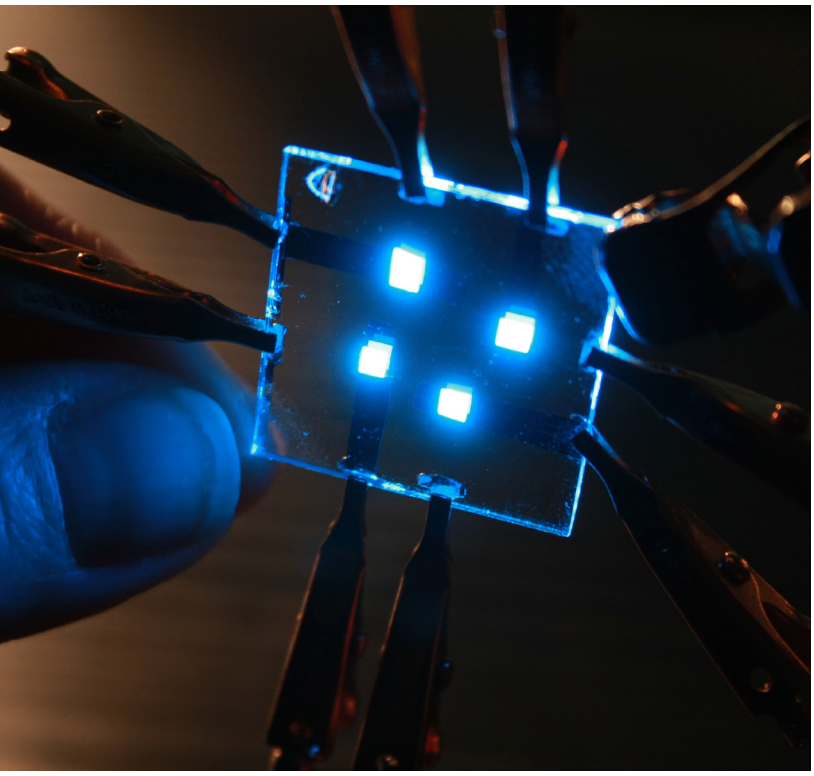
BUILDING TECHNOLOGIES OFFICE

Peer Review Report 2016



2016 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

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

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Introduction

The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) leads a vast 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. Residential and commercial buildings account for 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 more than $430 billion.[1] BTO's long-term objective is to reduce the energy intensity of residential and commercial buildings by 50% or more through the application of cost-effective efficiency technologies that yield substantial net economic benefits and result in significant reductions in greenhouse gas (GHG) emissions.

Knowledge about the quality and effectiveness of current BTO projects and programs is essential to enhancing existing efforts and designing future programs. To ensure that BTO projects and programs are relevant, effective, and productively assisting BTO in meeting its energy reduction goals, BTO conducts an annual Peer Review. Peer Review is a formal, documented evaluation process that uses objective criteria and qualified independent reviewers to assess the technical, scientific, and/or business case merits; the actual or anticipated results; and the productivity and effectiveness of BTO-funded projects. The BTO Peer Review is open to the public, and provides an opportunity to learn more about BTO's project portfolio as well as opportunities for collaboration and partnership.

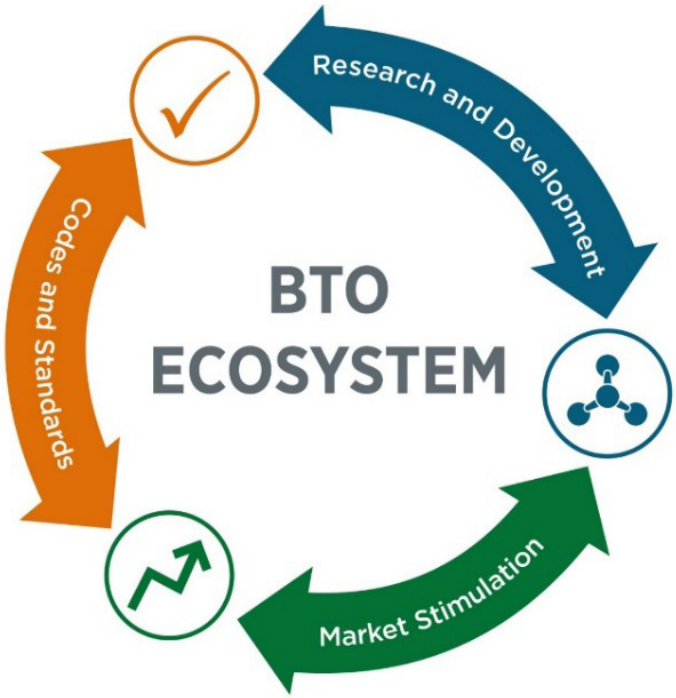


Figure 1. BTO Ecosystem

Mission and Goals

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:

1. Research and development to reduce cost and improve performance of high-impact energy saving technologies.
2. 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.
3. Codes and standards to remove market barriers, lock in lasting energy savings for all Americans, and drive further technology innovation.

BTO's strategy integrates innovation with market-priming efforts, in cooperation with researchers, private and public stakeholders, and other partners to accelerate the development and 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 product standards and state and local action to strengthen building codes. Like any ecosystem, each piece of the BTO framework supports the others, and each is equally important.

Introduction

BTO's Multi-Year Program Plan (MYPP) outlines the activities BTO will pursue over the next five years to enable these outcomes and provide compelling, affordable energy efficiency options for our nation's homes and buildings. The BTO MYPP outlines the three categories of goals: program performance goals for 2020, interim market outcome goals for 2025, and sectoral outcome goals for 2030.

Reducing building energy use per square foot, or energy use intensity (EUI), directly supports achievement of the U.S. national goals of reducing energy-related GHG emissions and doubling energy productivity.[3] BTO's efforts to reduce the EUI of buildings will also have other environmental benefits, help conserve valuable natural resources, and strengthen the U.S. economy by improving the productivity of businesses and helping families save money. Additionally, certain BTO technologies and activities support the achievement of other benefits, such as improving indoor air quality, developing substitutes for refrigerants with high global warming potentials, and enabling the integration of buildings with demand response systems implemented by operators of the nation's power grid.

2016 BTO Peer Review

The 2016 BTO Peer Review was held April 4–7, 2016, at the Falls Church Marriott in Falls Church, Virginia. The review was attended by more than 400 participants and included presentations on 67 projects representing three of BTO's five technology programs (see Figure 2).

For the 2016 Peer Review, the Building Energy Codes Program (BECP) did not conduct any project reviews. The Appliance and Equipment Standards Program is typically excluded from the BTO Peer Review process, as it is not involved with typical R&D or market stimulation projects.[4]

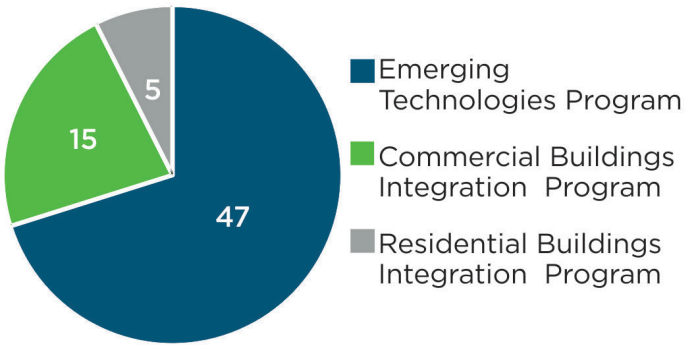


Figure 2. Peer Reviewed Projects by BTO Program

Overview of BTO 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. To support the achievement of this 2030 goal, each of BTO's five constituent technology programs has identified market-focused interim goals:

1. **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.[2]
2. **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.
3. **Residential Buildings Integration Program**: By 2025, improvements in the efficiency of space conditioning and water heating in single-family homes will reduce these energy uses by 40% from 2010 levels.
4. **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.
5. **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.

Introduction

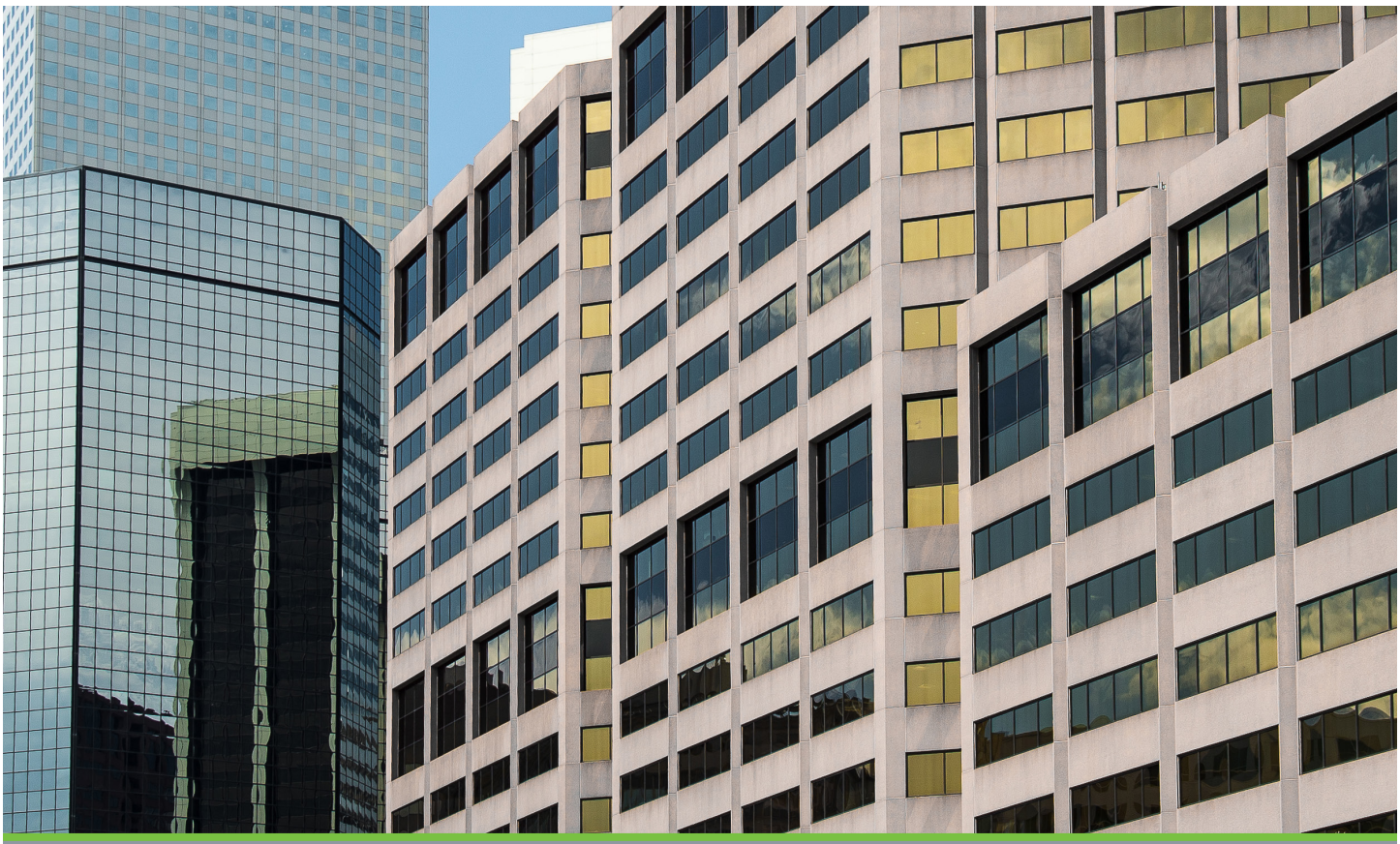
The objectives of the 2016 BTO Peer Review were to:

1. Conduct an independent evaluation of current BTO projects and performers, their efforts over the past year toward achievement of BTO goals, and their future plans;
2. Provide a forum to promote collaborations and partnerships among project performers and other stakeholders; and
3. Communicate the value of BTO investments.

Independent reviewers were drawn from a variety of building-related backgrounds and included experts from industry, academia, government, and other stakeholder groups. The reviewers were screened for conflicts of interest and assigned to projects based on their area of expertise and interests. The Appendix provides a complete list of reviewers.

This BTO Peer Review Report summarizes the scores and comments submitted by these reviewers for the 67 projects presented at the 2016 Peer Review.[5] Reviewers evaluated each project within the context of its respective technology program area. The following presents an overview of the goals and activities under each technology program area, a summary of project scores for each program, and a brief analysis of general evaluation trends within each program area or its constituent sub-programs. Individual project scores and comments are available on the 2016 BTO Peer Review webpage or in the Appendix.

