodes.gov/sites/default/files/documents/BenefitsReport_Final_March20142.pdf.

Building Energy Codes Goals

By accelerating the development, adoption, and implementation of improved building energy codes, the BEC Program provides critical support to the achievement of BTO's market outcome goal of reducing energy use intensity (EUI) in new construction by 40% by 2025 from 2010 levels. The most recent model codes for both residential and commercial buildings nearly meet the 40% target in comparison to modeled energy use intensity of the average new buildings in 2010. However, state and local jurisdictions must adopt the model codes, and compliance with the codes is required to realize the energy savings potential of the advanced codes.

As illustrated in Figure 41, the achievement of this goal—along with other BTO Program efforts that lead to advancements in energy codes—will ensure that new buildings substantially contribute to improving the national EUI of the building sector by 2030. The BEC Program will continue to provide high-quality, objective analysis and technical assistance to enable informed decisions by state and local jurisdictions, which result in more efficient new homes for building owners.

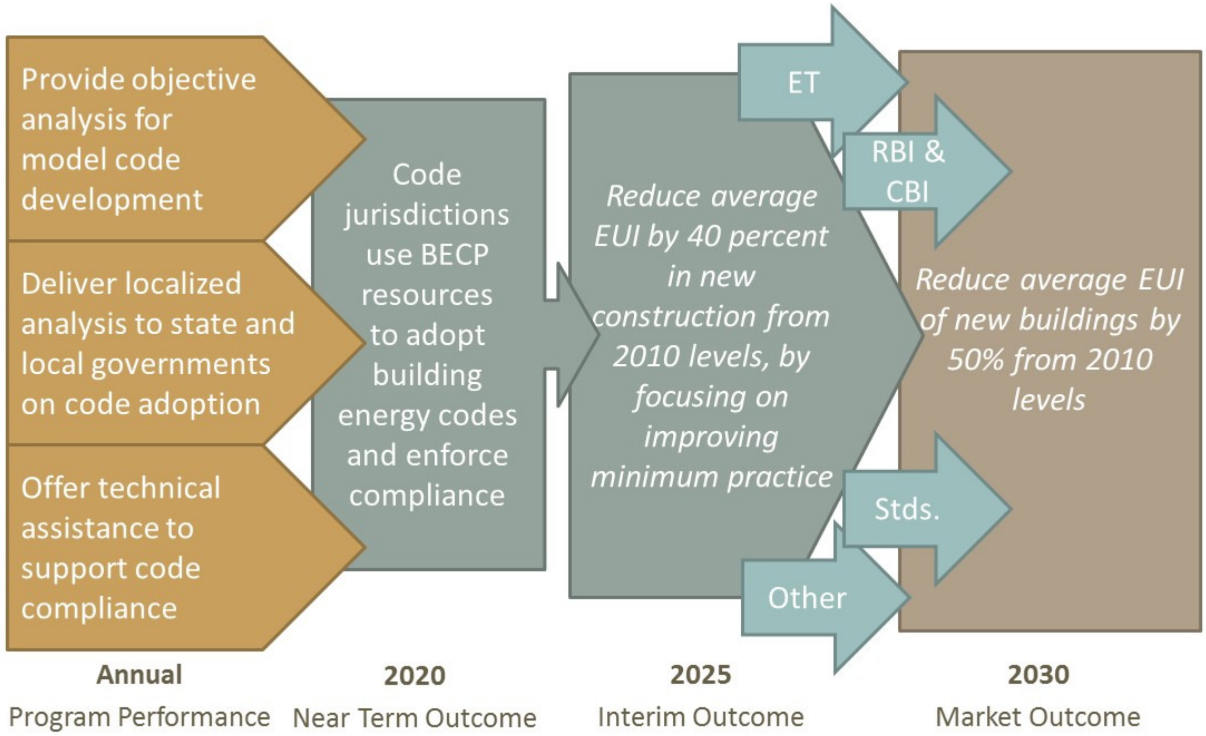

Figure 41. Building Energy Codes Program's goals hierarchy

To achieve these goals, the BEC Program has established performance targets focused on ensuring that stakeholders have the analysis and assistance they need to develop and implement building energy codes.

The BEC Program assesses the potential energy savings from the adoption and full compliance of building energy codes and aims for this analysis to be used in the adoption process by jurisdictions that represent at least 80% of all building floor space. Another program goal is that these jurisdictions will use compliance assessment methods developed or approved by the BEC Program in at least half of all new construction building floor area. These methodologies assess the energy savings in as-constructed buildings relative to the amount predicted by what is written in the code. These are currently under development and will be available by 2016 for residential buildings and late 2017 for commercial buildings.

