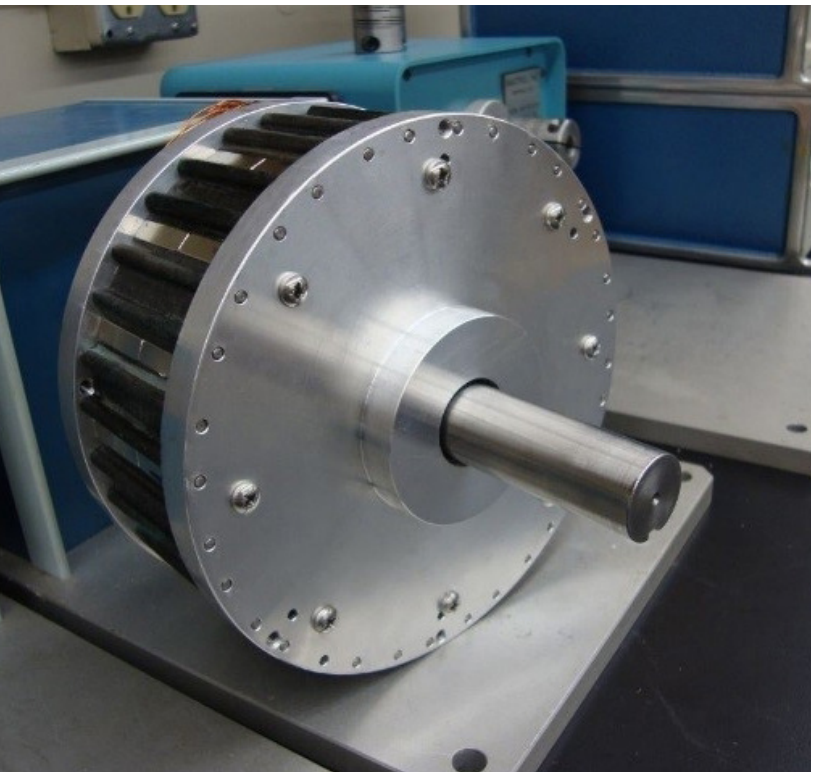
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

BUILDING TECHNOLOGIES OFFICE

Peer Review Report 2017



2017 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

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November 2017

The U.S. Department of Energy's (DOE) Building Technologies Office (BTO) leads a network of national laboratory, university, small business, and industry partners to develop innovative, cost-effective energy saving solutions for U.S. buildings, which are the single largest energy-consuming sector in the nation. Residential and commercial buildings account for 40% of the nation's total energy and more than 74% of the electrical energy, resulting in an estimated annual national energy bill totaling more than $380 billion.[1,2,3] BTO's long-term goal is to reduce the energy intensity of homes and commercial buildings by 50% or more through the application of cost-effective efficiency technologies that yield substantial net economic benefits.

Reducing building energy use per square foot, or energy use intensity (EUI), helps conserve valuable natural resources and strengthens the U.S. economy by creating jobs, improving the productivity of businesses, and helping families save money. In addition to saving energy, certain BTO technologies and activities also benefit the United States by improving indoor air quality and enabling the integration of buildings with demand response systems implemented by operators of the nation's power grid.

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

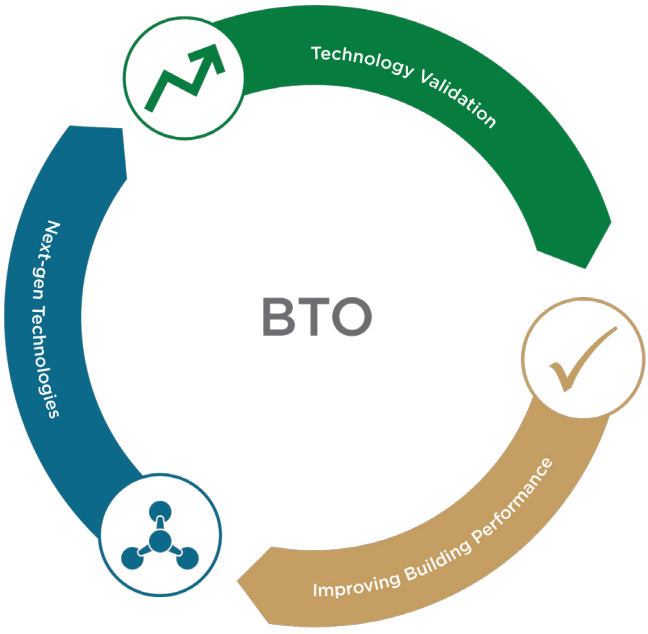


Figure 1. BTO Strategy

Mission and Goals

BTO's mission is to support the research and development (R&D), validation, and integration of affordable, energy-saving technologies, techniques, tools, and services, to enable industry and others to develop and deploy technologies that can improve the efficiency and reduce the energy costs of the nation's homes, offices, schools, hospitals, and other commercial and residential buildings in both the new and existing buildings markets.[4] BTO seeks to overcome the high degree of fragmentation across the heterogeneous buildings industry—spanning from construction to appliance and equipment manufacturing—which contributes to the building sector under-investing in R&D compared to the U.S. industry average.[5]

BTO's strategy for carrying out this mission has encompassed:

1. R&D for innovative, pre-commercial, energy-efficient building technologies, as well as their effective integration into efficient, resilient, grid-connected, and secure building systems.

2. Validation and verification of energy-saving solutions that help building owners and homeowners reduce energy waste by improving understanding of efficient building operational practices and technologies, as well as their costs and benefits.

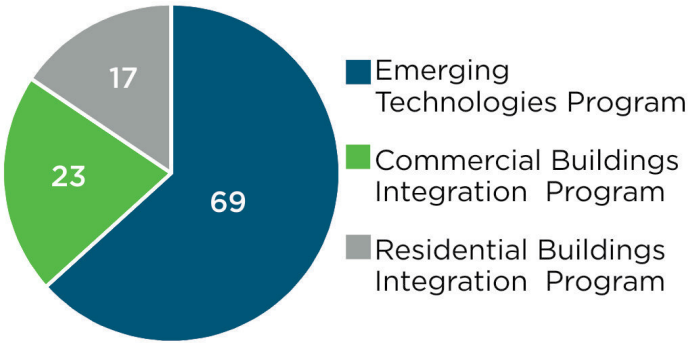
3. Collaboration with industry and other stakeholders to test and implement statutorily-mandated appliance and equipment efficiency standards, and evaluation of changes to model building energy codes to support state and local building code processes.

BTO's Multi-Year Program Plan (MYPP) outlines the activities BTO has pursued to enable these outcomes and provide compelling, affordable energy efficiency options for our nation's homes and buildings.

Introduction

2017 BTO Peer Review

The 2017 BTO Peer Review was held March 13–16, 2017, at the DoubleTree Crystal City in Arlington, Virginia. The review was attended by more than 400 participants and included presentations on 109 projects representing three of BTO's five technology programs:



The Building Energy Codes Program (BECP) did not conduct any project reviews at the 2017 Peer Review. The Appliance and Equipment Standards Program is typically excluded from the BTO Peer Review process, as the majority of its work is statutorily mandated.[7]

The objectives of the 2017 Peer Review were to:

1. Conduct an independent evaluation of current BTO projects and performers, their efforts over the past year toward 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. Each reviewer was screened for conflicts of interest and assigned to projects based on their area of expertise and interests. Reviewers evaluated each assigned project according to five criteria—relevance, approach, progress; collaboration; and future plans—providing a numerical score for each criterion and then substantiating these scores with additional comments. The Appendix provides a complete list of reviewers, as well as a detailed description of the evaluation criteria and scoring methodology.