For the first time, BTO hosted several panel discussions on R&D topics, during which project performers provided feedback from the field on current research trends and barriers. Additionally, each BTO program hosted a moderated session to solicit comments from project performers and other stakeholders on current goal-achievement strategies. This represents the second formal opportunity for BTO stakeholders to provide comment on goals, and was a follow-on to stakeholder feedback requested in 2015 on the draft BTO MYPP. During the 2016 Peer Review, stakeholders were asked specifically to comment on perceived gaps or disconnects between a program's projects and its goals. An overview of stakeholder feedback on each program's goal-achievement strategies is presented below alongside its programmatic overview



Downtown Denver, CO. Image courtesy of National Renewable Energy Laboratory.

Emerging Technologies

The Emerging Technologies (ET) Program works with industry, DOE national laboratories, and academia to advance both the research and development (R&D) and commercialization of energy-efficient, cost-effective building technologies and systems. The ET Program's primary focus is applied R&D of relatively near-term building energy efficiency technologies, or technologies expected to be commercialized within five years, although the portfolio also includes some longer-term energy solutions currently at an earlier stage of development.

The ET Program focuses on improving energy efficiency in four major technology areas, which together represent approximately 60% of the energy used in buildings and are expected to represent an even greater share of energy efficiency gains over the next several decades.[7] These four technology areas are:

- **Sensors and Controls**
- **Heating, Ventilation, and Air Conditioning (HVAC); Water Heating; and Appliances**
- **Windows and Building Envelope**
- **Solid-State Lighting**

The ET Program also works to advance the state-of-the-art in open-source Building Energy Modeling (BEM), and plans to explore R&D opportunities that could lead to significant improvements in the efficiency and management of end-use technologies that are not the focus of the current program, such as consumer electronics and small appliances.[8]

Prototyping new energy-efficient technologies in a laboratory setting. Image courtesy of Fraunhofer CSE.

The ET Program's 2020 goals, described in detail in BTO's Multi-Year Program Plan, encourage and support substantial improvements to the technologies that are available to reduce energy use in buildings, so that the resulting technologies are much better than those currently installed. Specifically, the ET Program works to:

- Enable the development of cost-effective technologies that will be capable of reducing a building's energy-use intensity by 30% by 2020, relative to 2010 high-efficiency technologies.
- Enable the development of cost-effective technologies that will be capable of cutting a building's energy use by 45% by 2030, relative to 2010 high-efficiency technologies.[9]

ET internal analysis using the BTO Prioritization Tool (P-Tool) has concluded that if these technologies were rapidly deployed, they would decrease annual energy consumption of the U.S. buildings sector by 20 quads, and cut annual carbon dioxide (CO_2) pollution by 1 billion metric tons.[10,11,12] Even with only partial deployment, these technologies would make a significant contribution to the achievement of BTO's 2030 goal of reducing building energy-use intensity (EUI) by 30% by 2030.[13]

The ET Program works with stakeholders and performers to identify strategies best suited to overcome the technical and market challenges associated with R&D for each of its technology areas, and then to develop corresponding technology roadmaps. The aim is to improve building energy performance and reduce costs by developing improved materials or components, improving equipment design or engineering, developing lower cost manufacturing processes, and/or enabling easier installation.

Feedback on ET Program Goals

Stakeholders participated in a session at the 2016 BTO Peer Review to discuss and provide feedback on ET Program goals. During this session, then-ET Program Director Pat Phelan provided an overview of the ET Program. Peer Review attendees were then asked (1) whether the 2020 and 2030 goals were appropriate for ET; (2) whether programmatic activities described in the MYPP would lead to the desired long-term

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outcomes; and (3) whether the metrics in place to measure progress toward success were appropriate.

Attendees provided numerous comments regarding the appropriateness of the ET Program's goals. Some of the comments focused on the ability of the ET Program to measure its progress, highlighting that its goals are inherently about enabling energy savings, but noting that it was unclear how "enablence" could be measured to determine if the program was achieving success. Others addressed the precision with which certain goals were described, noting that the term "cost-effective" could mean many different things to different people, and they suggested that a more concrete term might be preferred. Finally, attendees offered conflicting comments on the ambitiousness of the ET Program's goals, with one stating that the 2030 market outcome goal was too ambitious – given that some energy efficient technologies can take up to 20 years to achieve significant market penetration – while another individual felt that the Program's goals should be more ambitious.[14]

In response to questions about whether the ET Program's activities would lead to the achievement of desired outcomes, Peer Review attendees encouraged BTO to annually re-evaluate different program strategies and activities, allowing the mix of strategies and activities to evolve and grow in response to changing circumstances in both the R&D and commercialization realms.

Attendees reinforced the view that the suite of activities described in the MYPP were not bad or inappropriate, but rather that it was important for BTO to remain vigilant and adaptable. Attendees stressed that there are too many moving parts in the energy sector, many of which could have serious consequences for the market penetration of energy efficient technologies (e.g., the emergence of energy storage technologies) for BTO to be rigid in its approach.

In regards to the ET Program's metrics, session attendees observed that it was quite problematic for the Program to work toward total energy use and EUI goals since these are inherently deployment measures. They noted that the challenge is finding metrics that could distinguish between the contributions toward overall BTO goals of ET-supported technologies versus the contributions of BTO's deployment-focused programs. However, attendees did not offer a clear vision for what these alternative metrics should be, nor the metrics' level of accuracy or precision, but they did stress that stakeholder feedback would be valuable to nailing down the right measures.

High-Level Summary of Reviewer Comments

The ET Program peer reviewed 47 projects across five sub-programs: Sensors and Controls; HVAC, Water Heating, and Appliances; Windows and Building Envelope; Building Energy Modeling; and Solid-State Lighting. This section discusses the high-level evaluation trends by sub-program and Table 1 provides a high-level summary of project scores broken out by technology area.[15] Projects had a maximum potential score of 4 and a minimum potential score of 1. For individual project scores and comments, please visit the 2016 BTO Peer Review webpage or see the Appendix.

Table 1. High-Level Summary of ET Project Scores

			RANGE	
Sub-Program	Count	Average Score	Low	High
Sensors & Controls	5	2.68	2.19	3.10
HVAC/Water Heating/ Appliances	27[(a)]	3.09	2.58	3.61
Windows & Envelope	9	3.07	2.58	3.49
BEM	2	3.15	3.03	3.27
Lighting	4	3.51	3.37	3.82
Overall	47	3.08	2.19	3.82

[(a)] Five presentations under the HVAC, Water Heating, and Appliances technology area represent individual research opportunities but are considered a single project led by Oak Ridge National Laboratory.

Sensors and Controls

The goal of the Sensors and Controls (S&C) 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, photovoltaic) and automate energy transactions with the grid, making both buildings and the electrical 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.

The S&C Sub-Program focuses on strategies that enable simplified applications for building operation, open and easily accessible data from sensors, and novel applications of sensor data for building management systems. These solutions, which offer new services to building assets, were at the forefront of the five S&C projects reviewed at the 2016 BTO Peer Review.

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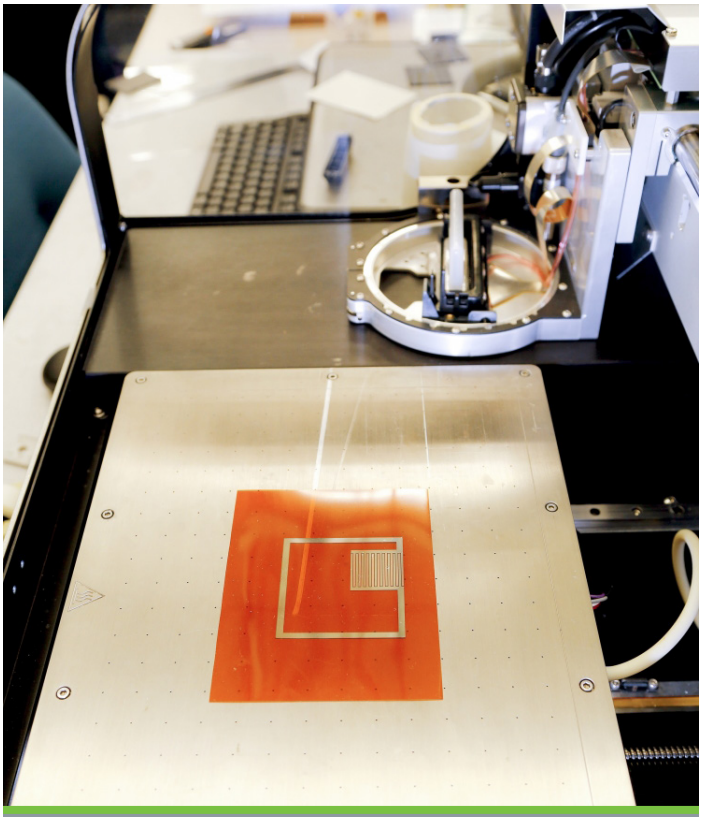
Monitoring and controlling building operations with energy management systems. Image courtesy of Pacific Northwest National Laboratory.

Reviewers assigned lower scores to projects where they disagreed with some of the project team's underlying assumptions regarding approach, as in the CBERD: Integrated Sensors and Controls project, or felt that the project team had misidentified the critical barrier their project was addressing, as with Building Energy Management Open-Source Software Development (BEMOSS). Reviewers also assigned lower scores where the approach was considered risky given the technical challenge of the project's objective, as in the case of the University-Industry-National Laboratory Partnership to Improve Building Efficiency by Equipment Health Monitoring with Virtual Intelligent Sensing.

In general, reviewers agreed with those approaches adopted by sensor node project teams, although in each case scores were tempered by reviewers' reservations about other aspects of the projects. For one project, Low-Cost Wireless Sensors for Building Applications, reviewers highlighted that the project team had identified—and were working to resolve—all major challenges to its manufacturing technique, but reviewers also felt that certain product performance characteristics were not being addressed. For the other sensor node project, Transforming Ordinary Buildings into Smart Buildings via Low-Cost, Self-Powering Wireless Sensors and Sensor Networks, reviewers observed that the project team appears to have engineered a successful product; however, some reviewers felt that this was a result of the bar being set low and that no novel technology development was occurring.

Regardless of how successful the projects were at achieving their objectives, low scores were assigned for a project's level of progress when it was not clear that the project had pushed the boundaries of existing technologies. For example, both the CBERD and Transforming Ordinary Buildings into Smart Buildings projects were perceived by reviewers as focusing more on technology integration than technology development, and reviewers also had a hard time differentiating the end product of the BEMOSS project from existing software offerings. Reviewers assigned Equipment Health Monitoring a strong score based on reviewers' belief that the project represented an attempt to advance building science, though reviewers were somewhat skeptical of the approach's ultimate feasibility. The highest score for accomplishment was assigned to the Low-Cost Wireless Sensors project, which reviewers expected to change the market by adjusting the price point of a core technology.

Across most S&C projects, reviewers noted a lack of industry collaboration. In the case of the CBERD project, reviewers felt the project team would have benefited from U.S. industry input on market developments in the U.S. versus India. The Low-Cost Wireless Sensors project was lauded for its close collaboration with a single industrial partner, but reviewers felt the project could have benefited from increased collaboration in other areas, notably potential technology end users.



Advanced manufacturing techniques for wireless sensor platforms. Image courtesy of Oak Ridge National Laboratory.

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HVAC, Water Heating, and Appliances

HVAC, water heating, and appliances account for an estimated 22 quads of primary energy consumed in the United States, with HVAC representing the largest energy end use in both residential and commercial buildings.[16] The HVAC, Water Heating, and Appliances Sub-Program has taken a leadership position in the development of several new technologies, including:

- Integrated heat pump (IHP) research, including the development of centrally ducted IHP technology, air-source, and ground-source.
- Cold climate heat pump (CCHP) research and equipment for building space heating in cold climates.
- Low-global warming potential (GWP) refrigerant research, including searching for and evaluating potential low-GWP alternative refrigerants.
- Heat exchanger research including both conventional and unique designs.
- Non-vapor compression research.

Each of these research thrusts were represented among the 27 projects reviewed under the HVAC, Water Heating, and Appliances Sub-Program at the 2016 BTO Peer Review, alongside projects seeking to advance other innovative technologies for specific products (e.g., clothes dryers) and product components (e.g., high-efficiency HVAC motors). HVAC projects represented the largest category of such projects in this Sub-Program with 16. The remaining 11 projects were divided between appliances (six) and water heating (five).

Advanced permanent magnet HVAC motor. Image courtesy of QM Power, Inc.

HVAC projects are further segmented into four technology sub-areas for better disaggregation of evaluations trends: advanced vapor compression, non-vapor compression, heat pumps, and assorted HVAC and refrigeration (HVAC&R) technologies. Each of these technology areas and sub-areas are discussed in the sections that follow.