The BEC Program tracks progress toward these goals by working with key stakeholders to determine the usage of Program analysis in the adoption of building energy codes and compliance methods by state and local jurisdictions. The Program also tracks adoption of codes by states. Beyond tracking these near term outcomes, the Program regularly assesses its performance relative to its program performance goals.

Building Energy Codes Strategies, Current and Planned Activities, and Key Targets

The BEC Program is directed by statute to publish determinations as to whether updated editions of the national model codes (Standard 90.1 and residential chapters of the IECC) will save energy relative to the preceding version. Quantifying the savings impacts and disseminating this information to policymakers supports state and local code adoption processes around the country.

To meet BEC Program goals, the Program has designed strategies to address barriers, as discussed above, affecting all phases of code development and implementation. A strong focus of the Program moving forward is increasing and measuring energy code compliance to ensure that intended energy savings are realized.

Success in the Model Codes

DOE provides technical assistance to the IECC and Standard 90.1 code development processes, providing technical and economic analyses to support code improvement. The IECC and ASHRAE develop the IECC and Standard 90.1, respectively, which are designated as the national model building energy codes in federal legislation. Recent editions of each code represent a 30% savings opportunity compared to the codes currently adopted by the majority of U.S. states.

Strategies

- *Participate in industry processes through which energy codes are developed, discussed, or approved and provide information of benefit to others in advancing energy codes.*
- *Establish the BEC Program in a leadership position by convening forums for discussing and sharing information on all aspects of codes.*
- *Empower those who seek to improve energy codes by providing research, analysis, tools and resources; developing code change proposals; establishing the value of energy codes to all stakeholders; and ensuring coordination with other building codes.*
- *Ensure intended energy savings by supporting education and outreach activities aimed at increasing energy savings and developing methodologies to measure changes in code-related energy use.*

Strategy 1: Participate in industry processes through which energy codes are developed, discussed, or approved and provide information of benefit to others in advancing energy codes.

The BEC Program participates in the national code development processes by developing code change proposals that are supported by rigorous analysis and then publicly reviewed to ensure that they are technologically feasible and economically justified. The proposals support energy saving, cost-effective technologies and construction practices and are based on the BEC Program's objective, transparent analyses. The Program also participates in "stretch" and "reach" code development processes, such as Standard 189.1[141] and the National Green Building Standard

[141] ANSI/ASHRAE/USGBC/IES. *Standard 189.1-2014—Standard for the Design of High-Performance Green Buildings*. Atlanta, GA: ASHRAE

(NGBS),[142] whose purpose is to go beyond the national model codes and provide nationally reviewed codes to those jurisdictions seeking more advanced requirements and greater energy savings.

Strategy 2: Establish the BEC Program in a leadership position by convening forums for discussing and sharing information on all aspects of codes.

The BEC Program creates forums for stakeholders to share information that can pave the way for advancement of building energy codes. For example, the Program holds the only conference in the country dedicated solely to energy codes. This conference provides an unparalleled opportunity for discussion among code practitioners and sharing of best practices on all phases of codes, including the future evolution of energy codes. The Program also organizes forums that follow the building codes cycle and enable sharing of ideas on code development proposals. Other areas of discussion include best practices on how to use technical and economic analysis methodologies and adoption and compliance tools and resources.

Strategy 3: Empower those who seek to improve energy codes by providing research, analysis, tools and resources; developing code change proposals; establishing the value of energy codes to all stakeholders; and ensuring coordination with other building codes.

The BEC Program produces technical and economic analysis reports, including energy and cost-effectiveness analyses, at both the national and state level to assist states and municipalities in adopting updated building energy codes, and to establish the value of savings that can be realized through energy codes. Following the issuance of an updated model code, the Program provides states, utilities, and other key stakeholders with analyses that quantify the energy savings, cost savings, and cost-effectiveness of the new code. The BEC Program tracks the usage of these reports and gathers feedback through the REEOs to ensure continual improvement.

The Program also provides tools and materials that aid stakeholders to improve and implement energy codes. Two important, widely used tools developed and maintained by the BEC Program are the RES*check* and COM*check* software programs, which make it easy for architects, builders, designers, and contractors to know whether their buildings meet the energy code. Both programs are available at no cost for individuals to download or use through the BEC Program website;[143] approximately 300,000 projects are uploaded each year.[144] Additionally, the Program maintains a web-based help desk for people to submit questions on any topic regarding energy codes. Many additional resources, such as design guides and compliance checklists, are also available to help ensure compliance is achieved in the field.