Overview of BTO Goals

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

1. **Emerging Technologies Program:** By 2020, accelerated R&D will make available new, cost-effective technologies capable of reducing the energy use of typical buildings by 30% compared to high-efficiency technologies available in 2010.[6]
2. **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.
3. **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.
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.

Zero Energy Ready Home in Charleston, SC.
Image courtesy of Johns Island Custom

Panel Discussions

For the second year, BTO hosted several informational panel discussions at the Peer Review on key R&D topics and other areas of interest for BTO's stakeholders. These panels provided attendees with an opportunity to learn about and engage with subjects that were not fully addressed or covered as part of project review sessions. Topics covered during these discussions included zero energy buildings, BTO's Scout tool, the overall state of building energy efficiency, and the future of buildings-to-grid integration. Presentation materials delivered during these panel sessions can be found on the 2017 BTO Peer Review webpage.

Weather-Related Disruptions

The onset of inclement winter weather on the evening of March 13 interrupted travel to the Washington, D.C. region for a number of project performers, reviewers, and other BTO stakeholders. To accommodate those affected by this weather, BTO offered remote participation for most Peer Review sessions held on March 14-16. A number of project performers remotely delivered their review session presentations and answered audience questions via webinar. Several reviewers similarly utilized the webinar functionality to conduct their independent evaluations remotely. This is the first time that remote participation in the BTO Peer Review was made available. Reviewers' or performers' remote participation in the proceedings was not factored into the evaluation criteria for any project.

BTO Peer Review Report

This report summarizes the scores and comments submitted by reviewers for the 109 projects presented at the 2017 BTO Peer Review. Each project was evaluated on work completed in fiscal year 2016 (FY16), within the context of its Program's priorities at that time. The following sections present an overview of the goals and activities for BTO's various technology research and program areas, a summary of project scores for each Program, and a brief analysis of general evaluation trends and highlights for each Program or its constituent sub-programs. Individual project scores and comments are available on the 2017 BTO Peer Review webpage or in the Appendix.

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 support research and development (R&D) of pre-commercial, energy-efficient, cost-effective building technologies and systems. In FY16, the ET Program focused on six major technology areas:

- Heating, Ventilation, and Air Conditioning (HVAC); Water Heating; and Appliances
- Windows and Building Envelope
- Solid-State Lighting
- Building Energy Modeling
- Sensors and Controls
- Buildings-to-Grid Integration

Four of these technology areas—HVAC, windows and building envelope, SSL, and sensors and controls—together represent approximately 60% of the energy used in existing buildings, and are expected to represent an even greater share of energy efficiency gains over the next several decades.[8]

In FY16, the ET Program also supported two international collaborations—the U.S.-India International Collaboration on Building Energy Efficiency (CBERD) and the U.S.-China Clean Energy Research Center (CERC). Projects carried out under these collaborations focused on building technologies from each of BTO's technology research areas.[9]

High-Level Summary of Reviewer Comments

The ET Program peer reviewed 61 projects across six sub-programs: Sensors and Controls; Buildings-to-Grid; HVAC, Water Heating, and Appliances; Building Envelope; Building Energy Modeling; and Solid-State Lighting. Eight additional projects were reviewed from the CERC and CBERD programs.

This section discusses the high-level evaluation trends by technology area and Table 1 provides a high-level summary of project scores broken out by sub-program. Projects had a maximum potential score of four and a minimum potential score of one. For individual project scores and comments, please visit the 2017 BTO Peer Review webpage or see the Appendix.

Table 1. High-Level Summary of ET Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
HVAC/Water Heating/ Appliances	27	3.07	2.37	3.79
Windows & Envelope	6	2.77	2.05	3.32
Solid-State Lighting	8	3.43	3.07	3.90
Building Energy Modeling	7	3.23	2.74	3.75
Sensors & Controls	4	3.16	3.03	3.62
Buildings-to-Grid	9	3.41	3.25	3.57
International	8	3.45	3.28	3.56
Overall	69	3.20	2.05	3.90

Pacific Northwest National Laboratory's Lighting Metrology Lab can perform photometric, photoelectric, and other performance testing for LED lighting systems.

Image courtesy of Pacific Northwest National Laboratory/Andrea Starr.

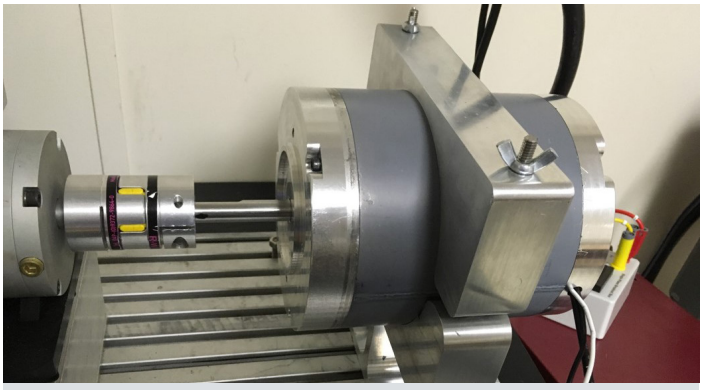
HVAC, Water Heating, and Appliances

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.[10,11] In FY16, the HVAC, Water Heating, and Appliances sub-program continued to lead 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.
- Alternative refrigerant development and testing, including low-global warming potential (GWP) 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 2017 BTO Peer Review, alongside projects seeking to advance other innovative technologies for specific products (e.g., clothes dryers), water heating (e.g., electrochemical compression), and product components (e.g., high-efficiency HVAC motors). HVAC projects represented the largest category of projects in this sub-program with 21 projects reviewed. The remaining six projects were divided between water heating (three) and appliances (three).

HVAC projects are further segmented into the following four technology sub-areas for better disaggregation of evaluations trends: advanced HVAC technologies, alternative refrigerants, 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.