Table 2 provides a high-level summary of project scores; projects had a maximum potential score of 4 and a minimum potential score of 1.

Table 2. High-Level Summary of HVAC, Water Heating, and Appliance Project Scores

			RANGE	
Technology Area	Count	Average Score	Low	High
HVAC	16	3.05	2.69	3.38
Advanced Vapor Compression	2	3.04	3.00	3.08
Non-Vapor Compression	5	2.95	2.74	3.20
Heat Pumps	6	3.08	2.69	3.38
Assorted HVAC&R	3	3.16	3.05	3.33
Water Heating	5	3.25	3.09	3.61
Appliances	6	3.06	2.58	3.38

HVAC – Advanced Vapor Compression

HVAC systems presently represent the largest energy end-use in buildings, requiring almost 14 quads of primary energy annually, or nearly 30% of all energy used in U.S. commercial and residential buildings. Conventional refrigerants used in vapor-compression equipment contribute to global climate change when released into the atmosphere, and BTO is working with several partners to transition away from them and towards low-GWP refrigerants. Advanced vapor compression projects aim to reduce the cost and improve the performance of air conditioning systems in buildings using refrigerants that have minimal effect on the global environment in the near term. Reviewers evaluated two advanced vapor compression projects: High Efficiency Low Global-Warming Potential (GWP) Compressor and Low-Global Warming Potential HVAC System with Ultra-Small Centrifugal Compression.

Reviewers agreed that both projects had a good approach. Reviewers felt that neither project presented enough specific technical information to enable the projects to be fully evaluated. However, reviewers also thought that each project was taking a reasonable approach to address a range of conditions.

Both projects also received a good score for accomplishment; however, reviewers' rationale for their assessment of each

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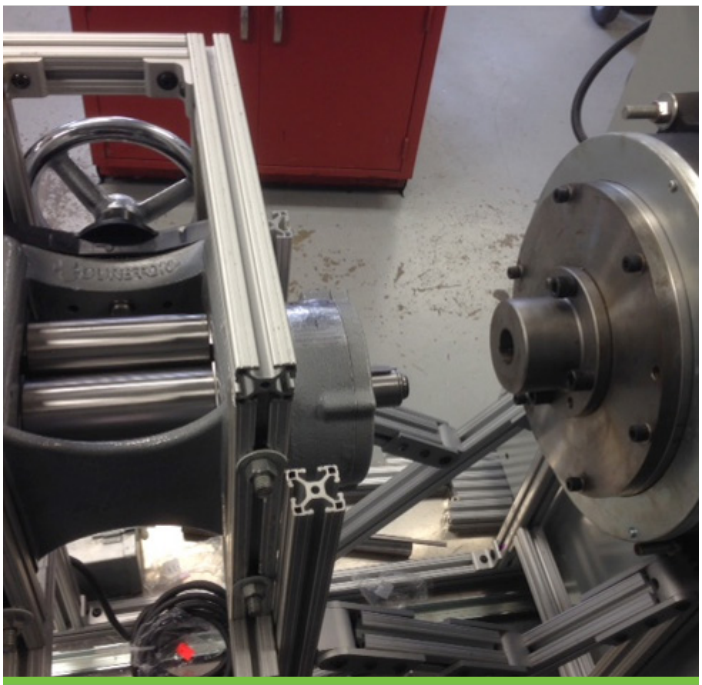
project was different. Reviewers were divided over the accomplishments of the Ultra-Small Centrifugal project, with some saying it was too early in the process to make a determination and others claiming the task was not well-defined. The Low-GWP Compressor project received high marks because the project appeared to be on track, although reviewers similarly felt that it was too early and that there was not much to review in terms of accomplishments.

Reviewers felt the level of collaboration in both projects was relatively strong, finding that each project team had a solid industry partner to help with production and future commercialization.

HVAC – Non-Vapor Compression

Given the energy usage of HVAC systems and the harmful environmental impacts from conventional refrigerants, BTO is working alongside its partners to develop next-generation HVAC systems that do not use hydrofluorocarbon (HFC) refrigerants. Non-vapor compression projects seek to develop highly-efficient HVAC systems that can achieve cost-effectiveness in the long-term.

One non-vapor compression project, Membrane Based Air Conditioning, received a low score for approach because reviewers were confused about whether the project was truly focused on non-vapor compression given the components involved. For another lower-rated project, Compact Thermoelastic Cooling System, reviewers felt that while the project team had identified many technical barriers – including size, temperature lift, cost of materials, and physical architecture of a system – additional risk mitigation was necessary to address many of these barriers.



Compact Thermoelastic Cooling System. Image courtesy of Maryland Energy and Sensor Technologies, LLC.

Projects with higher scores for approach identified and addressed critical barriers, both in terms of fundamental research barriers standing in the way of technology development (by focusing on module/system development) and market barriers (such as cost and operating efficiency). Reviewers also positively commented on the Magnetocaloric Air Conditioner project team's reaching out to commercial partners in the early stages of the project, although they recommended engaging with a material supplier sooner.

The bulk of the projects reviewed in this track are still in their early stages, and thus reviewers were not able to identify many accomplishments at this point. Most projects have successfully met first milestones, however, such as establishing partners, formulating concept designs, and initial modeling.

The non-vapor compression projects with the highest scores had both strong and broad partnerships with industry, academia, and national laboratories. The highest scoring project, Low-Cost Electrochemical Compressors Utilizing Green Refrigerants for HVAC Applications, engaged stakeholders focused on fundamental research (University of Delaware), testing and validation (Oak Ridge National Laboratory), and commercialization (Haier). Another high scoring project, Higher-Efficiency Solid-State Heat Pump Module, was recognized for its in-house partnership with Carrier, while others were lauded for their good mix of partners. The projects that received lower scores in this area had smaller project teams, and although their collaboration with partners was viewed as strong, reviewers wanted to see partnerships expanded.

HVAC – Heat Pumps

Heat pumps provide space conditioning and/or hot water by capturing energy from their surroundings, whether it is the ambient air, the ground, or water. While these technologies have been commercially available within the United States for decades, they have traditionally been used in niche markets – such as space conditioning for moderate climates. Projects reviewed in this technology area seek to innovate heat pumps across new geographic areas and using new fuel types.

Heat pump projects with the highest scores described and addressed key market barriers, including first cost, operating costs, and cold climate heat pump operation. In one well-regarded project, High Performance Commercial Cold-Climate Heat Pump, reviewers praised the iterative design steps, attention to overcoming market barriers, and utilization of a realistic approach to raising the supply air temperature in cold weather. In contrast, a project that received a lower score, Natural Refrigerant High-Performance Heat Pump for Commercial

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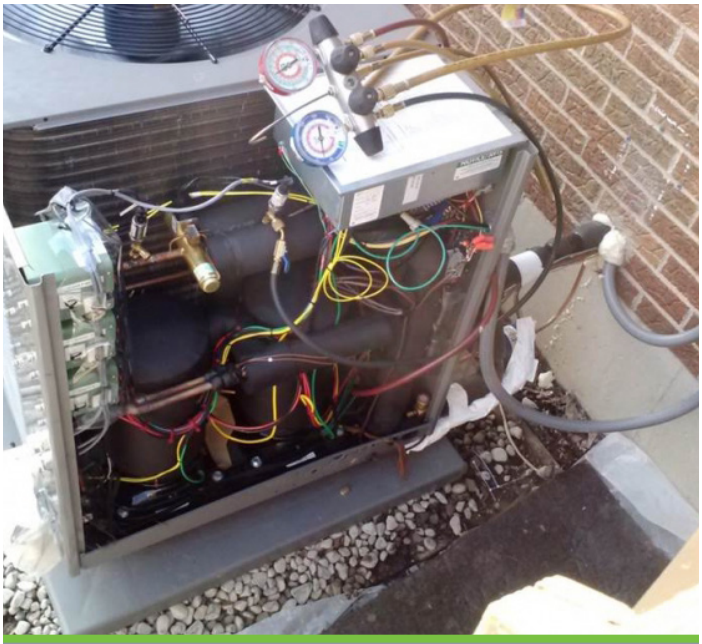


Cold-climate air-source heat pump. Image courtesy of Oak Ridge National Laboratory.

Applications, was still in the process of overcoming a major market barrier, namely, developing a suitable compressor. Another lower-scored project, Natural Gas Fired Air Conditioner and Heat Pump, had reviewers concerned about marketability and industry acceptance, as well as whether the technology could be manufactured at a reasonable cost.

Heat pump projects with the lowest scores either were behind schedule to meet project goals, or reviewers could not determine how current project accomplishments would translate into market goals. The lowest score was assigned to the project Manufacturing Competitiveness and Supply Chain Analysis based on agreement among reviewers that it would – at best – contribute only indirectly to BTO and some even expressing doubt about this project's eventual impacts.

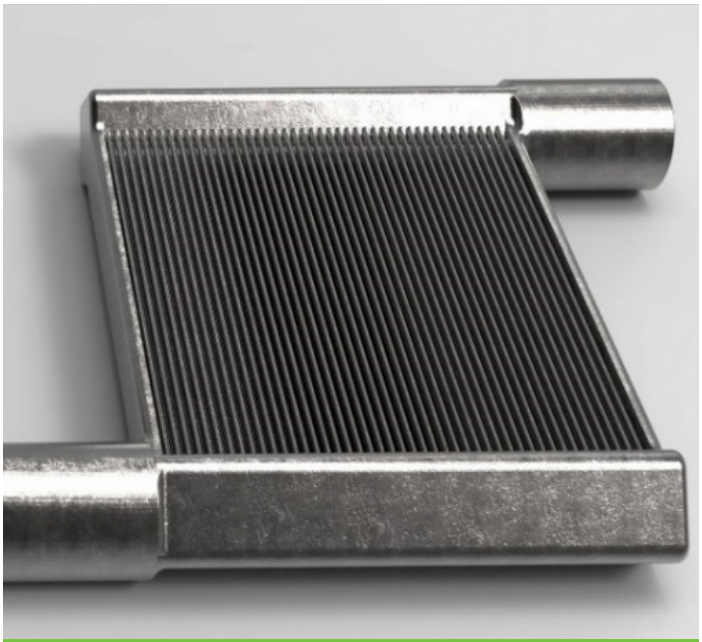
In contrast, reviewers assigned the highest scores to projects that had already met or exceeded BTO's coefficient of performance (COP) through prototype testing. However, even though these high-scoring projects had met performance targets, reviewers still had suggestions for improvement. A case in point is the Commercial Cold-Climate Heat Pump project, for which reviewers recommended meeting with an electric utility company to determine if the technology would contribute to winter peak loads. For the project High-Performance Cold-Climate Multi-Stage Heat Pump, reviewers suggested proceeding with planned testing in Alaska to order to further determine the progress of the technology. For the project Low-Cost Gas Heat Pump for Building Space Heating, reviewers suggested emphasizing issues of serviceability to improve market entry.

While nearly all projects scored relatively well in collaboration, there were no projects where reviewers did not feel further stakeholder engagement was warranted. Suggestions for further stakeholder engagement included: manufacturers, installation and maintenance communities, builders in cold climates, air handler/water heater manufacturers, system integrators, and electric utilities. The project with the lowest collaboration score, Manufacturing Competitiveness and Supply Chain Analysis, received mixed reviews regarding stakeholder engagement, with some reviewers finding collaboration lacking in the project, especially with manufacturers.

HVAC – Assorted HVAC&R

Components such as compressors and heat exchangers (HXs) are key drivers of energy consumption and performance in common HVAC and refrigeration (HVAC&R) equipment. BTO seeks to take advantage of unrealized opportunities to increase the efficiency of HVAC&R equipment by improving the design and engineering of individual system components.

One such assorted HVAC&R project, Miniaturized Air to Refrigerant Heat Exchangers, received a high score for approach. Reviewers saw critical barriers identified and tasks accomplished efficiently, though they acknowledged that it was difficult to address the project's market barriers since the study was focused more on design optimization potential. In contrast, the other assorted HVAC&R projects – Higher Efficiency HVAC Motors and RVCC Technology: A Pathway to Ultra-Efficient Air Conditioning, Heating, and Refrigeration – received lower



Miniaturized air-to-refrigerant heat exchanger. Image courtesy of University of Maryland, Center for Environmental Energy Engineering.

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marks for approach because reviewers questioned the ability of these projects to address critical barriers. Some reviewers also expressed concern about the ability of these two projects to meet their targets on schedule.