Strategy 4: Ensure intended energy savings by supporting education and outreach activities aimed at increasing energy savings and developing methodologies to measure changes in code-related energy use.

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[142] See http://www.homeinnovation.com/ngbs for more information.

[143] See REScheck, https://www.energycodes.gov/rescheck and COMcheck, https://www.energycodes.gov/comcheck

[144] Liu, B. "Building Energy Codes Overview." Presented at the 2014 Building Technologies Office Peer Review. Accessed August 22, 2014: http://energy.gov/sites/prod/files/2014/05/f15/cod07_Liu_042214.pdf.

The BEC Program develops training materials that outline requirements related to residential and commercial building energy code provisions. These are used by trainers and code practitioners to increase understanding of new codes and how to comply with them. The Program also produces resource guides on common challenges faced by energy code stakeholders, such as code officials and designers. In addition, the Program provides technical assistance for code implementation through national and regional organizations that support code adoption and compliance efforts within states and municipalities.

BECP recently awarded $6 million in competitive funds to conduct baseline studies measuring code-related energy use in new construction of single-family homes and to support follow-on education, training, and outreach targeted at weak areas identified in the studies. This project will generate standard methodologies that can guide stakeholders in analyzing the value of investments in code compliance. This information is intended to convince private investors, particularly utilities, to substantially increase their activities in this area. Going forward, the BEC Program will work with national and regional partners to track the usage of these methods across states and localities. The Program is also currently exploring methods to assess energy code compliance in commercial buildings.

6.0 Appliance and Equipment Standards

The Department of Energy (DOE) currently implements standards for more than 60 types of appliances and equipment, in accordance with the Energy Policy and Conservation Act of 1975 (EPCA), as amended. These products represent about 90% of home energy use, 60% of commercial building energy use, and 30% of industrial building energy use.[145] The Appliance and Equipment Standards Program (sometimes referred to as the Appliance Standards Program) helps consumers save billions of dollars on their utility bills and delivers energy and water savings by establishing energy and water efficiency requirements for a wide range of covered products,[146] including home appliances, heating and cooling equipment, lighting, electric motors, and distribution transformers. Building on the Building Technologies Office's (BTO's) efforts in research, development, and market transformation as well as product demonstration and labeling programs, the Appliance and Equipment Standards Program contributes to BTO goals by "locking in" or preserving these efficiency gains.

The Appliance and Equipment Standards Program's mission is to fulfill its statutory obligation to:

- *Develop and amend energy conservation standards that achieve the maximum energy efficiency that is technologically feasible and economically justified.*
- *Develop and amend test procedures that are repeatable, reproducible, representative, and enforceable.*
- *Enforce its certification and compliance regulations to ensure consumer savings and manufacturer adherence to DOE requirements.*

DOE promulgates energy conservation standards and test procedures in a rulemaking process in which decisions are based on technical merit; economic analysis; the full consideration of impacts on consumers, manufacturers, and the environment; and stakeholder feedback. The Program also works with research and development (R&D) organizations, including those funded by BTO, to gain insights into future technologies in the R&D pipeline, as well as potential improvements that will reduce the cost of current technologies. As new, cost-effective technologies are commercialized and adopted in the market place, DOE can consider them as the basis for future standards.

In fulfilling its statutory responsibilities, the Appliance Standards Program works closely with a broad range of stakeholders, including manufacturers, states, utilities, energy efficiency advocates, and others. Each rulemaking process provides opportunities for stakeholder review and comment, and the Program has established the Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) as another means of facilitating stakeholder engagement by allowing for negotiated rulemakings under the guidelines set forth in the Federal Advisory Committee Act.

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[145] U.S. Department of Energy. *Saving Energy and Money with Appliance and Equipment Standards in the United States*. Washington, DC: U.S. Department of Energy, 2015. Accessed August 24, 2015: http://energy.gov/sites/prod/files/2015/07/f24/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet%207-21-15.pdf

[146] *See* 42 U.S.C. § 6292 for "Covered Products."