A high-efficiency HVAC motor. *Image courtesy of QM Power, Inc.*

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

Technology Area	Project Count	Average Score	Low Score	High Score
HVAC	21	3.06	2.37	3.79
↳ *Adv. Vapor Compression*	*2*	*3.03*	*2.82*	*3.23*
↳ *Non-Vapor Compression*	*5*	*2.83*	*2.37*	*3.17*
↳ *Alternative Refrigerant*	*3*	*2.92*	*2.40*	*3.43*
↳ *Heat Pump*	*3*	*3.27*	*2.93*	*3.79*
↳ *Assorted HVAC&R*	*8*	*3.18*	*2.90*	*3.51*
Water Heating	3	3.20	2.97	3.53
Appliances	3	3.01	2.98	3.04

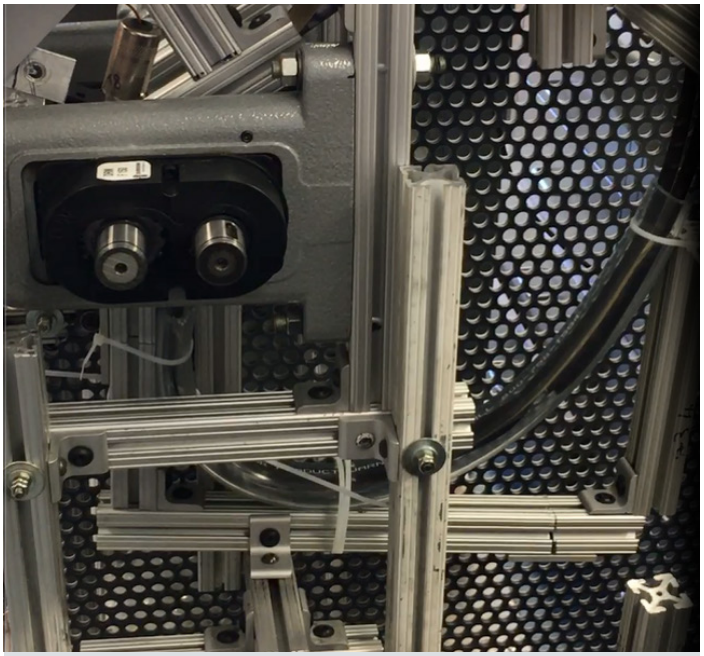
Table 2 provides a high-level summary of project scores; projects had a maximum potential score of four and a minimum potential score of one.

Advanced HVAC Technologies

HVAC systems presently represent the largest energy end-use in buildings, requiring almost 13 quads of primary energy annually, or approximately one-third of all energy used in U.S. commercial and residential buildings.[12] Given this energy usage, BTO worked with several partners in FY16 to develop advanced HVAC technologies that improve energy performance while also transitioning away from the use of conventional refrigerants and towards low- or zero-GWP alternatives. In the near term, advanced vapor compression (AVC) projects aimed to reduce the cost and improve the performance of air conditioning systems in buildings using low-GWP refrigerants that have minimal effect on the global environment. Non-vapor compression (NVC) projects sought to develop innovative new classes of highly-efficient HVAC technologies that do not use refrigerants and can achieve cost-effectiveness in the long-term.

At the 2017 BTO Peer Review, five NVC and two AVC projects were reviewed. Among these seven projects, reviewers assigned strong scores to projects whose approaches were perceived to be overcoming technical barriers to the emergence of new technologies, and which therefore had the potential to move

Emerging Technologies



Roller-based compressive thermoelastic cooling.
Image courtesy of Maryland Energy and Sensor Technologies, LCC.

the market toward new HVAC architectures and designs (in the case of NVC projects) or enable wide-scale market adoption of alternative-refrigerant systems (in the case of AVC projects). In contrast, reviewers assigned lower scores to projects where reviewers felt that market barriers were either not identified or not fully defined, or where barriers were not being fully addressed; in some cases reviewers noted that it might be too early in the project timeline for market barriers to be effectively resolved.

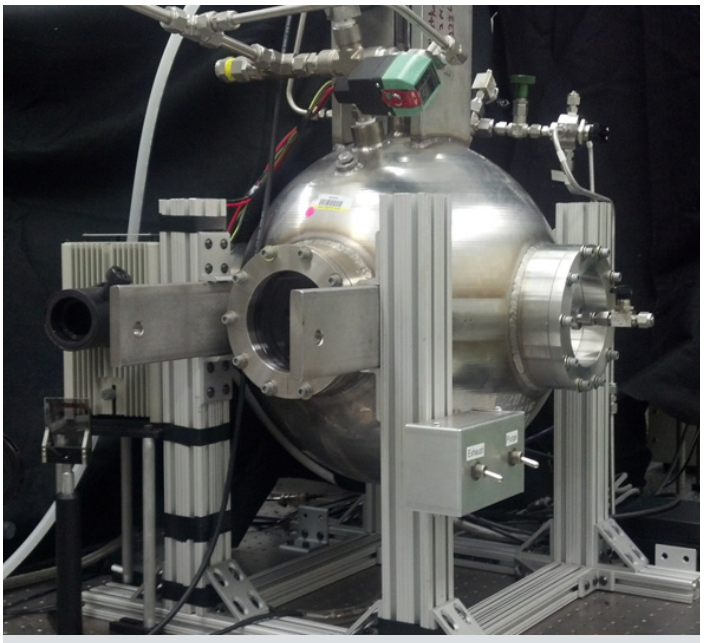
Reviewers strongly rated the progress of several advanced HVAC projects—AVC and NVC both—for which reviewers felt that consistently strong achievements were being made around the technical challenges being tackled. One NVC project was described as having some technical achievements, but also some important technical areas where progress lagged, resulting in lower scores being assigned. Three advanced HVAC projects received mixed scores, with some reviewers positively evaluating each project's accomplishments and others rating the same project's progress poorly—in two instances this disagreement appeared to stem from the fact that some reviewers focused on progress that was achieved, while other reviewers focused on a lack of progress relative to expectations. Despite the high praise received by some of the projects, reviewers encouraged project teams to maintain focus in their future work on technical and market risks, in some instances suggesting specific considerations that project teams should take into account.

A number of advanced HVAC projects—particularly those focused on NVC technologies—were lauded for their strong stakeholder engagements and were described as having good collaboration with a wide-range of stakeholders, particularly around technical matters. For several projects, however, reviewers encouraged project teams to undertake increased outreach to potential manufacturing and commercialization partners who could help ensure that a viable market product was being developed. Both AVC projects were commended for their collaborations with industry partners, but reviewers felt that both project teams could benefit from greater diversity in their collaborations. Lower scores were assigned to those projects where reviewers encouraged stronger or more well-defined partnerships.

Alternative Refrigerants

Commercially-available products for certain types of HVAC&R applications already use alternative refrigerants and have comparable or improved efficiency relative to today's typical equipment. To expand the number of HVAC&R applications for which high-performing, alternative refrigerants are a viable option, in FY16 BTO worked with industry and the national labs to understand how alternative refrigerant candidates perform in common HVAC&R equipment under different conditions, evaluating alternative refrigerants along a number of dimensions including performance, efficiency, flammability, and cost.

Among the three alternative refrigerant projects reviewed at the 2017 BTO Peer Review, reviewers generally agreed that two were relevant to BTO goals, but they felt that the third was focused more on safety than energy use.