The Miniaturized Air to Refrigerant Heat Exchanger project had reviewers impressed by progress to date, including the fact that the project team had analyzed over 15 HX geometries, developed multi-scale modeling and optimization methodologies, developed a system-test facility, and fabricated both 1-kW and 10-kW prototypes. Reviewers also gave good accomplishment scores to the RVCC Technology project for its initial investigation results and its potential impact should technical challenges be overcome. Reviewers similarly rated the Higher Efficiency HVAC Motors project's level of progress and accomplishment as good, but they expressed concern about the project's lack of performance data and the fact that HVAC motors had already achieved high efficiencies.

The assorted HVAC&R project with the highest score, Miniaturized Air to Refrigerant Heat Exchanger, received praise from reviewers for its partners' role in helping with the budget, and for the project team's efforts to disseminate findings through publication in open literature. The other assorted HVAC&R projects also received high marks for their engagement with solid and key industry and/or research partners, though reviewers recommended that the RVCC Technology team look to bring in a manufacturing partner once prototyping begins.

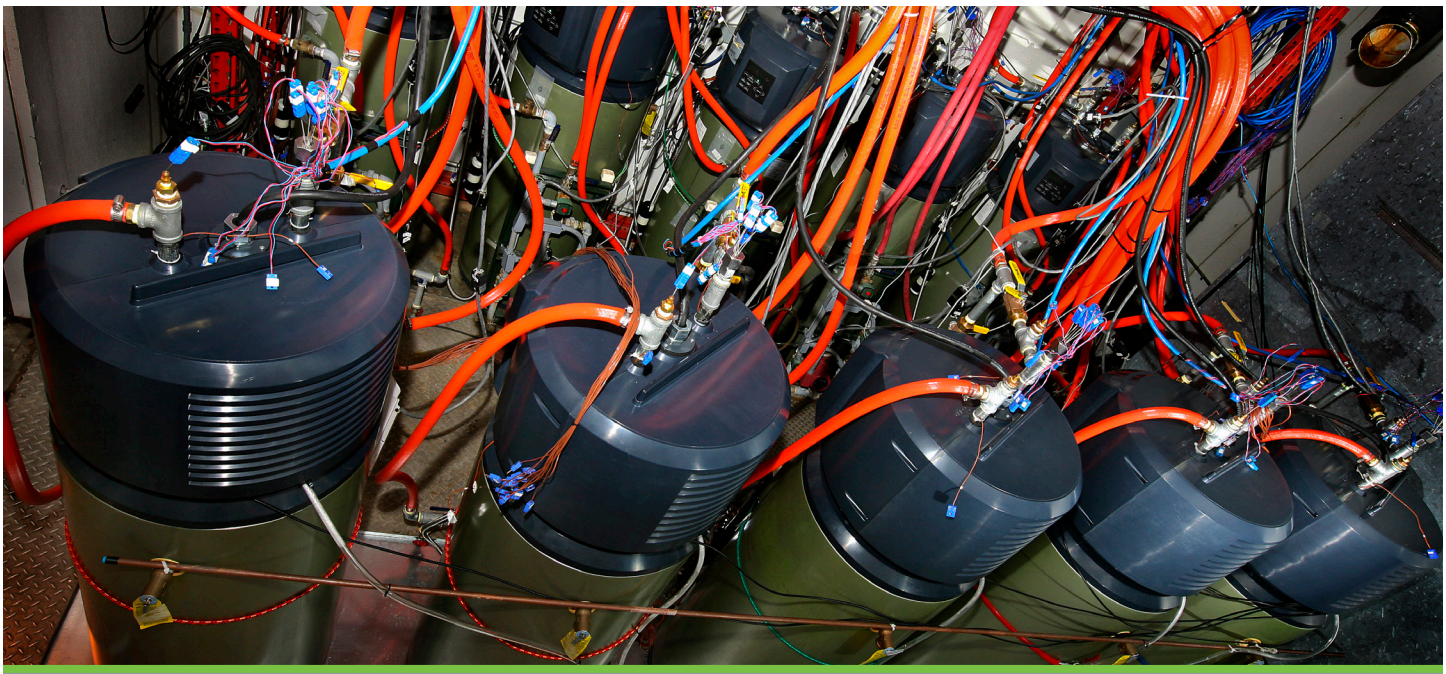
Water Heaters

Water heaters provide buildings with continual sources of hot water. While more efficient tankless water heaters have made inroads into the market in recent years, non-efficient, storage-type water heaters still dominate the market (with nearly 90% market share).[17] BTO seeks to reduce the cost and complexity, while improving efficiency of water heaters for both residential and commercial buildings.

In the 2016 Peer Review, there were five projects reviewed in this technology area, including projects investing lower-cost and more-efficient heat pumps, as well projects supporting BTO's Next Generation Heating and Cooling R&D Strategy by developing non-vapor compression systems utilizing zero-GWP refrigerants.

The water heater project with the lowest score for approach, Commercial Absorption Heat Pump Water Heater, was the only project of the five with disparate reviewer evaluations; some reviewers described the project approach as worthwhile, while others felt that key market barriers were not discussed. For the other four projects, there was general consensus that they appropriately addressed and identified critical market barriers. Reviewers commented in particular that the project CO_2 Heat Pump Water Heater identified critical market barriers, assessed them quantitatively, and oriented the product R&D accordingly.

Overall, reviewers gave these projects relatively high scores for accomplishment, stating that they appropriately identified critical market barriers; developed capabilities to measure a



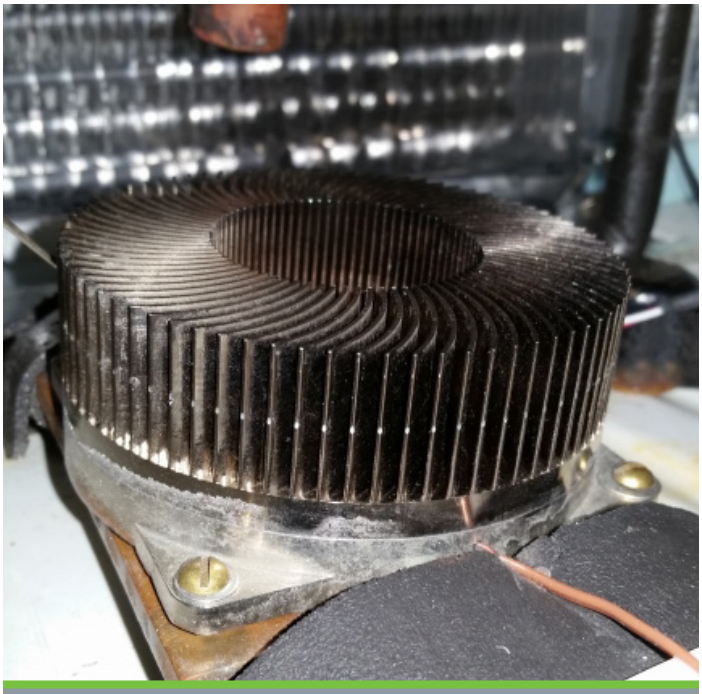
Water heater test facility. Image courtesy of Oak Ridge National Laboratory.

range of criteria (including thermal conductivity, capacity, heat of absorption, density, viscosity, etc.); tested a technology that is now commercially available; provided a good demonstration of technology; and included simulation, selection, fabrication, and evaluation in their design process.

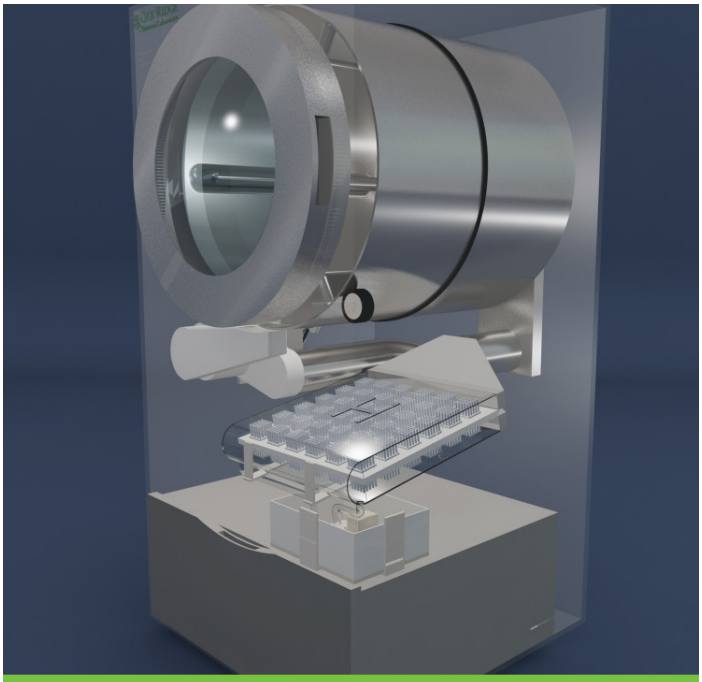
The project with the highest overall score, Advanced Hybrid Water Heater Using Electrochemical Compressors, was the only one that did not raise concerns among reviewers about collaboration. While other projects also received high scores for stakeholder engagement, reviewers still pointed out missing opportunities for partnerships or questioned partners' roles. The projects that received lower collaboration scores (e.g., Heat Pump Water Heating Using Solid-State Energy Converters and A Combined Water Heater, Dehumidifier, and Cooler) raised reviewer concerns over the lack of apparent collaboration with key sectors, specifically manufacturers and the maintenance and repair communities.

Appliances

Residential appliances consume large amounts of energy within the United States; the daily use of refrigerator/freezers, dishwashers, laundry equipment, and cooking equipment accounts for approximately 15% of residential building primary energy consumption.[18] The appliances used in commercial buildings for cooking and refrigeration are another potential source of energy savings, particularly for buildings such as grocery stores and hotels. This BTO Sub-Program primarily focuses on refrigerator/freezers and clothes washers and dryers, which have the most opportunity for energy savings. The six appliance projects reviewed in the 2016 BTO Peer Review were evenly divided between refrigeration and clothes drying technologies.



Novel rotating heat exchanger. Image courtesy of Oak Ridge National Laboratory.



Thermoelectric clothes dryer. Image courtesy of Oak Ridge National Laboratory.

Appliance projects receiving lower scores tended to see reviewer disagreement regarding project approach. In contrast, reviewers generally concurred in their remarks concerning projects with higher scores. Additionally, in projects with low scores, there were consistent remarks that market barriers were not being addressed, such as barriers to efficiency. The projects receiving higher scores addressed and mitigated market barriers, and reviewers remarked that they found barriers typical of cutting edge technologies. Appliance projects with lower scores had collaborations that were too focused on one or two large partners, such as one academic or industry partner. Reviewers were looking for a more diverse and robust group of stakeholders, and thus gave higher scores to projects that included a greater number of partners.

Refrigeration projects received widely varying scores for their progress and /or accomplishments. The lowest score was assigned to the project, Magnetocaloric Refrigerator, as reviewers concluded that it was difficult to see how the technology could be transferred into a marketable and reliable product. The highest score went to the project High-Efficiency, Low-Emission Refrigeration, which exceeded its energy and emissions savings targets. Reviewers disagreed on accomplishments to date for the project High-Performance

Emerging Technologies

Refrigerator Using Novel Rotating Heat Exchanger, with its score falling approximately midway between the other two.

Clothes dryer projects were also given divergent accomplishment scores, though in each case reviewers highlighted potential impediments to technology impacts. Reviewers assigned a low score to the project Energy-Efficient Clothes Dryer with IR Heating and Electrostatic Precipitator, pointing to potential mechanical issues that could reduce efficiency given the dust and lint typically found in most clothes dryers. Reviewers assigned a good score to the project Novel Ultra-Low Energy Consumption Ultrasonic Clothes Dryer, although they questioned the capability of the technology to handle complex, multi-layer fabrics – a requirement they said was key to convincing skeptics of the technology. The highest score was assigned to the project Novel Energy-Efficient Ventless Thermoelectric Clothes Dryer, though one reviewer cautioned that the incremental first cost impact of thermoelectric technology remains to be seen, and that this could have a major impact on the project's ability to meet its cost goals.

Windows and Building Envelope

Space heating and cooling represents 30% of the primary energy consumed in residential and commercial buildings;[19] the building envelope, including windows, forms the main thermal barrier between interior and exterior spaces – when it fails to provide a tight seal due to drafts, material inefficiencies, or solar heat gain, it can greatly impact how much energy is required to heat or cool the interior to meet occupant comfort needs. The Windows and Envelope Sub-Program focuses on R&D for next-generation windows and building envelope technologies that have substantial potential to reduce energy consumption in buildings.

Windows R&D strategies include:

- Developing low-cost, next-generation window technologies, such as highly insulating windows, dynamic windows, and window film and visible light redirection technologies, with focus on materials and manufacturing processes that reduce the total installed cost.
- Improving testing and modeling capabilities, including window design tools.