The Appliance Standards Program works with other federal, state, and utility programs to continually increase the energy efficiency of covered appliances and equipment. For example:

- BTO's Emerging Technologies (ET) Program improves the energy efficiency and cost-effectiveness of technologies.
- BTO's Residential Buildings Integration (RBI) and Commercial Buildings Integration (CBI) Programs demonstrate those technologies and accelerate the adoption of more efficient products in both new and existing buildings.
- Federal Trade Commission's (FTC) EnergyGuide provides easily understandable information to consumers on the energy performance of a wide range of products.
- Environmental Protection Agency (EPA) ENERGY STAR® labels, together with utility incentives and government procurements, help build the markets for energy-efficient products.

Appliance and Equipment Standards Market Overview

Appliance and Equipment Market: Appliances and building-related equipment account for almost all energy use in buildings, and a substantial portion of the energy used in industry. Space heating and cooling equipment use the most energy in buildings, although lighting, water heating, refrigeration, and electric motors are also very large energy users. A broad range of electronic products, used in both homes and offices, have become major energy users over the past 20 years as well. A broad range of companies, both domestic and foreign, manufacture energy-using products.

Market Barriers: There is a gap between the typical efficiency of products in the market and the maximum product efficiency that is both technologically feasible and economically justified for U.S. consumers. Standardized testing and labeling provides consumers with information to compare the relative energy efficiency (or energy and water use) of different appliances and equipment. Even with such information, many energy users have difficulty estimating and comparing the lifetime benefits, first costs, and life cycle costs of products with different efficiencies, thereby not always making the best purchase decision.

Since policymakers have long recognized these barriers, the resulting efficiency gap, and the opportunities for large national energy and economic benefits, government (both state and federal) programs to increase product efficiency were first enacted in the 1970s and have been substantially expanded and strengthened since then.

Appliance and Equipment Standards Program History

EPCA provided the federal statutory authority for product testing and labeling, yet it was not until the late 1980s, after several individual states began establishing their own energy conservation standards, that the first federal conservation standards were established. Since then, EPCA has been modified by multiple legislative amendments requiring increasingly aggressive schedules and adding new products to be covered by DOE regulations. For example, the Energy Independence and Security Act (EISA) 2007 substantially elevated the level of activity within the Appliance Standards

Program, requiring new product test procedures and standards, and expanding its coverage of energy use in residential, commercial, and industrial buildings. The Program also works within its authority to proactively expand the scope of coverage, such as the recent final rule expanding the coverage of existing electric motor efficiency standards to new categories of motors. The Program has recently developed and amended test procedures at an unprecedented pace, publishing 12 final rules in FY 2014, and has expanded its role in developing test procedures for the ENERGY STAR program.

Appliance and equipment standards have had a significant impact on energy demand and consumer energy costs since the mid-1990s. Consumer utility bill savings totaled approximately $60 billion in 2014 alone.[147] The Program also strives to enforce existing standards to ensure energy savings. Since 2010, DOE has vigorously enforced its standards and has assessed more than $15 million in penalties on manufacturers for various violations. Additionally, the Appliance Standards Program supports the ENERGY STAR program and the FTC EnergyGuide labeling program through its test procedure development and verification testing.

Opportunities for Future Savings: Despite the substantial energy and monetary savings already achieved by the Program, the U.S. can achieve significant additional savings. Regular updates to existing standards are required by statute, and these updates ensure savings available from improved, cost-effective technologies are fully realized. The Program will also continue to identify new energy-consuming products for development of new energy conservation standards where appropriate.

Benefits of Recent Standards

Since 2009, 31 final rules have been issued, establishing energy conservation standards for more than 40 products. Between 2009 and 2030, these standards are projected to save consumers more than $522 billion in utility costs, reduce energy consumption by 39.3 quads, and reduce carbon dioxide emissions by over 2 billion metric tons. Through the end of 2016, as outlined in the Obama Administration's Climate Action Plan, DOE plans to issue more final rules that could reduce carbon pollution by an additional 1 billion metric tons between 2014 and 2030.

Source: U.S. Department of Energy. *Saving Energy and Money with Appliance and Equipment Standards in the United States*. Washington, DC: U.S. Department of Energy, 2015. Accessed August 24, 2015: http://energy.gov/sites/prod/files/2015/07/f24/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet%207-21-15.pdf

[147] U.S. Department of Energy. *Saving Energy and Money with Appliance and Equipment Standards in the United States*. Washington, DC: U.S. Department of Energy, 2015. Accessed August 24, 2015: http://energy.gov/sites/prod/files/2015/07/f24/Appliance%20and%20Equipment%20Standards%20Fact%20Sheet%207-21-15.pdf

Figure 42 shows the energy savings resulting from standards that have been issued since the establishment of the first energy conservation standards, and how those savings have and will continue to accrue over time. This data demonstrates the cumulative nature of energy savings from efficiency standards.[148] Figure 42 also indicates the savings resulting from rulemakings expected to be completed over the next several years.