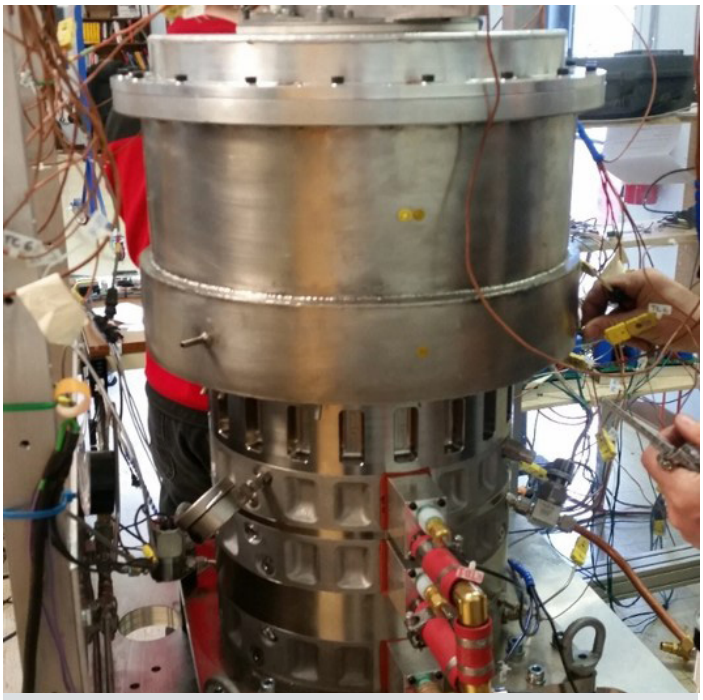
Chamber for testing the laminar burning velocity of refrigerant.
Image courtesy of National Institute of Standards and Technology.

Reviewers assigned the highest score for approach to the project where it was agreed that the technical approach was sound and that most market barriers were being addressed. Lower scores were assigned to the projects where reviewers disagreed on the appropriateness of a project's approach to either technical or market barriers, or both; reviewers raised concerns about both the soundness of refrigerant evaluation methodologies and the scope of manufacturer concerns about alternative refrigerant options. To better manage project costs, reviewers encouraged multiple project teams to seek out existing facilities with the necessary tools to conduct their research, rather than developing in-house infrastructure and capabilities.

When evaluating project accomplishments, stronger scores were assigned where reviewers agreed that progress was being made and goals being met, while lower scores were given when reviewers either disagreed on a project's progress to date or questioned the testing techniques and parameters used to test refrigerants. Two of the projects were lauded for their collaborations with multiple organizations and stakeholders, including one project team's work with a panel of international experts. Reviewers noted that further collaboration would be beneficial for the other project, however, specifically suggesting engagement with regulatory institutions and better laboratory integration.

Heat Pumps

Heat pumps provide space conditioning and/or hot water by capturing energy from their surroundings, including 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. In FY16, BTO sought to innovate heat pumps across new geographic areas and using new fuel types.



Prototype natural gas heat pump. *Image courtesy of ThermoLift.*

At the 2017 BTO Peer Review, reviewers found each of the three heat pump projects reviewed to be highly relevant to the goals at BTO. In particular, projects that addressed each of three main residential energy end uses—heating, cooling, and water heating—were very well regarded. Both projects' technical approaches and their approaches to overcoming market barriers were noted, with reviewers assigning higher scores to those projects addressing both domains; some projects were found to be inadequately focused on addressing market barriers, particularly barriers related to cost and performance.

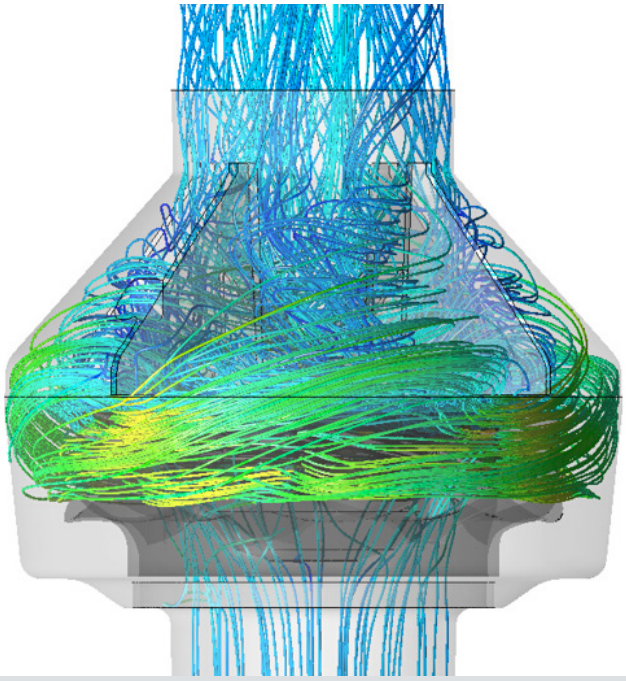
In evaluating heat pump projects' accomplishments, reviewers tended to assign higher scores to projects that were more mature; one project, for example, was rated lower because it was still in its design phase. Reviewers gave high marks to one project for which one reviewer felt represented R&D that would probably not have been completed without DOE support.

Reviewers found most heat pump projects to have strong collaboration and relationships with industry partners and national labs, but for two projects reviewers questioned partners' role, finding the actual extent of their participation unclear. Reviewers placed high value on having a clear path to commercialization. For example, one project, though close to being at a commercialization stage, lacked a commercialization plan with its industry partner; reviewers consequently assigned this project a low score, recommending that the project team explore new partnerships in the future. One reviewer also suggested diversifying projects' collaborations, specifically recommending partnerships with universities.

Assorted HVAC&R Technologies

Components such as compressors and heat exchangers (HXs) are key drivers of energy consumption and performance in common HVAC and refrigeration (HVAC&R) equipment. In FY16, BTO sought to take advantage of unrealized opportunities to increase the efficiency of HVAC&R equipment by improving the design and engineering of individual system components, as well as the integrated performance of these components within packaged HVAC equipment. Eight projects reviewed at the 2017 BTO Peer Review were focused on assorted HVAC&R technologies, including a high-efficiency HVAC motor and radon fan, a new architecture for vapor compression equipment, and novel HX manufacturing processes and joining techniques aimed at reducing air or refrigerant leakage in HVAC and refrigeration applications.

Emerging Technologies



Computational Fluid Dynamics (CFD) modeling of radon fan.
Image courtesy of Mechanical Solutions, Inc.

Reviewers highly rated those assorted HVAC&R projects that not only demonstrated energy saving potential in line with BTO goals, but also addressed a market gap in the field. Reviewers put a premium on the novelty of technology projects, assigning lower scores to projects focused on a topic for which there were technologies or products already on the market.

Reviewers generally rated the various projects' approaches well, though reviewers found that several of projects failed to adequately address relevant market barriers. Even in the face of upcoming technical challenges, projects that clearly identified and addressed imminent problems regarding market penetration and adoption received relatively high reviewer scores; projects that effectively addressed both market and technical barriers were also well regarded. In terms of collaboration, reviewers valued partnerships that could enable a project have a profound impact on the market, assigning high marks to project teams who collaborated with strategic industry players.

In analyzing the accomplishments of this diverse set of projects, reviewers tended to rate highly those projects with clearly defined milestones and that clearly demonstrated progress. Reviewers found some projects to lack clear definition around milestone objective, assigning lower scores accordingly. Overall, reviewers were pleased with the technical progress being made by many of the projects, but emphasized the importance of demonstrating technology performance in the field in addition to the lab.

Water Heaters

Water heaters provide buildings with continual sources of hot water. In FY16, BTO sought to improve the efficiency of new water heaters for residential and commercial buildings, while reducing both the cost and complexity of installation.