Building envelope R&D strategies include:

- Developing 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.
- Devising new air sealing systems that are capable of preventing uncontrolled heat, moisture, and airflow at reduced installation costs.

The Windows and Envelope Sub-Program also seeks to address cross-cutting challenges that include:

- Developing a "seamless" transition between functional areas (e.g., roof-walls, walls-windows);
- Devising simple, accurate, low cost methods for evaluating envelope air sealing;
- Reducing "soft" costs as a fraction of total installed costs; and
- Creating products and methods that reduce retrofit cost and complexity.

A total of nine projects were reviewed under this Sub-Program at the 2016 BTO Peer Review. Table 3 provides a high-level summary of scores among window- and building envelope-focused projects; projects had a maximum potential score of 4 and a minimum potential score of 1.

Table 3. High-Level Summary of Windows and Building Envelope Project Scores

			RANGE	
Technology Area	Average Score	Count	Low	High
Windows	2.99	5	2.58	3.43
Envelope	3.08	4	2.80	3.49

Windows

Reviewers evaluated five windows projects. Windows projects that received lower scores were those which reviewers thought generally lacked a well-grounded technical approach or failed to address core technical challenges. For example, a reviewer for the project Certification and Rating of Attachments for Fenestration Technologies attributed the slippage of project goals to the difficulty of achieving consensus in a fragmented industry. By contrast, projects receiving higher scores for their approaches were judged to have identified key challenges and developed clear plans to overcome them, often through testing, measuring, and incorporating protocols.

The windows project with the lowest score, Low-Cost Haziness-Free Transparent Insulation Based on Hierarchical Porous Silica Particles, had yet to integrate the technology into a window application, contributing to reviewer concern over the ability to reach both near-term and long-term project goals. Another low-scoring project, Fabricate On-Demand Vacuum Insulating Glazings, simply did not achieve the project's primary goal. Reviewers were concerned about accomplishments for the Certification and Rating of Attachments for Fenestration Technologies project, which was seen to have focused its efforts on forming an organization and conducting outreach to stakeholders, rather than on realizing the necessary technical

Emerging Technologies

Double-paned windows. Image courtesy of Lawrence Berkeley National Laboratory/Roy Kaltschmid.

achievements to creating a certification program, which was the main objective of the project.

Reviewers concluded that two windows projects – Fenestration Software Tools and Novel Thermal Break with Simplified Manufacturing for R7 Commercial Windows – were on track to reach project goals, had demonstrated evident potential market impact, and were in the process of or had already validated their models. As a result, these two projects received higher scores.

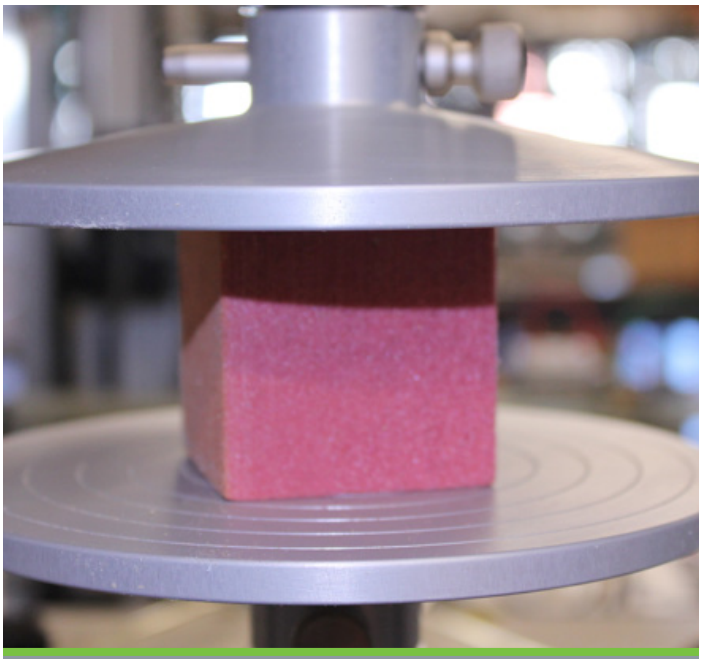
Reviewers generally agreed that there was strong collaboration and partnership among the windows projects, with effective utilization of public interest groups, manufacturers, national laboratories, technology partners, and other subcontractors. However, reviewers expressed conflicting views on stakeholder engagement for the project Low-Cost Haziness-Free Transparent Insulation, with some reviewers believing there was strong collaboration and others feeling that project team did not demonstrate any strong connections with partners.

Building Envelope

Reviewers evaluated four building envelope projects. Higher scores were assigned to the two building envelope projects that followed a comprehensive approach to identifying and addressing critical market barriers, even though there were technical elements about which reviewers were concerned. A case in point was the otherwise well-regarded project, Bio-Based, Noncorrosive, Nonflammable Phenolic Foam Insulation, for which one reviewer noted that the level of thermal conductivity of the proposed foam – a key parameter to be addressed – had not been defined, and that a key cost metric (cost per square foot) for the proposed foam materials had not been proposed. In the case of the R25 Polyisocyanurate Composite Insulation Material project, a reviewer warned that the void-to-solid ratio had not been considered.

In contrast to these examples, the CBERD: Building Envelopes project elicited reviewer comments that while some technical barriers and characteristics had been addressed, the main market barrier – which appeared to be cost – had not been. The lowest-scoring envelope project, Building Integrated Heat and Moisture Exchange, raised similar reviewer concerns, with reviewers citing major architectural and mechanical issues that they felt would have to be addressed before the project's technology could be widely accepted.

Envelope projects that were meeting key milestones and contributing to the field received high scores. Reviewers lauded the six patent applications of the Bio-Based Foam Insulation project, and they viewed the favorable performance of test products from the R25 Insulation Material project as a valuable achievement. In contrast, reviewers commented that measures of accomplishment for the CBERD project were still vague, and that it was too early to assess market impacts or BTO goal results. For the Integrated Heat and Moisture Exchange project, which received the lowest accomplishment score, reviewers found it difficult to see how the technology could achieve sufficiently high performance and market penetration to meet BTO goals.



Mechanical testing of bio-based phenolic foam for building insulation. Image courtesy of Fraunhofer CSE.

Emerging Technologies

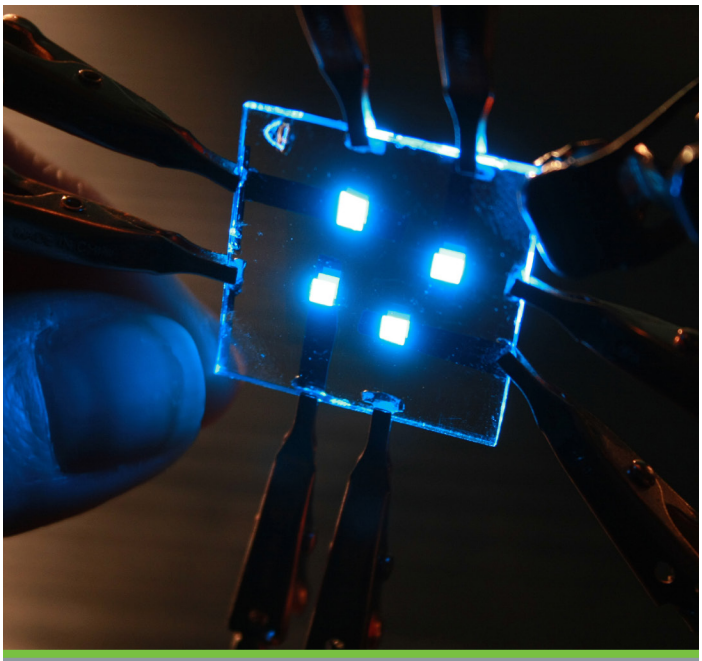
Overall, the four building envelope projects received relatively high scores for project collaboration, with reviewers noting that the partnerships established now will provide these technologies with accelerated access to the market in the future. Building envelope projects were generally seen to have established well-balanced teams of industry stakeholders, though reviewers recommended that the CBERD project develop closer collaboration with partners in India.

Solid-State Lighting

Light-emitting diodes (LEDs) and organic LEDs (OLEDs) have the potential to be ten times more efficient than incandescent lighting and twice as efficient as fluorescent lighting products. If the Solid-State Lighting (SSL) Sub-Program reaches its goals, SSL technology has the potential to reduce U.S. energy consumption by 395 Terawatt-hours (TWh) annually by 2030 relative to a scenario in which LEDs do not exist. This translates to annual cost savings of $40 billion.[20]

Four projects were reviewed under the SSL Sub-Program at the 2016 BTO Peer Review, with three focused on OLEDs and one focused on next-generation LED technologies. All four SSL projects scored highly, relative to the entire field of 67 BTO projects reviewed, though there was variation among SSL projects across the different evaluation categories.

The projects with the highest scores effectively identified and addressed critical market barriers, whereas projects with lower scores either did not address market barriers appropriately or did not identify the correct barriers. Reviewers felt the approach of the project The Approach to Low-Cost High-Efficiency OLED Lighting was promising due to its effort to develop a scalable, low-cost process to fabricate an OLED substrate that integrates high surface conductivity, low surface roughness, and high light extraction efficiency in a plastic sheet using silver nanowires (Ag NW). Reviewers were also encouraged by the approach of the project Advanced Light Extraction Structure for OLED Lighting because of its use of stable scatter/nanocomposite formulation that promises low-cost manufacturing and for overcoming a well-defined technical barrier involving light extraction efficiency.



Blue phosphorescent OLED. Image courtesy of Pacific Northwest National Laboratory.

Lower-scored projects elicited reviewer remarks related to uncertainty and deviations from the original project plan. In two instances – Novel Transparent Phosphor Conversion Matrix with High Thermal Conductivity for Next-Generation Phosphor-Converted LED-based Solid State Lighting and ITO-Free White OLEDs on Flexible Substrates with Enhanced Light Outcoupling – reviewers questioned whether the projects could meet their targets based on current test results. In the case of the project Advanced Light Extraction Structure, reviewers raised questions about whether the lack of computation (a result of deviation from the project plan) has affected the current formulation for creating an optimal gradient index layer. The project with the highest score, Approach to Low-Cost High-Efficiency OLED Lighting, was praised for its demonstrated results and its progress toward project goals, an area where other projects were struggling.

Of the four SSL projects, three received high scores for project collaboration, as reviewers noted close work with key industry partners. While still receiving high remarks for collaboration, reviewers had questions regarding partner roles for one of these three projects, Novel Transparent Phosphor Conversion Matrix, in particular involving financial roles. For the one project that received a lower collaboration score, ITO-Free White OLEDs, reviewers remarked on the lack of, and need for, industry collaborators, as well as the need for clarification on partner roles.

Building Energy Modeling

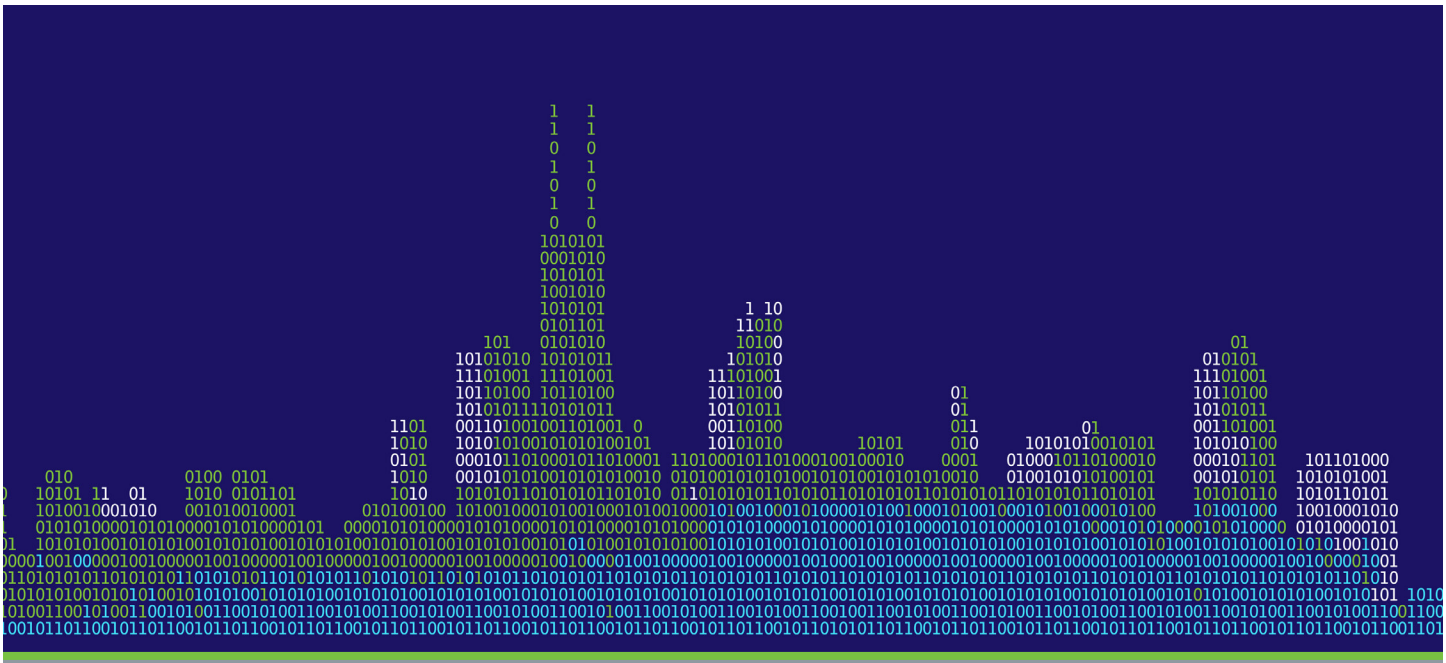
BTO's Building Energy Modeling (BEM) portfolio is jointly managed under BTO's Commercial Buildings Integration (CBI) and Emerging Technologies (ET) Programs. The program aims to accelerate the use of energy modeling in established use cases and to develop new use cases. As such, it has enumerated separate goals for expanding energy modeling for two specific use cases: (1) the design of new buildings and deep retrofits and (2) continuous building commissioning and dynamic building control.