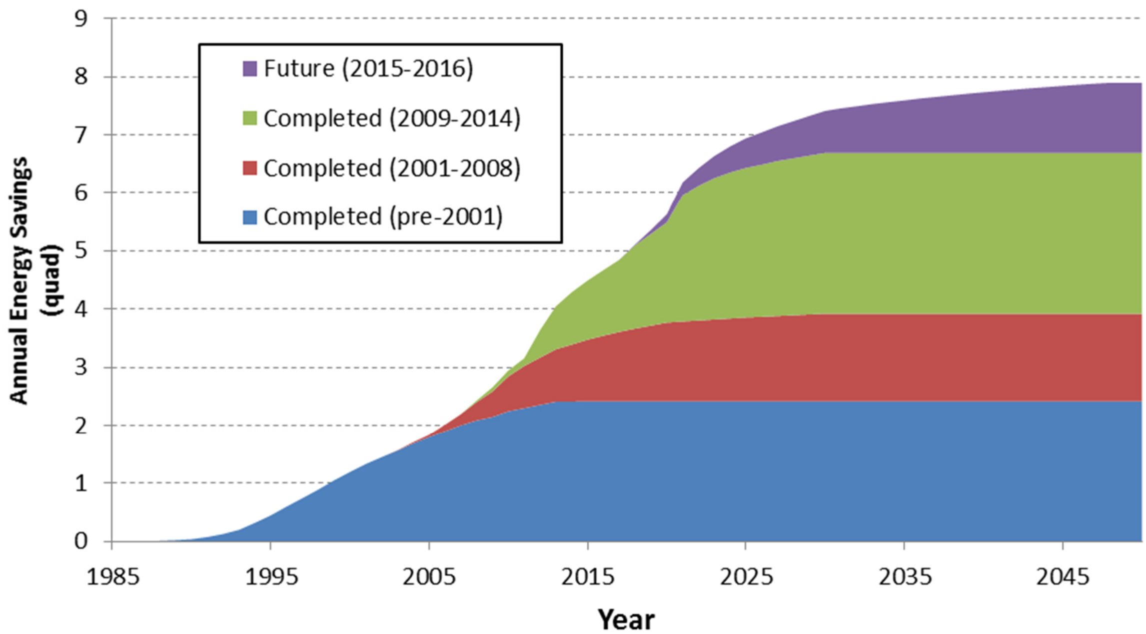

Figure 42. Appliance and equipment standards energy savings over time

Notes: Includes standards established by DOE and specified in legislation.

**Through August 2014 and based on BTO analysis*

[148] The plateau in the figure indicates that standards may continue to affect new products over time, if product efficiency continues to improve more than would have been the case without standards.

Appliance and Equipment Standards Goals

The Appliance Standards Program develops energy conservation standards that satisfy legislative directives and are technologically feasible and economically justified. These energy conservation standards have a broad impact on the energy use intensity (EUI) of all buildings. Given the expansive coverage of the Appliance Standards Program, its interim market goal for 2025 is to reduce the energy use intensity of the entire building sector by 20% from 2010 levels.

To achieve the 2025 goal, the Appliance Standards Program has identified three program performance goals for 2020:

- Establish, regularly review, and update, as needed, test procedures that reliably rate the efficiency of all products covered by energy efficiency standards or labeling, or that may be covered in the near future.
- Develop or update standards for 60 types of appliances and equipment.
- Support the verification of product efficiency by the testing of covered products.

As illustrated in Figure 43, the Program's efforts will significantly contribute to BTO's 2030 goal of reducing average EUI in the buildings sector by 30% relative to 2010.