Reviewers found that each of the three sater Heater projects that were reviewed at the 2017 BTO Peer Review was successfully addressing key technical barriers limiting water heating performance. The three projects varied in the extent to which they had identified and were addressing non-technical market barriers, however. Higher scoring projects were found to have correctly identified key non-technical market barriers, while the lower scoring project raised reviewer doubts about whether the project's technology could overcome some of the hurdles identified.

Reviewers found that each of the three water heating projects was making good progress relative to their project plans, and that each was achieving an impressive level of technology performance. Relatively lower scores were assigned, however, where reviewers expressed some concern over the potential market impact of a project's technology; in one instance, a technology's applicability to different climate zones was questioned, and in another instance a reviewer perceived there to be problematic overlap between the project's accomplishments and the accomplishments of other related projects in BTO's portfolio.

Reviewers assigned higher ratings to projects with strong project collaborations with key stakeholders and industry partners. Reviewers noted that these projects often collaborated with leaders in the field, including manufacturing partners with a large market share. Collaboration scores tended to be lower for projects where only initial collaborations were evident. The lowest collaboration score was reserved for the project where reviewers could identify little to no collaboration between the project team and external partners; reviewers felt that the lack of external engagement with stakeholders was a primary market barrier that still needed to be addressed for this project.

Seven generations of electrochemical compression prototype for use in advanced hybrid water heaters.
Image courtesy of Xergy, Inc.

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.[13] 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. In FY16, BTO research in this area primarily focused on refrigerator/freezers and clothes washers and dryers, which have the most opportunity for energy savings. Of the three appliance projects reviewed at the 2017 BTO Peer Review, one focused on residential refrigeration while two addressed clothes drying technologies.

When evaluating these projects, reviewers generally felt that they were addressing a number of critical barriers. For the clothes dryer projects, however, reviewers noted that payback and price might still be barriers to market acceptance, while one reviewer wondered why the European market already sold heat pump clothes dryers but the U.S. market did not. A few reviewers noted that the refrigerator project team should keep in mind that the technology would ultimately need to be scaled for mass production.

For each of the three projects, reviewers highlighted the prototype development and testing that occurred, but they also expressed a desire to see more information on project elements like potential technology price points and payback periods, how predicted performance levels were calculated, and how technologies performed relative to predicted values. For both clothes dryer projects, reviewers also called out lint as a potential issue that needed to be addressed, and flagged that pathways to commercialization should be determined. For the refrigerator project, reviewers felt a greater understanding of materials science and further reliability testing needed to be pursued.

Life-cycle performance testing of supermarket refrigeration.
Image courtesy of Oak Ridge National Laboratory.

All of the projects collaborated with General Electric Appliances (GE), which was positively noted by reviewers. Reviewers still recommended additional collaborations, however, including with universities, European researchers, and additional companies that could offer outside expertise, as well as with possible technology adopters.

Windows and Building Envelope

Space heating and cooling represents 30% of the primary energy consumed in residential and commercial buildings;[14] 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. In FY16, the Windows and Building Envelope sub-program focused 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 included:

- 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 included:

- 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 sought to address cross-cutting challenges that include:

- Developing a “seamless” transition between functional areas (e.g., roof-walls, walls-windows);

Emerging Technologies

Installation of a primer-less self-adhere membrane that serves as an air, liquid water, and water vapor barrier. *Image courtesy of 3M.*

- 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.

Six projects were reviewed under this sub-program at the 2016 BTO Peer Review, all focused on the building envelope. Table 3 provides a high-level summary of scores among building envelope projects; projects had a maximum potential score of four and a minimum potential score of one.

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

Technology Area	Project Count	Average Score	Low Score	High Score
Building Envelope	6	2.77	2.05	3.32

Building Envelope projects that were rated higher in approach identified and were addressing market barriers, though for some projects reviewers cautioned that questions about market acceptance persisted. The projects receiving the lowest scores were those for which market barriers remained to be identified or addressed, even though reviewers found these projects' underlying approaches to be technically sound and/or innovative. For one of these projects, reviewers commented that while some market barriers had been addressed in the lab, findings still needed be verified in the field.

Reinforcing reviewers' beliefs that overcoming market barriers was critical to the success and ultimate impact of a project, reviewers noted for one project—which received the highest rating for accomplishment—that the project team had explicitly identified next steps focused on overcoming all remaining market barriers in order to create a market-ready product. In contrast, for two projects receiving lower scores for their accomplishments, reviewers agreed that good progress was being made, but also that there were major market barriers that still needed to be addressed. For another low-rated project, reviewers noted that learning outcome were highly valuable, but also that actual accomplishments were not in line with stated goals.

Reviewers assigned higher ratings to projects with strong project collaborations with key stakeholders and industry partners. Reviewers noted that these projects often collaborated with leaders in the field, for example a manufacturing partner with a large market share. Collaboration scores tended to be lower for projects where only initial collaborations were evident. The lowest collaboration score was reserved for the project where reviewers could identify little to no collaboration between the project team and external partners; reviewers felt that the lack of external engagement with stakeholders was a primary market barrier that still needed to be addressed for this project.

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.[15]

Eight projects were reviewed under the SSL sub-program at the 2017 BTO Peer Review, with six focused on next-generation LED technologies and two focused on OLEDs. Table 4 provides a high-level summary of scores among SSL projects; projects had a maximum potential score of four and a minimum potential score of one.

An LED patient room lighting system.
Image courtesy of Philips Lighting Research North America.

Table 4. High-Level Summary of SSL Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Solid-State Lighting	**8**	**3.36**	**3.07**	**3.85**
↳ ***LED***	***6***	***3.30***	***3.07***	***3.82***
↳ ***OLED***	***2***	***3.53***	***3.48***	***3.57***

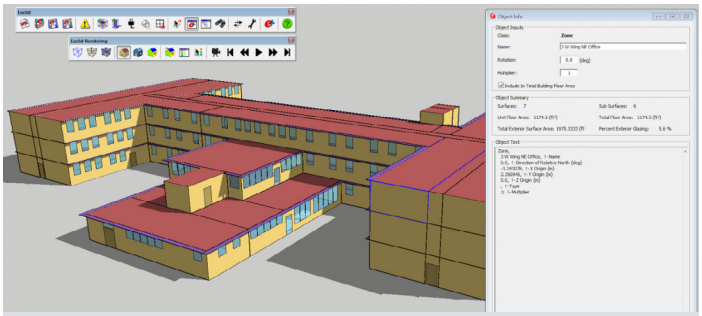
A majority of SSL projects were assigned strong scores for their approaches to addressing market barriers and their collaborations with external stakeholders. Strong project designs, however, were not always associated with comparable ratings for project accomplishments. Projects receiving accomplishment scores that were notably lower than those scores assigned for approach and collaboration tended to be early-stage research projects that reviewers felt were too nascent to fairly evaluate against BTO's interim market goals, or were project where reviewers felt that stated objectives seemed too ambitious relative to the time remaining in the project term. Nonetheless, reviewers expressed that the novelty of certain projects' approaches had directly unlocked technology breakthroughs, with one—the highest scoring SSL project—described as having accelerated the entire industry's learning curve.