The BEM Program focuses on six activity areas:

1. Ongoing development of the EnergyPlus™ whole-building energy simulation engine.
2. Ongoing development of the OpenStudio™ software-development kit (SDK) and demonstration application.
3. Supporting testing and validation of energy modeling programs.
4. Funding research, advanced development, and deployment of BEM technologies through competitive solicitations and small business awards.
5. Partnering with organizations such as the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), the International Building Performance Simulation Association (IBPSA), and the American Institute of Architects (AIA) to support the energy modeling community.
6. Providing technical guidance and support for BEM projects in other BTO programs, such as the CBI Program's Commercial Building Asset Score; the Residential Buildings Integration (RBI) Program's Home Energy Score and BeOpt; and the Building Energy Codes Program's (BECP's) COMCheck.

The four BEM Program key strategies related to software development, testing and validation, and external partnerships are:

- Continue to improve the open-source, whole-building, energy modeling engine EnergyPlus; lighting engine Radiance; and middleware OpenStudio.
- Improve characterization of energy modeling engine accuracy and improve accuracy as necessary.
- Expand partnerships with commercial software vendors to create end-user applications that utilize 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.



City of Big Data. Image courtesy of Argonne National Laboratory.

Building Energy Modeling

High-Level Summary of Reviewer Comments

During the 2016 BTO Peer Review, three BEM projects were reviewed, combined from ET and CBI. Projects had a maximum potential score of 4 and a minimum potential score of 1.

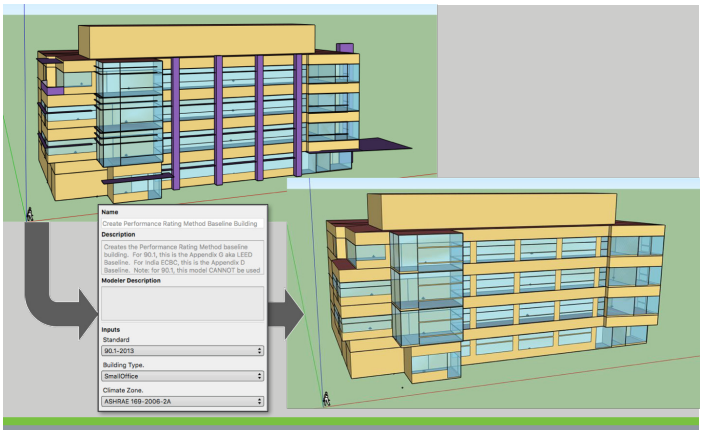
Table 4. High-Level Summary of BEM Project Scores

			RANGE	
Program	Count	Average Score	Low	High
ET	2	3.15	3.03	3.27
CBI	1	3.21	N/A	N/A
Overall	3	3.17	3.03	3.27

ET Building Energy Modeling Projects

EnergyPlus was a very well regarded project, with reviewers describing it as an indispensable energy modeling engine and best-in-class software for determining predictions of energy usage. Some reviewers noted that addressing critical market barriers – a key evaluation criterion for a project's approach – was not as applicable to EnergyPlus, as it is an ongoing effort to continually improve a solid piece of energy modeling software. However, other reviewers felt that there was a market barrier that the software did address, namely, being able to analyze energy performance with a high level of accuracy. Regarding project accomplishments, reviewers recognized that directly attributing energy savings to EnergyPlus is a challenge, but they concurred that it indirectly enables significant amounts of savings.

Reviewers agreed on the appropriateness of the project approach for A New Hybrid Approach to Energy Modeling. Reviewers concluded that the project team clearly understood the problem and were utilizing well-established methods and processes to solve it. However, reviewers felt the project did not provide techniques for integrating the proposed hybrid modeling with existing design tools, and it also failed to identify how to isolate the specific uncertainties of infiltration and thermal mass from other potential sources of uncertainty. Using a two-step validation approach – prototype models and EnergyPlus, followed by field validation in FLEXLAB – was a clear accomplishment that all reviewers agreed upon for the Hybrid Approach to Energy Modeling project. However, while some reviewers felt this could lead to significant energy savings, others expressed doubts about the accuracy of modeling tools to actually provide energy savings.



OpenStudio in action. Image Courtesy of the National Renewable Energy Laboratory/Andrew Parker.

Reviewers were generally pleased with the partner collaboration of both projects, although they would have liked to have seen further stakeholder engagement, including collaboration with potential end users.

CBI Building Energy Modeling Projects

OpenStudio is DOE's front-end "operating system" for building energy modeling. Because OpenStudio is built on the EnergyPlus modeling engine, many of the comments expressed by reviewers about EnergyPlus were echoed for OpenStudio. These included the following: (1) the concept of market barriers is not perfectly applicable to this project; (2) it was difficult to directly relate project outcomes to BTO's quantitative goals and performance targets; and (3) increased stakeholder engagement should be pursued with end users in order to supplement otherwise strong partner collaborations.

Reviewers approved of the project's approach, but noted a few additional features that they would like to see incorporated into the tool, and stressed that future plans should prioritize efforts to identify cross-over functionality between the OpenStudio and other major DOE tools.

Commercial Buildings Integration

BTO's Commercial Buildings Integration (CBI) Program accelerates energy performance improvements in existing and new commercial buildings by developing, demonstrating, and deploying a suite of cost-effective technologies, specifications, design and management tools, and other solutions. The CBI Program partners with and supports market decision-makers such as building owners, managers, investors, and tenants. CBI catalyzes the commercial building industry to adopt underutilized yet proven technologies that meet performance standards, provide positive economic returns, and reduce energy usage.

The U.S. commercial buildings market is comprised of 87 billion square feet of floor space.[21] These are buildings of all sizes, ages, and construction types; are located in all climate zones; and are used for a broad range of purposes, including commercial and government offices, retail, education, health care, warehousing, and sometimes large multi-family buildings, among others uses. Commercial buildings account for approximately 18% of total U.S. energy consumption, 36% of U.S. electricity consumption, and 18% of the nation's carbon dioxide emissions.[22]

The CBI Program accelerates the adoption of energy saving technologies and solutions in commercial buildings by helping to overcome specific technical and market barriers. CBI Program activities are targeted toward two market segments characterized as efficiency leaders and early adopters, known henceforth as market leaders. Market leaders represent the segment of the market with the most energy-efficient buildings, and are the most

Denver, Colorado skyline. Image courtesy of National Renewable Energy Laboratory.

As stated in the BTO Multi-Year Program Plan the CBI Program contributes to a 2025 market outcome goal focused on improving the performance of buildings in partnership with market leaders, who represent the top 20% of all commercial buildings (as measured on a square foot basis). Market leaders 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, the CBI Program's 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 need to reduce the energy use per square foot – known as the energy use intensity (EUI) – 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.

The Program achieves these goals through the following 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 the 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.

Commercial Buildings Integration

willing to push the boundary of energy efficiency. Their actions play a vital role in paving the way for those stakeholders further down the technology diffusion curve to adopt energy saving technologies.

The CBI Program'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. It also develops tools and resources that help building owners monetize the value of their energy saving investments.

Feedback on CBI Program Goals

Stakeholders participated in a session at the 2016 BTO Peer Review to discuss and provide feedback on CBI Program goals. During this session, CBI Program Director Jason Hartke provided an overview of the Program. Peer Review attendees were then asked (1) whether the 2020 and 2030 goals were appropriate for CBI; (2) whether programmatic activities described in the BTO MYPP would lead to the desired long-term outcomes; and (3) whether the metrics in place to measure progress toward success were appropriate.

Many attendees thought CBI's market goal for new buildings was appropriate, while others discussed whether the existing buildings market goals were too ambitious. Questions from the audience included how BTO was defining market leaders, what market stock was being included when defining commercial buildings, and how mixed-use buildings were included in these goals. An additional comment indicated that a feedback loop would be helpful for many of the campaigns in order to determine what kind of penetration occurred after one, two, and/or five years.

Attendees disagreed on the approach targeting market leaders. While some attendees thought that targeting market leaders was the most efficient way to enact energy efficiency changes, others found the goal to reach market leaders difficult to achieve given the current CBI portfolio. Still other attendees wanted to see a pathway to reach those who are not market leaders in energy efficiency.

High-Level Summary of Reviewer Comments

There was a total of 15 projects reviewed within the CBI Program during the 2016 BTO Peer Review. These projects are divided among four types of activities, including market engagement, commercial demonstration and deployment, analysis tools, and workforce development. (As noted already, projects under the Building Energy Modeling (BEM) Program are jointly managed by both the CBI and ET Programs, and are discussed in those sections of this report). Table 5 provides a high-level summary of CBI project scores; projects had a maximum potential score of 4 and a minimum potential score of 1.

Table 5. High-Level Summary of CBI Project Scores

			RANGE	
Activity	Count	Average Score	Low	High
Market Engagement	6	3.00	2.54	3.44
Commercial Demonstration and Deployment	5	2.90	2.35	3.82
Workforce Development	1	3.33	N/A	N/A
Analysis Tools	3[a]	3.18	3.15	3.21

[a] Includes one BEM Project: OpenStudio.

Market Engagement

One of the CBI Program's focus areas is increasing partnerships with market leaders to help scale adoption of energy efficiency solutions. The first step is technology demonstration, but once that has occurred, the CBI Program expands its reach through formalized market partnerships in which members commit to reduce energy use to target levels, provide data, and document best practices. In 2008, the Program initiated a series of partnerships with industry 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 the CBI Program and its partners to promote innovative and replicable solutions and best practices to improve energy efficiency.

Envision Charlotte Building Portfolio. Image courtesy of Envision Charlotte.

Commercial Buildings Integration

There are two program performance goals related to market engagement:

1. **Proving Solutions via Market Partnerships in Existing Buildings**: Prove with market leaders that, by 2020, it is possible to cost-effectively reduce average energy use in commercial buildings by at least 25% relative to 2010 levels. The indicator of success is achieving this of energy savings in at least 10 billion square feet and covering every climate zone and major building type.

2. **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.

At the 2016 BTO Peer Review, there were six Market Engagement activity projects reviewed. The following trends related to BTO goals and stakeholder engagement were found throughout reviewer remarks.

Of the six market engagement projects, four projects received comments from reviewers regarding the applicability of BTO goals. Reviewers concluded that two of the projects did an excellent job supporting BTO goals, while the other two required additional metrics more closely tied to those goals. Reviewers felt that the Accelerate Performance project supported BTO's long term goal of reducing EUI in commercial buildings. Reviewers also saw a direct link between the well-articulated and measurable efforts of the Envision Charlotte project and BTO's goals, though some questioned the project's significance to BTO's nationwide objectives since the project is targeted to one region. However, other reviewers argued that the project was a great model to replicate in other areas, which could lead to a much broader impact.

In two projects, Better Buildings Challenge-Milwaukee and Financial Management for Retail Energy Efficiency, reviewers expressed concern that there were not clear metrics for measuring the project's contribution toward BTO's energy savings targets and recommended that the problem statement be tied to specific metric-based goals that link to those targets.

Collaboration and stakeholder engagement are critical components of BTO's Market Engagement projects. Among these six projects, project collaboration was consistently rated highest out of all the other categories.