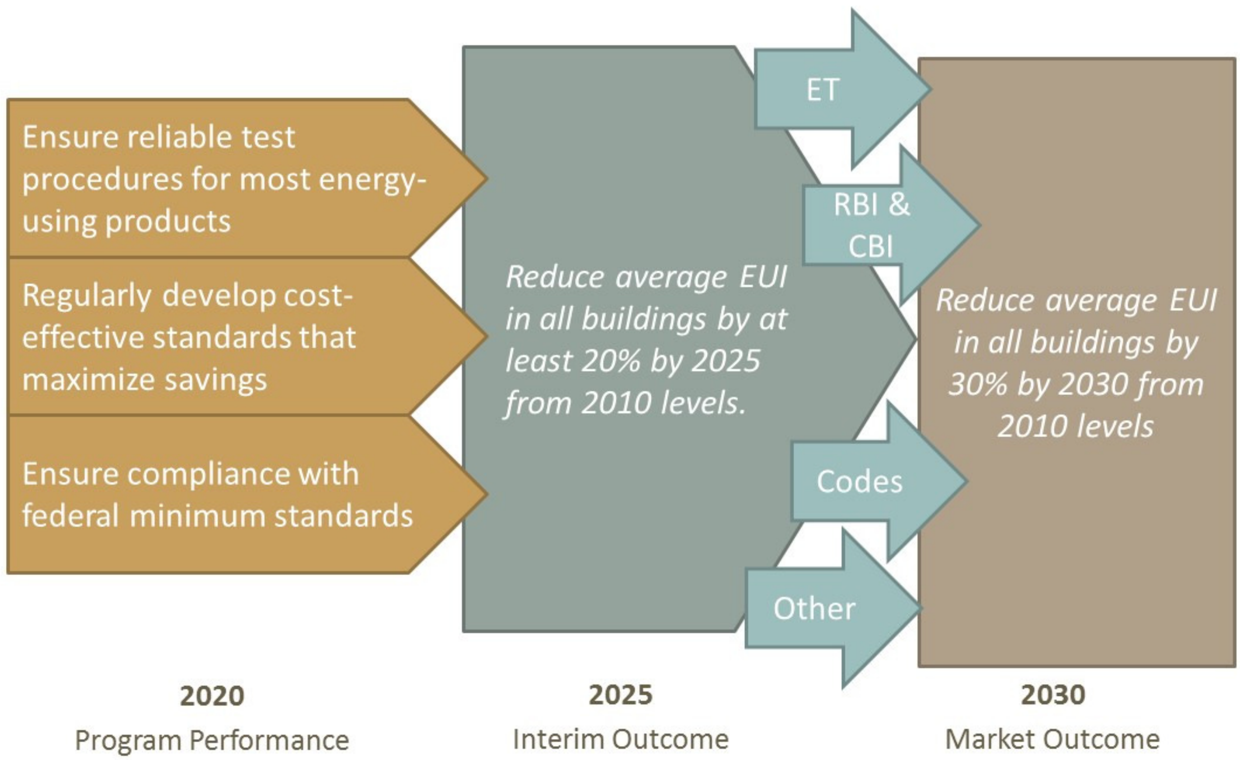

Figure 43. Appliance Standards Program's goals hierarchy

In addition, President Obama's Climate Action Plan (CAP) has set a goal for the United States to double energy productivity by 2030 relative to 2010 levels. As part of achieving this energy productivity goal, the CAP requires the Appliance Standards Program to issue new or updated standards, between the years 2009 and 2016, that will reduce carbon pollution by at least 3 billion metric tons cumulatively by 2030 and will continue to reduce consumers' energy bills.[149] The Appliance Standards Program has set internal targets to achieve this goal.

The Appliance Standards Program publishes a semi-annual report to Congress that reports its progress with respect to rulemaking actions regarding the implementation of energy conservation standards and test procedures. The Program also determines the impact of each new standard and regularly estimates their cumulative impact.

Appliance and Equipment Standards Regulatory Challenges

The primary challenges facing this regulatory program are meeting the many statutory requirements, as well as the numerous process requirements established by executive orders and related directives. The relevant statutes set numerous demanding deadlines for the development, periodic review, and updating of product test procedures and standards and requirements for extensive supporting analyses. In addition, ensuring the effective enforcement of requirements is becoming a growing challenge, as the number of products, manufacturers, and importers subject to these requirements has multiplied.

[149] Executive Office of the President. *The President's Climate Action Plan*. Washington, D.C.: Executive Office of the President, 2013. Accessed August 21, 2015: https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf

Appliance and Equipment Standards Strategies, Current and Planned Activities, and Key Targets

The Appliance Standards Program produces semi-annual reports to Congress that cover past, present, and future DOE rulemaking activities, as required by the Energy Policy Act (EPACT) 2005 and EISA 2007, pertaining to DOE's plans for the issuance of new or amended energy conservation standards. The August 2015 report[150] is available, and the next update will be released after February 2016. These reports provide extensive information related to the Program's current activities and future dates of expected issuance of key rulemaking documents. The Program is committed to complying with applicable deadlines and maximizing energy savings within budget constraints. To meet statutory requirements while at the same time expanding product coverage, the Program has developed new strategies to help in meeting the schedules set forth in the statute.