Collectively, SSL projects were some of the highest scoring projects among all of BTO's technology R&D portfolio, but reviewers still identified some critical project elements that required additional attention from project teams. For example, though both OLED projects' overall scores were among the portfolio's highest, one reviewer was consistently concerned about these projects' lack of risk mitigation plans. In several LED projects, reviewers questioned whether the correct or full suite of market barriers had been identified and addressed, especially with regard to issues of cost and affordability. For the two LED projects focused on technology demonstrations, reviewers wished for greater clarity and more quantifiable data to evaluate progress, which contributed to these project receiving two of lowest scores within the portfolio. Lower collaboration scores were assigned to those projects where reviewers believed that some potential stakeholders had been omitted from economic sectors that could have positively influenced the project's outcomes. The lowest collaboration score was given to a project where reviewers felt that no external collaborators had been engaged, identifying this lack of collaboration as the project's main weakness.

Building Energy Modeling

BTO's Building Energy Modeling (BEM) portfolio has been jointly managed under BTO's Commercial Buildings Integration (CBI) and Emerging Technologies (ET) Programs.[16] The program seeks to characterize and implement models of the physical phenomena for building components and systems that enable increased use of building energy modeling tools for the design and operation of energy-efficient buildings in the U.S. In FY16, the goal of the program was to accelerate the use of energy modeling in both new and established use cases.

Seven BEM projects were reviewed during the 2017 BTO Peer Review. Table 5 provides a high-level summary of project scores; projects had a maximum potential score of four and a minimum potential score of one.



The Legacy OpenStudio SketchUp plug-in simplified the creation, inspection, and editing of EnergyPlus geometry and geometry related information. *Image courtesy of Big Ladder Software.*

Emerging Technologies

Table 5. High-Level Summary of BEM Project Scores

Project Type	Project Count	Average Score	Low Score	High Score
Building Energy Modeling	7	3.23	2.74	3.75
↳ *Standard Projects*	*5*	*3.40*	*2.91*	*3.75*
↳ *SBV Projects*	*2*	*2.80*	*2.74*	*2.86*

Two of the BEM projects reviewed were initiated under DOE's Small Business Vouchers (SBV) program.[17] In BTO's response to reviewer comments (see the Appendix), the BTO technology manager for BEM noted that SBV projects do not fit neatly into the BTO Peer Review rubric, in that Peer Review criteria for relevance, collaboration, and future work are generally not applicable because an SBV's project scope, timeline, and partnerships are not specifically designed to advance a BTO program or sub-program's strategic plan; the technology manager suggests that these circumstances likely influenced reviewers' comments and scores for the two SBV projects.

When looking at the remaining five BEM projects, reviewers generally approved of each of the projects' approach to overcoming the market barriers that were identified; a recurring theme, however, was disagreement among some reviewers over whether the identified market barriers were the most important, significant, or relevant barriers affecting a project's technology. In some instances, reviewers disagreed on whether all relevant market barriers were being effectively addressed, with some arguing they had been and others saying that important barriers had not been identified or that less impactful barriers were being overcome while the largest hurdles were going unattended. Projects received lower scores when there was disagreement among reviewers over whether they were addressing the "correct" market barriers.

Projects where there was observed or expected market impacts—as measured by expected or actual deployment or use of project outputs—were well-regarded by reviewers for their progress and accomplishments. Projects also scored well when they appeared to be making good progress against their project plans. Lower scores were assigned when a project appeared to be running out time and would be challenged to complete all milestones, or when a project which appeared to be meeting all of its objectives was not expected to have much impact on the industry. The best scored project was one that appeared to be making good progress against its project plan and was expected to produce outputs that would be valuable and impactful in the field.

In terms of collaborations and project integration, reviewers commented that most projects exhibited a strong understanding of relevant stakeholders and were engaged in appropriate partnerships and collaborations, which benefited project goals. For all projects, however, one or more reviewers flagged one or more specific classes of stakeholders (e.g. end-users, industry, manufacturers, and standards bodies) whose participation in the project could add value, and whom the reviewers' recommended project teams target with new and/or additional outreach. Those projects for which a single stakeholder group was identified scored slightly higher than those projects where two or more groups were flagged.

Sensors and Controls

Studies how shown that as much as 30% of commercial building energy consumption can be eliminated through more accurate sensing, more effective use of existing controls, and deployment of advanced controls.[18] In FY16, the goal of the Sensors and Controls (S&C) sub-program was to improve building energy management and optimize building operating conditions through the development of low-cost and fully automated building sensors and controls systems, which together would improve data collection, monitoring, and the optimization of building energy use, as well as effectively integrate building energy loads with the rest of the electric grid and support energy-related transactions outside the building envelope.

The sub-program is organized around four technology areas: multifunction plug-and-play wireless sensors, occupant-centered and occupant-comfort sensors and controls, whole-building submetering, and adaptive and fault tolerant controls. Advancements in these sensor and control strategies will

Advanced building controls can reduce equipment energy use, including for commercial building heating and cooling system.
Image courtesy of Pacific Northwest National Laboratory/Andrew Starr.

improve the efficiency—and enable energy savings—for other building technologies, including HVAC, water heating, lighting, windows, and the building envelope.

Four projects were reviewed under this sub-program at the 2017 BTO Peer Review, each focused on controls technologies. Table 6 provides a high-level summary of scores among these projects; projects had a maximum potential score of four and a minimum potential score of one.

Table 6. High-Level Summary of S&C Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Controls	4	3.19	3.03	3.62

Reviewers found the S&C projects reviewed were mixed in their approach and ability to address market barriers. Those projects that received particularly high reviews were those which had outlined a particular problem within the market, and were providing cutting-edge technologies to address them. Reviewers assigned higher scores to projects that provided multiple benefits to the user and/or were user friendly and therefore easily adopted. The project receiving the highest score addressed key issues of equipment integration, energy efficiency, and occupant comfort, all while demonstrating real-world application. Reviewers assigned lower scores to projects without a clear commercialization strategy, and expressed concern that without such a strategy, a project would not remain relevant—given the fast-paced nature of the field—and not have any actual impact.

Reviewers provided mixed scores for the accomplishments of the four projects reviewed. Broadly, and when considering accomplishments both relative to the project plan and from a real-world perspective, reviewers acknowledged that while newer projects were innovative in their approaches, less had been accomplished due to the timeline. Reviewers tended to be less critical of the commercialization pathway for these projects, since they had had less time to make significant market impacts than older projects.

Projects demonstrating engagement with a number of partners were well regarded by reviewers, particularly when partners had industry connections that could help with the commercialization of project deliverables. For example, one project initiated under the BUILD Funding Opportunity was lauded for its creative engagement with undergraduate students—who performed the majority of the research—but reviewers encouraged strengthening the project's engagement with industry moving forward. Reviewers critically assessed projects without a diversified collaboration portfolio, or project teams who were collaborating with appropriate partners but lacked a market strategy.[19]

Buildings-to-Grid Integration

In FY16, the goal of the Buildings-to-Grid (B2G) sub-program was to enable industry to develop and deploy truly smart buildings capable of connecting with the power grid in new and increasingly adaptive manners to help with overall electric system efficiency, resiliency, and bringing down energy prices across the grid. As part of this effort, BTO conducted R&D on key building blocks for cyber-physical systems for buildings, and coordinated strategies and activities with stakeholders to address the integration and optimization of homes and commercial buildings with the nation's energy grid. BTO also explored the fundamental concepts of transaction-based energy systems, the characterization of building end-uses, and the opportunities each brings to the larger energy system. BTO envisions this research enabling energy transactions within buildings, between buildings, and with the electric grid.