The project rated lowest by reviewers, SoCal Edge, was found to demonstrate good local engagement, creatively matching interested and motivated building owners with an incubator of new, innovative technologies. However, reviewers felt that the project failed to leverage other important partners, such as the Design Lights Consortium's Qualified Products List. Similarly, the Financial Management for Retail Energy Efficiency project received mixed reviewer comments for stakeholder engagement, with some reviewers indicating that industry partners were a great strength, while others concluding that critical stakeholders were missing, such as landlords, contractors, governments and utilities. In the project Putting Data to Work, reviewers found that there were connections with some of the right stakeholders in the pilot cities, but that important stakeholders in the private sector were being excluded.

The other three projects were described as exemplary, with an impressive array of partnerships. In reviewers' estimation, these projects found success through close collaboration and coordination with their partners, deep understanding of the diverse networks of their stakeholders, and the ability to properly utilize their stakeholders.

Commercial Demonstration and Deployment

One of the CBI Program's main activities to address market barriers in the commercial market is to demonstrate and validate technology performance. The CBI Program is working with market leaders, including building owners, engineers, and operators, to demonstrate and validate energy efficient technologies and practices in a variety of building types and climate zones. Demonstrating technologies in operational, occupied buildings provides the performance, cost, and critical application information needed to inform decision-makers. Each year, the CBI Program conducts research, identification, and evaluation exercises to develop deployment strategies for those technologies that can make the most impact in achieving

QM Power demonstrating the company's high-efficiency fan motor. Image courtesy of QM Power, Inc.

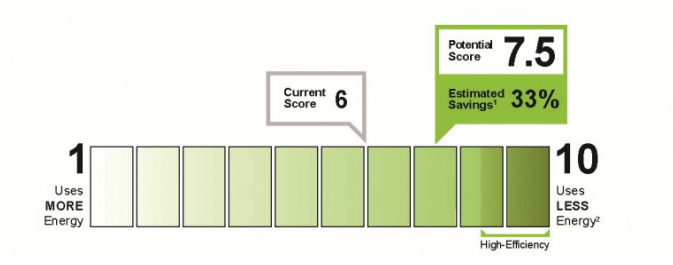
Commercial Buildings Integration

BTO's energy savings goals. The CBI Program refers to the technologies that offer the greatest impact as HITs – short for high impact technologies.

At the 2016 BTO Peer Review, five competitively selected Commercial Demonstration and Deployment projects were reviewed. Across the five projects, reviewers' comments consistently touched on the topics of wide-scale technology adoption and utility engagement.

In three of the five projects, reviewers shared recommendations with project teams to consider and address market barriers for wide-scale adoption of the relevant technology or program. Demonstrations are designed as an initial step in the larger commercial building strategy to drive wide-scale adoption of high impact technologies. Thus, large-scale adoption should be a factor in demonstration project planning, but it is not necessarily the outcome of any one demonstration project. Critical market barriers for the initial scope of the projects were usually well-addressed, but reviewers were concerned about wider market adoption, as well as replicability of projects. One project, Significant HVAC Energy Savings Enabled by Practical Low-Cost Air Treatment Technology, had a number of pilot projects that seemed to the reviewers to face significant installation and technical barriers to wider acceptance of the technology. Reviewers also felt that another project, Advanced Retro-commissioning Technology: Predictive Energy Optimization (PEO) and Automated Demand Response for Commercial Building HVAC, should recognize that many building owners and operators are skeptical about energy savings from an unproven concept. Additionally, since this project was focused on government- and university-owned buildings, reviewers felt that the project was not representative of the broader commercial buildings market.

The level of involvement and engagement by utility partners was an additional topic discussed by reviewers. In their evaluations of the project Commercial Advanced Lighting Control (ALC) Demonstration and Deployment, reviewers were very encouraged by the number of utility partners involved, and thought these partners could help define a course for utility programs to advance solid state lighting (SSL) controls adoption. Reviewers also felt that engagement with utilities was very useful for the Practical, Low-Cost Air Treatment Technology project. However, reviewers concluded that a lack of engagement and collaboration with utilities by the Advanced Retro-commissioning Technology project team has negatively impacted the project. Reviewers suggested to this project that they bring utilities on board to offer incentives to mitigate risk adverse concerns over skepticism about energy savings from an unproven concept.



Building Energy Asset Score

Clean Energy Workforce and Analysis Tools Development

Two additional areas of focus for the CBI Program are the development of both a skilled clean energy workforce and analysis tools that can be used for a variety of purposes, including collecting, managing, and analyzing information about buildings' performance; implementing energy efficiency programs and policies; and better understanding the potential for and impacts of investing in energy efficiency.

At the 2016 BTO Peer Review, one Workforce Development and three Analysis Tools projects were reviewed, with commonalities found among reviewer remarks on the topics of stakeholder engagement and technology adoption.

Stakeholder engagement was an area of common concern across these projects. Generally, reviewers felt collaboration with stakeholders was effective, but in each case they questioned why certain classes of stakeholder were not involved, specifically noting architecture, engineering, and construction firms; larger real estate companies; and regulatory partners. Effectively addressing market barriers to enable wide-scale adoption was also a consistent topic of reviewer comments for these projects. For the Better Buildings Workforce Guidelines project, reviewers were concerned that the project focused solely on barriers to building energy efficiency, while disregarding workforce development barriers. The project Assessment of Advanced Measurement and Verification Methods (M&V 2.0) addressed the market barrier of building owners' skepticism about investments in energy efficiency measures. However, reviewers felt that, while the project was well focused on the market barrier it did address, it needed to broaden its scope to include those barriers of adoption and longer term functionality within the community. In regards to the Building Energy Asset Score project, reviewers thought that the project failed to address certain barriers related to the usefulness of the tool, which could prevent its adoption among key stakeholders.

The remaining project, OpenStudio, is discussed in the Building Energy Modeling (BEM) Program section of this report.

Residential Buildings Integration

The Residential Buildings Integration (RBI) Program accelerates energy performance 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 RBI Program addresses technology integration and installation issues that can affect total home performance, including energy efficiency. It especially focuses on 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.

The U.S. residential housing market is comprised of more than 114 million households and represents more than 223 billion square feet of floor space.[23] In 2014, approximately 1 million new residential housing units were built.[24]

Existing residential buildings account for approximately 21% of total U.S. energy consumption, and in 2012, the annual household energy bill amounted to approximately $2,000, on average, or about 3% of annual household income.[25] 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 RBI Program collaborates with homebuilders, contractors, energy professionals, state and local governments, utilities, product manufacturers, universities, national laboratories, and other researchers to improve energy performance in new and existing homes. To identify cost-effective solutions that reduce energy consumption beyond current minimum codes (for new construction) and common practice (for home retrofits), the Program focuses on research, development, and demonstration (RD&D) activities, as well as innovative approaches to accelerate the adoption of energy-efficient technologies.

Zero Energy Ready Home in New Paltz, NY. Image courtesy of Greenhill Contracting.

As discussed in BTO's Multi-Year Program Plan, the RBI Program's goal is to reduce the energy used for space conditioning and water heating in single-family homes by 40% from 2010 levels by 2025. This market outcome goal comprises two 2025 goals for the existing and new homes market:

- A 35% energy use intensity (EUI) 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.

The Program achieves these goals through the following strategies:

- 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 the 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.

Feedback on RBI Program Goals

Stakeholders participated in a session at the 2016 BTO Peer Review to discuss and provide feedback on RBI Program goals. During this session, RBI Program Director David Lee provided an overview of the RBI Program. Peer Review attendees were then asked (1) whether the 2020 and 2030 goals were appropriate for RBI; (2) whether programmatic activities described in the BTO MYPP would lead to the desired long-term outcomes; and (3) whether the metrics in place to measure progress toward success were appropriate.

Residential Buildings Integration

Zero Energy Ready Homes in Denver, CO. Image courtesy of New Town Builders.

The discussion of program goals centered on achieving these goals through its current portfolio, both in the existing and new homes markets. The majority of attendees felt the RBI Program goals were appropriate for the portfolio of projects, although some wondered if they were too conservative. In regards to RBI's portfolio, most attendees found the majority of activities appropriate to meet BTO goals, but suggested data collection, tools, and workforce development as areas for further development.

High-Level Summary of Reviewer Comments

At the 2016 BTO Peer Review, five Building America projects were presented and reviewed. Building America is the principal platform through which the RBI Program proves energy saving solutions for both new and existing homes and addresses issues that affect indoor air quality, resiliency, moisture control, and the advancement of building energy codes. The Program has been a source of innovations in residential building energy performance, durability, quality, affordability, and comfort for 20 years. 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. Since 1995, this work has helped households across the nation save up to $54 billion and avoid the emissions of 500 million tons of carbon dioxide.

In late 2015, Building America completed a Research-to-Market Plan which details three "Technology-to-Market Roadmap" strategies focused on solving three primary technical challenges over the next five years: (1) high performance, moisture-managed envelope systems; (2) optimal comfort systems for low-load homes; and (3) optimal ventilation systems and indoor air quality (IAQ) solutions for low-load homes. Together, the five RBI projects presented at the 2016 BTO Peer Review addressed all three of these technical challenges.

A high-level summary of RBI project scores can be found below; projects had a maximum potential score of 4 and a minimum potential score of 1.

In addition to advancing state-of-art technology, a significant focus of these projects was on development of support activities – including modeling, field testing, and codes and standards development – to facilitate deployment of high-performance technologies. This section discusses high-level evaluation trends among the five projects presented.

Table 6. High-Level Summary of RBI Project Scores

			RANGE	
RBI	Count	Average Score	Low	High
Building America	5	3.09	2.55	3.49

Building America

The highest rated Building America projects were those where the project focused not only on identifying and better understanding relevant critical barriers, but on addressing and overcoming these barriers as well. For example, in Advanced Technical Solutions for Zero Energy Ready Homes, reviewers noted that the project seeks to address known issues identified in RBI Program and BTO strategic documents, and will add to the knowledge needed to overcome the lack of humidity control in low load homes. Higher scores were assigned by reviewers to projects that engaged with those market actors considered most important to overcoming critical barriers, as well as to projects which considered important market barriers alongside technical ones (e.g., an approach's cost relative to its efficiency gains).

Reviewers assigned projects lower scores when it was not clear that the project's objective addressed a critical market barrier. A case in point is the Buildings America Envelope and Advanced HVAC Research project. Reviewers noted that while laboratory testing of the technology would provide data for integration with building systems, the project team appeared to lack focus on critical barriers such as market awareness, operational savings, and training needs for implementation. Similarly, reviewers commented that in Energy Savings with Acceptable Indoor Air Quality Through Improved Air Flow Control, there appeared to be a disconnect between the approach taken and the project's objectives.

Residential Buildings Integration

Reviewers gave higher scores to projects where their progress and accomplishments advanced industry's awareness and understanding of key issues; successfully addressed or produced recommendations for overcoming critical barriers; or successfully demonstrated technology. Reviewers noted that the research team from A "Plug-n-Play" Air Delivery System for Low-Load Homes and Evaluation of a Residential Thermal Comfort Rating Method was well aware of the code barriers facing the project and was focusing on fully addressing all barriers to reach market. Scores across projects varied based on the degree to which actual market impact was achieved to-date, as well as by the amount of work that remained to turn project outputs into actionable tools.

All projects were generally well regarded in terms of their level of collaboration and partnership. Higher scores were assigned to those projects where key stakeholders were well represented and where collaboration with industry and other relevant stakeholders was apparent and beneficial. Of note, the highest score was assigned to a Healthy Efficient Homes Research & Standards Support, which actively engaged with relevant standards-setting organizations, and which secured substantial cost-share support from a number of other parties. Both Buildings America Envelope and Advanced HVAC Research and Advanced Technical Solutions for Zero Energy Ready Homes were also highlighted for their collaboration with manufacturers and researchers, but were flagged for their minimal collaboration with deployment-side partners (e.g., builders and the retrofit market).

High-performance wall panel construction in Johns Landing, SC. Image courtesy of Insulsteel Building Enclosure.

Zero Energy Ready Home in Charleston, SC. Image courtesy of Amerisips Homes, LLC.

Newer projects tended to receive lower scores for project integration and collaboration. However, reviewers noted that for projects such as "Plug-n-Play" Air Delivery System and Energy Savings with Acceptable Indoor Air Quality, lower scores were appropriate given their early stage of development. They also expressed the expectation that collaboration would expand as the projects advanced.

Building Energy Codes Program

The mission of the Building Energy Codes Program (BECP) is to support the development, adoption, implementation, and enforcement of U.S. building energy codes and standards in order to achieve the maximum practicable and cost-efficient improvements in energy efficiency while providing safe and healthy buildings for occupants.

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.[26] Building energy codes establish minimum energy conservation requirements for new construction, additions, and substantial renovations of residential and commercial buildings. They also represent an opportunity to incorporate successfully commercialized energy-efficient technologies into standard design and construction practices.