Strategies

- *Test Procedure Development: Enhance test procedures to capture innovative designs and to ensure they are resistant to "gaming."*
- *Standards Development: Raise minimum standards and expand the scope of covered products.*
- *Enforcement: Increase compliance testing and enforce certification and compliance with standards and product representation requirements.*

Strategy 1: Test Procedure Development: Enhance test procedures to capture innovative designs and ensure they are resistant to "gaming."

Stemming from the statutory directive to develop, revise, and implement energy conservation standards, the Appliance Standards Program develops or enhances test procedures for measuring energy efficiency of covered projects. DOE's test procedure development activities focus on:

- Increasing energy savings by better accounting for energy use.
- Keeping up with changing technologies to help avoid special exceptions (waivers), which are necessary when a test procedure is not applicable to a new technology.
- Reviewing test procedures for all covered products at least once every 7 years per the EISA.
- Expanding DOE's role in ENERGY STAR through test method development.

[150] U.S. Department of Energy. *Energy Conservation Standards Activities, Report to Congress*. Washington, DC: U.S. Department of Energy, 2015. Accessed August 24, 2015: http://energy.gov/sites/prod/files/2015/09/f26/2015%20Aug%20Report%20to%20Congress.pdf

Strategy 2: Standards Development: Raise minimum standards and expand the scope of covered products.

The Appliance Standards Program establishes mandatory energy conservation standards that meet the maximum level of energy efficiency that is technologically feasible and economically justified. The Program also works to expand the scope to include new products, such as commercial/industrial pumps, blowers and compressors, providing end users with additional energy savings.

The Appliance Standards Program facilitates active stakeholder involvement in the development of new product standards. In the development of a typical energy conservation standard, the Program uses a formal rulemaking process in which the Program engages stakeholders through numerous public meetings and comment periods. In addition, the Program has established ASRAC as a means of enabling greater stakeholder participation in the rulemaking process. Through ASRAC, the Program has initiated efforts to involve stakeholders in several negotiated rulemakings, including those for commercial HVAC, water heating, and refrigeration products, and commercial/industrial pumps.[151] In addition to formal negotiated rulemakings, the Program encourages stakeholders to work together to develop agreed upon proposals for DOE regulatory action, as was done previously for certain home appliances such as refrigerators and clothes washers, or for voluntary actions by the affected manufacturers, as was recently done for set-top boxes.

Success Story: Electric Motors

A recent final rule, with a compliance date of June 1, 2016, establishes energy conservation standards for a number of different groups of electric motors that DOE has not previously regulated. Previous standards have concentrated on general purpose motors with standard features; this updated rule garners further energy savings by bringing more specialized motor types up to those same premium-efficiency levels. This amended standard will save approximately 7 quads of energy and result in approximately $41 billion in energy bill savings for products shipped from 2016 to 2045. The standards will avoid about 395 million metric tons of carbon dioxide emissions. The rule closely mirrors a joint petition by a diverse group of stakeholders, including manufacturers and energy efficiency advocacy organizations.

Source: "Electric Motors." Washington, DC: U.S. Department of Energy, 2014. Accessed August 22, 2014: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/50

Finally, the Program seeks to accelerate rulemaking schedules by improving efficiencies in the rulemaking process, while also exploring new approaches to establishing conservation standards. For example, with DOE support, in September 2013, a broad representative group of Pay-TV, consumer electronics industries, and energy efficiency advocates announced a Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Set-Top Boxes (Agreement). Under the terms of the Agreement, it is projected that consumers will realize approximately $1

[151] An earlier negotiated rulemaking focused on distribution transformers.

billion of electricity savings annually**.** The Agreement provides for energy savings to consumers, while eliminating a need (at this time) for a longer rulemaking process.

Strategy 3: Enforcement: Increase compliance testing and enforce certification and compliance with standards and product representation requirements.

The Appliance Standards Program tests products to verify compliance with DOE regulations and enforces regulations when necessary. DOE can order manufacturers to take corrective action if their products do not meet the conservation standard levels. Product compliance ensures energy savings are achieved from the energy conservation standards.

Key Targets

To achieve the performance goal for rulemakings from FY 2015 through FY 2020, the Appliance Standards Program establishes detailed schedules for all public notices and regulatory documents to be issued over the next several years. Most standards rulemakings involve the issuance of four or more public notices, and two or more public meetings and webinars. Test procedures usually require two public notices. All public notices, meetings, and webinars are intended to solicit stakeholder review and comment.