In FY16, BTO also participated in DOE's Grid Modernization Initiative (GMI), which works across DOE to develop the concepts, tools, and technologies to measure, analyze, predict, protect, and control the power grid of the future. In particular, BTO sponsored a number of projects under the Grid Modernization Lab Consortium (GMLC), which was established under GMI as a strategic partnership between DOE and the national laboratories to support critical R&D in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas.

Raspberry Pi powered by VOLTTRON.
Image courtesy of Pacific Northwest National Laboratory.

Emerging Technologies

Nine projects were reviewed under this topic at the 2017 BTO Peer Review, all of which were initiated as part of the GMLC.[20] Table 7 provides a high-level summary of scores among these projects; projects had a maximum potential score of four and a minimum potential score of one.

Table 7. High-Level Summary of B2G Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Buildings-to-Grid	9	3.41	3.25	3.57

Overall, reviewers were impressed with the ambition and scope of B2G projects, expressing that projects were either central and necessary endeavors for the achievement of BTO's goals, or essential to enabling transactive energy across the grid. When considering projects' approaches, however, reviewers explicitly acknowledged the nascence of many of the projects. For example, reviewers flagged that relevant market barriers had not been identified for some projects, but they also noted that certain of these market barriers may have been omitted from the project approach simply because they were unforeseen. Additionally, for some projects, reviewers were optimistic that the project's approach incorporated steps that would ultimately identify additional market barriers.

Reviewers consistently expressed a desire to see additional project collaborators, assigning a higher rating to those projects with utility involvement. In addition to further engagement with utilities, reviewers also noted other potential project collaborators, for example the Federal Energy Regulatory Commission, but acknowledged that it might be too early in the project's R&D process for some of these desired collaborators to contribute. Reviewers gave their lowest project integration and collaboration scores to projects where they could not determine what the collaborators had specifically contributed, particularly when such collaborators were considered vital to the overall success of B2G efforts in general.

Reviewers were generally pleased with the accomplishments of a majority of projects. Reviewers seemed to express their greatest enthusiasm for project results that were perceived to be laying a strong foundation for transactive energy across the grid, as well as for the early accomplishments of newer projects, such as the achievement of initial peak load reductions in testbed facilities. Reviewers assigned lower accomplishment scores to some less mature projects, but explicitly noted that this was because these projects had demonstrated few accomplishments to date rather than because of poor project design or execution.

International Collaborations

In FY16, BTO participated in two international collaborations focused on clean energy and energy efficiency R&D, working within each on multiple technology R&D projects spanning the ET Program's technology research areas. Both bilateral initiatives brought together governments, researchers, and industry to promote innovation in energy efficiency and achieve significant reductions in energy use in both participating countries.

Eight projects within these international collaborations were reviewed at the 2017 BTO Peer Review, including five as part of the U.S.-India International Collaboration on Building Energy Efficiency (CBERD) and three as part of the U.S.-China Clean Energy Research Center (CERC).[21] Table 8 provides a high-level summary of scores among international projects; projects had a maximum potential score of four and a minimum potential score of one.

Table 8. High-Level Summary of International Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
International	8	3.45	3.28	3.56
↳ *CBERD*	*5*	*3.42*	*2.28*	*3.55*
↳ *CERC*	*3*	*3.5*	*3.39*	*3.56*

CBERD

CBERD is a multi-year international effort focused on developing and implementing energy efficiency building technologies in both the U.S. and India. CBERD's approach is to facilitate high performance building design, construction, and operation through integration of building information technologies and building physical systems, focusing specifically on commercial and high-rise multi-family buildings. While key targets are new construction in India and retrofits and existing operations in the U.S., CBERD's research is expected to have spillover benefits to other building sectors.

When considering the various approaches of the five CBERD projects reviewed at the 2017 BTO Peer Review, reviewers applauded projects that anticipated the needs of their target audiences and sought to address market barriers through the use of new and innovative technologies. Reviewers also praised projects which they believed could engender strong market uptake, assigning the highest score to a project whose energy information management tool was user-friendly and well-tailored to its targeted user base, and reviewers saw potential for it to

CBERD and CERC strive to promote innovation in energy efficiency and reductions in building energy consumption in both participating countries.

become a strong asset management tool. In contrast, reviewers cautioned project teams whose approaches and technologies were similar to services or products that were already available on the market.

Collaborations with partners was perceived to be good and sufficient across all CBERD projects, with one reviewer even recommending that a certain project's methods for industry collaboration be integrated into other CBERD and CERC projects. For most projects, however, reviewers still generally recommended more diverse partnerships, with stakeholders such as building science experts, end users, and other relevant interest groups. Reviewers also repeatedly encouraged more and better collaboration between BTO's international projects—both CBERD and CERC—to promote best-practice sharing.

Reviewers were generally pleased with the progress and accomplishments of the CBERD suite of projects, as well as with the future direction of these projects based on project teams' planned next steps.

CERC

CERC is a bilateral program supporting clean energy R&D by teams of scientists and engineers from the U.S. and China. While BTO's participation in CERC focuses on building energy efficiency, other research areas addressed by CERC include vehicles, energy generation, and water.

The building energy efficiency technologies and strategies researched and developed in the U.S. and China as part of CERC are intended to make significant reductions in building energy consumption in both countries, but will also be applicable worldwide. CERC's building sector strategy to achieve real world impacts is implemented through a collaborative research agenda organized around numerous topics, including building design and operation, the building envelope, building equipment, and policy and market promotion.

Each of the three CERC projects reviewed at the 2017 BTO Peer Review were well received by reviewers, who valued these projects' demonstrated savings potential. Reviewers generally assigned high scores to the projects' approaches, though scores favored those projects that clearly identified the market barriers that needed to be overcome. To better align project approaches with relevant barriers, reviewers recommended that project teams give greater consideration to their target audiences as well as to the market barriers inhibiting industry adoption of their focus technologies. Although reviewers were generally impressed with the level of collaboration found in these international projects, they recommended improved and expanded engagements across the board, including highlighting potential industry partnerships to pursue in relevant fields. Reviewers also recommended gleaning lessons learned from partners that have endeavored on similar projects.

Reviewers were pleased with the accomplishments being made by each of these projects, particularly those projects in the earlier stages of development. Reviewers felt that all projects were making significant progress towards their milestones, and assigned scores accordingly.

Air-sealing a new construction building in China.
Image courtesy of CERC.

Commercial Buildings Integration

BTO's Commercial Buildings Integration (CBI) Program seeks to accelerate energy performance improvements in existing and new commercial buildings. The U.S. commercial buildings market is comprised of 90 billion square feet of floor space.[22] 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 19% of total U.S. energy consumption and 37% of U.S. electricity consumption, and cost nearly $165 billion to power each year.[23,24,25] This is a growing sector, with more than four billion square feet of net new floor area expected to be added over the next four years.[26]

In FY16, the CBI Program advanced research on targeted high-impact technologies and innovative energy efficiency strategies to verify and validate energy performance improvements in commercial buildings, creating a basis for private sector entities to voluntarily test these new and improved technologies and efficiency solutions to provide field-based feedback to DOE and its national labs. CBI Program activities targeted toward two market segments characterized as efficiency leaders and early adopters, referred to here as market leaders. Market leaders represent the segment of the market with the most energy-efficient buildings, and are the most willing and interested in voluntarily pushing the boundary of energy efficiency.