In addition to significantly reducing energy use, building energy codes substantially reduce consumer utility expenditures and greenhouse gas emissions over the lifespan of buildings. The majority of BECP's effort is focused on the implementation of building energy codes, as the intended energy savings are realized through achieving high levels of compliance.

Because the energy code is frequently one of the least understood building codes, BECP plays a critical role by developing training curricula and providing software resources like REScheck™ and COMcheck™ to aid in demonstrating energy code compliance. BECP and its partners develop tools, state-specific analyses, and informational resources for use across the nation. DOE contracts with national and regional energy efficiency organizations to provide additional technical assistance to ensure that activities and resources are tailored to the needs of regions and individual states.

Image courtesy of Pacific Northwest National Laboratory.

As described in BTO's Multi-Year Program Plan, to achieve these goals, BECP has established two performance targets focused on ensuring that stakeholders have the analysis and assistance they need to develop and implement building energy codes.

- BECP aims for its assessments of economic and energy benefits from model energy code adoption to be used in the adoption process of jurisdictions representing at least 80% of all building floor space.
- BECP aims to get jurisdictions representing at least half of all new construction building floor area to use compliance assessment methods developed or approved by the Program.
- To meet BECP goals, the Program utilizes the following strategies to address barriers affecting all phases of code development, adoption, and implementation.
- 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 BECP 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.

Building Energy Codes Program

By accelerating the development, adoption, and implementation of improved building energy codes, BECP provides critical support to the achievement of BTO's 2025 market outcome goal of reducing energy use intensity (EUI) in new construction by 40% from 2010 levels. While the most recent model codes for both residential and commercial buildings have the potential to achieve a substantial portion of this 40% target, state and local jurisdictions must formally adopt and comply with the model codes to realize this energy savings potential.

Feedback on BEC Program Goals

Stakeholders participated in a session at the 2016 BTO Peer Review to discuss and provide feedback on BECP goals. During this session, BECP Manager David Cohan provided an overview of the BECP. Peer review attendees were asked (1) whether the 2020 and 2030 goals were appropriate for BECP; (2) whether programmatic activities described in the BTO MYPP would lead to the desired long-term outcomes; (3) and whether the metrics in place to measure progress toward success were appropriate.

There was limited discussion on the appropriateness of the Program's goals, as a large majority of session attendees agreed with the Program's stated objectives. In response to questions about whether BECP's activities would lead to the achievement of desired outcomes, many stakeholders expressed support for the Programs' stated work plan. A few stakeholders warned, however, of the potential impact on the Program's success of future changes in the energy market (e.g., as a result of substantial solar generation and energy storage assets coming online), and encouraged BECP staff to be vigilant in their consideration of these changes and be willing to adjust course as necessary.

Another attendee warned that the structure of the Program's metrics could put pressure on new buildings in later years to perform very well in order to achieve the goals, noting that this could have implications for the Program's activities in the future. On a related point, one stakeholder encouraged BECP staff to consider changes or additions to the metrics that would allow the Program to differentiate improvements in building performance attributable to code adoption and compliance versus improvements coming from market trends or other government interventions.

Appliance and Equipment Standards Program

The Appliance and Equipment Standards Program, hereafter 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, including home appliances, heating and cooling equipment, lighting, electric motors, and distribution transformers. Building on BTO's efforts in research, development, and market transformation, as well as product demonstration and labeling programs, the Appliance Standards Program contributes to BTO goals by "locking in" or preserving these efficiency gains.

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 energy use.[27]

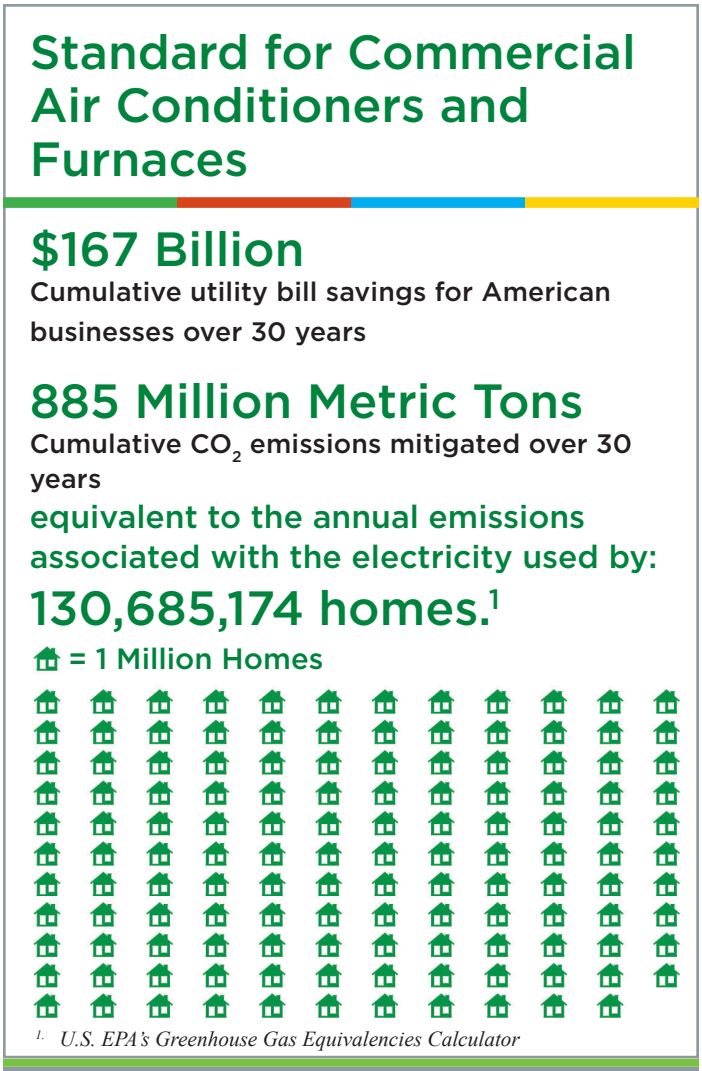


Figure 3: Largest energy-saving standard in DOE history. Issued December 2015.

The energy conservation standards developed by the Appliance Standards Program 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.

As described in BTO's Multi-Year Program Plan, 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 (from 2010).
- Support the verification of product efficiency by the testing of covered products.

On behalf of DOE, the Appliance Standards Programs 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, the Appliance Standards Program 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 as another means of facilitating stakeholder engagement by allowing for negotiated rulemakings under the guidelines set forth in the Federal Advisory Committee Act. The Appliance Standards

Appliance and Equipment Standards Program

Program works with other federal, state, and utility programs to continually increase the energy efficiency of covered appliances and equipment.

The Appliance Standards Program produces semi-annual reports to Congress that cover past, present, and future DOE rulemaking activities, detailing DOE's plans for the issuance of new or amended energy conservation standards.

To meet statutory requirements while at the same time expanding product coverage, the Program has developed new strategies to help meet the schedules set forth in EPCA, the Energy Policy Act of 2005 (EPAct 2005), and the Energy Independence and Security Act of 2007 (EISA). These strategies include:

- 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

BTO Stakeholder Feedback on Appliance Standards Program Goals

Stakeholders participated in a session at the 2016 BTO Peer Review to discuss and provide feedback on Appliance Standards Program goals. During this session, Appliance and Equipment Standards Program Manager John Cymbalsky provided an overview of the Appliance Standards Program. Peer review attendees were then asked (1) whether the 2020 and 2030 goals were appropriate for the Appliance Standards Program; (2) whether programmatic activities described in the BTO MYPP would lead to the desired long-term outcomes; (3) and whether the metrics in place to measure progress towards success were appropriate.

An overwhelming majority of session attendees agreed with the appropriateness of the Program's goals, and also with the idea that the Program's activities would lead to the achievement of its long-term objectives. Attendees flagged the issue that external influences could have a big impact on the achievement of the Program's goals, specifically identifying occupant behavior, equipment maintenance, and advanced buildings controls (e.g., daylighting) as some of the potentially confounding factors that could affect the Program's success.

Stakeholders also offered numerous recommendations for ways to improve and/or adjust the Program's metrics in order to better capture the impact of the Program's activities. For example, one stakeholder suggested that the Appliance Standards Program needs to better capture the relationship between an appliance's function and its energy usage. Another stakeholder commented that because energy use in buildings depends on the building envelope while Appliance Standards Program in interested in the energy use of equipment, the Program's topline target should better capture the relationship between what an appliance does and the energy it uses, rather than being just about energy use in relation to a building's square footage. Yet another stakeholder noted that the Program's targets fail to account for the issue of cost – an important dimension that is factored into the metrics of other BTO programs – while a fourth stakeholder expressed a desire for program metrics to consider differences in the energy savings accrued from efficiency standards based on geographic location and the primary energy source used in different areas.

Energy-efficient appliances. Image courtesy of Oak Ridge National Laboratory/Jason Richards.

End Notes

1. U.S. Energy Information Administration. Annual Energy Outlook 2015 with projections to 2040. DOE/EIA-0383(2015). Washington, DC: U.S. Department of Energy, April 2015. Accessed August 10, 2016: http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf.
2. "2010 technologies" are defined as technologies available in 2010 that cost effectively save energy in a typical residential or commercial building.
3. Energy productivity is measured by gross domestic product (GDP) per unit of energy use. For more information on this goal, see http://energy.gov/epsa/accelerate-energy-productivity-2030.
4. The Appliance and Equipment Standards Program also already works closely with a large range of stakeholders to ensure its energy conservation standards, test procedures, and certification and compliance regulations are based on technical merit. Decisions are also made based on economic analyses and the consideration of impacts on consumers, manufacturers, and the environment.
5. Reviewer comments and scores for individual projects can be found on the 2016 BTO Peer Review website.
6. A draft version of the Multi-Year Program Plan 2016 – 2020 was available for public comment in late 2015.
7. Supra 1; Annual Energy Outlook 2015 with projections to 2040; Accessed June 1, 2016.
8. The BEM portfolio of projects are spread across the ET and Commercial Buildings Integration (CBI) Programs within BTO, and are discussed in a separate section.
9. The ET Program's 2020 and 2030 goals are defined relative to the cost-effective, energy-efficient technologies that were available in 2010. ENERGY STAR 2010 product specifications are used to represent the performance of these cost-effective, energy-efficient technologies. For technologies that do not have a 2010 ENERGY STAR specification, BTO relies on either the most recent version of the applicable model energy code or the appropriate federal efficiency standard for a baseline performance measure.
10. BTO Multi-Year Program Plan: Fiscal Years 2016 – 2020. Accessed August 9, 2016: http://energy.gov/eere/buildings/downloads/multi-year-program-plan.
11. One quad is a unit of energy equal to one quadrillion (10^{15}) British thermal units (BTUs). The U.S. consumes approximately 100 quads of energy each year.
12. The U.S. Environmental Protection Agency reports that the U.S. greenhouse gas emissions in 2014 totaled 6.87 billion metric tons CO_2 equivalent. U.S. Greenhouse Inventory Report: 1990 – 2014. Accessed August 9, 2016: https://www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014.
13. Supra 10; BTO Multi-Year Program Plan; Accessed August 9, 2016.
14. The ET Program clarified that the 2030 goal is a deployment measure – which looks at the energy impact of the stock of technologies in the market in 2010 versus the stock of technologies in the market in 2030 – and that technologies commercialized in 2020 will only make up a small percentage of technologies deployed in 2030; the ET Program's 2030 market goal takes this modest market penetration into account.
15. The two ET-funded BEM projects are included in this chart for accuracy, but their overview can be found in the separate Building Energy Modeling overview section.
16. Supra 10; BTO Multi-Year Program Plan; Accessed June 2, 2016.
17. Ibid.
18. Ibid.
19. Ibid.
20. Ibid.
21. U.S. Energy Information Administration. "2012 CBECS Preliminary Results." Washington, DC: U.S. Department of Energy. Accessed August 10, 2016: http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm.
22. Supra 10; BTO Multi-Year Program Plan; Accessed August 10, 2016.
23. U.S. Energy Information Administration. "2009 RECS Survey Data." Residential Energy Consumption Survey. Washington, DC: U.S. Department of Energy, 2012. Accessed August 10, 2016: http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption#summary.
24. Supra 1; Annual Energy Outlook 2015 with projections to 2040; Accessed June 2, 2016.
25. Supra 10; BTO Multi-Year Program Plan; Accessed August 10, 2016.
26. 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 10, 2016: http://www.energycodes.gov/sites/default/files/documents/BenefitsReport_Final_March20142.pdf.
27. 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. Updated in 2016. Accessed August 8, 2016: http://energy.gov/eere/buildings/downloads/appliance-and-equipment-standards-fact-sheet.

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