An example of two rulemakings and related implementation milestones associated with one product, portable air conditioners, from 2014 is provided in Figure 44**.** As indicated, typical standards rulemakings require approximately 3 years to complete; test procedure rulemakings usually require about 2 years.

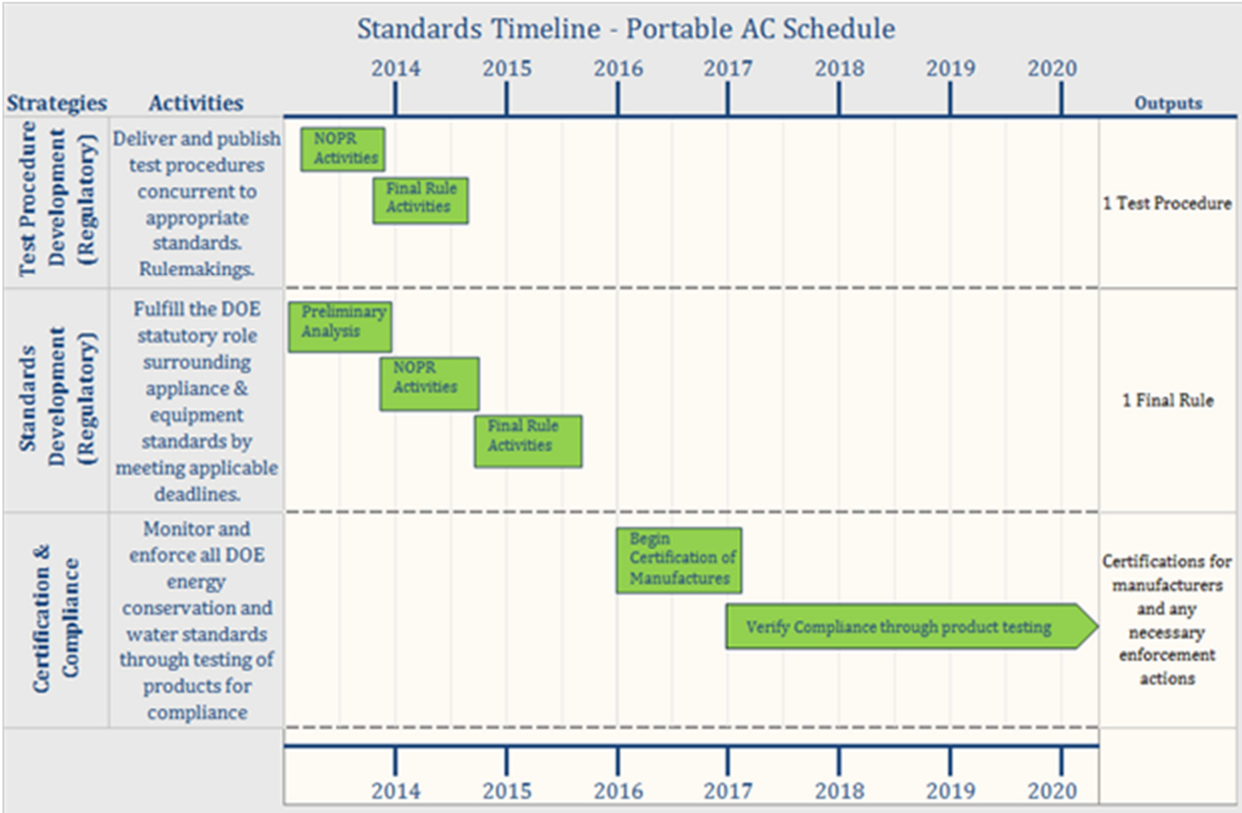

Figure 44. Illustration of how one product (portable air conditioners) moves through each strategy implemented by the Appliance Standards Program

The schedule of upcoming public notices and other rulemaking activities is included in regular reports to Congress[152] and in the Obama Administration's published Regulatory Agenda.[153] The Appliance Standards Program aims to publish 30 energy conservation standard final rules between calendar years 2015 through 2017, as detailed in Table 19. Beyond this time horizon, the Program can project future rulemakings based on the statutory requirements to regulate, review, and update all test procedures and standards.

Table 19. Schedule of final rule publications for calendar years 2015-2017

Final Rule Publication Calendar Year	Number of Published Final Rules
2015	12
2016	14
2017	4

[152] See: http://energy.gov/eere/buildings/reports-and-publications
[153] See: http://www.reginfo.gov/public/do/eAgendaMain

7.0 Appendix