The CBI Program's FY16 strategy sought to engage market leaders to demonstrate that significant building energy use reductions are possible and cost-effective. The Program worked 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 developed tools and resources to help building owners monetize the value of their energy saving investments.

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).

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.

Commercial buildings come in many different shapes and sizes.
Image courtesy of National Renewable Energy Laboratory.

High-Level Summary of Reviewer Comments

There was a total of 23 projects reviewed within the CBI Program during the 2017 BTO Peer Review. These projects are divided among three types of activities: data tools, finance, and technology deployment. Table 9 provides a high-level summary of CBI project scores; projects had a maximum potential score of four and a minimum potential score of one.

Table 9. High-Level Summary of CBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Data Tools	8	2.74	2.07	3.37
Finance	5	2.81	2.58	3.10
Technology Deployment	10	3.17	2.71	3.70
Overall	23	2.94	2.07	3.70

Data Tools

In FY16, the CBI Program worked to develop 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 2017 BTO Peer Review, there were eight projects reviewed that were focused on building energy performance data and CBI's analysis tools. When evaluating these projects' approaches and their consideration of relevant market barriers, reviewers gave high scores to projects whose outputs could easily be incorporated into the market, where lower scores were assigned to projects with narrow market application. In this vein, reviewers tended to assign higher scores to projects with deliverables that were able to integrate well with other analytical tools. In contrast, reviewers expressed concern with how one project's data tools would interact and relate to existing data tools, warning that it could slow adoption of the project's tool if

the relationship between tools appeared adversarial. Reviewers also cautioned against developing tools that were too tailored to the needs of their stakeholders, for fear that narrowing the scope of deliverables in this would limit tools' ultimate applicability. Overall, many projects were perceived to be addressing market barriers, but reviewers provided lower scores to projects that failed to address *all* significant market barriers.

When considering project accomplishments, reviewers assigned higher scores to projects that could clearly substantiate their accomplishments. Reviewers also assigned higher scores to projects that had met and exceeded internal goals for market adoption, integration, and partner collaboration. For projects that had fallen behind in their project plans, reviewers suggested future work that was aggressive, and which attempted to make up deficits in progress.

Reviewers highly rated projects that engaged with a number of stakeholders and partners, but they also consistently recommended more robust collaboration. Occasionally, reviewers found it difficult to determine the degree to which partners were collaborating, and this was reflected in project scores. In contrast, reviewers rated projects more highly when they demonstrated clear integration with key participants and stakeholders and were seen to be leveraging these relationships to full effect.

Finance

Closely related to the CBI Program's development of data and analytical tools, CBI worked with industry partners in FY16 to show that energy performance data can be combined with financial performance data to inform real estate decisions such as building appraisal, underwriting, investment, and leasing. While the commercial buildings sector is currently implementing energy-efficiency measures and actualizing cost-savings, there is more progress to be made to ensure that these energy factors are acknowledged within the underwriting process. CBI conducted research to help overcome difficulties in isolating moderating factors and identifying specific drivers behind sustainability-related improvements in building financial performance and value to investors. This can help inform further developments in underwriting and risk valuation processes to fully consider energy factors (i.e., energy-related risks *and* benefits), and help building owners develop a business case for energy efficiency by demonstrating that energy performance drives financial performance in commercial buildings.

Reviewers praised the five Finance projects reviewed at the 2017 BTO Peer Review for their focus on resolving known gaps and issues for commercial energy efficiency, including the gap in commercial financing and education resources, the need for targeted outreach to hard-to-reach building owners and tenants,

Energy directly affects Net Operating Income used in commercial building valuation

and the persistent issue of data availability on commercial building energy data. Reviewer raised serious questions about project teams' approaches to overcoming these persistent issues, however. In some cases, for example, the project teams were praised for developing targeted educational materials; in others, reviewers felt that project strategy and resource development could be targeted further (e.g., by geographic area, building type, or building stakeholder) to increase opportunities to move from educational effort to changing investment patterns in more efficient technology deployment. Access to commercial real estate data was also a significant hurdle for many teams; while some were utilizing public data, reviewers cautioned project teams to be aware of the limits of public data and advised working with additional partners to secure additional data for their research.

Overall, reviewers considered Finance projects to have strong collaborations with commercial building stakeholder groups. Reviewers praised project teams for working with the "right" collaborators, including industry leaders such as corporate finance groups, mortgage lenders, and building energy managers. Additional levels of granularity were suggested, however, including involving building tenants and prominent private individuals.

While many teams had strong partnership models and information dissemination strategies, reviewers worried that project teams were not thinking long-term enough and asked them to consider questions such as: Where will these efforts live after DOE funding ends? How can existing partnerships be broadened, or have current partners already make public commitments to implement lessons learned and work products? How will work ultimately become the default in financial transactions and decision making processes?

Commercial Buildings Integration

Technology Deployment

One of the CBI Program's main activities is to validate technology performance. In FY16, the CBI Program worked with market leaders—including building owners, engineers, and operators—to demonstrate and validate energy-efficient technologies and practices in a variety of commercial building types and climate zones. Demonstrating technologies in operational, occupied buildings provides the performance, cost, and critical application information needed to inform decision-makers. The CBI Program conducted research, identification, and evaluation exercises to develop deployment strategies for those technologies that can make the most impact in achieving 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 2017 BTO Peer Review, ten technology deployment projects were reviewed, including three competitively-awarded projects and seven projects directly funded at the national labs.

Reviewers described the approaches taken by high-scoring technology deployment projects as effective, efficient, and/or robust, calling out each of these projects for its identification of, and efforts to address, relevant market barriers. For all projects, however, reviewers pointed out certain deficits in the project approach or potential improvements, including engaging with additional stakeholders to advance project objectives or taking a different approach for specific elements of a research methodology or plan. For the lowest scoring projects, reviewers highlighted that market barriers relevant to a project's focus technology were not clearly identified or addressed.

Reviewers generally agreed on the level of progress and the accomplishments of the four top-rated projects. A common reviewer recommendation among several of these projects, however, was for the project teams to collect additional data to enhance program evaluation, in an effort to further increase projects' effectiveness and impact. In this context, reviewers mentioned several specific types of data, including data on potential energy savings, cost, and building operations related to specific technologies, as well as qualitative information about projects' stakeholder engagement efforts.

Relatively lower-rated projects tended to engender disagreement among reviewers about the extent of the progress being made, or raised doubts among some reviewers about the ultimate impact or significance of the project's accomplishments. Among the lowest scoring projects, reviewers consistently noted their inability judge the projects' ultimate impacts, pointing to either a project's limited impact to date, a low apparent correlation between project activities and energy savings, or a lack of compelling data.

Well-rated projects were noted for their relevant, diverse, and/or comprehensive partnerships with stakeholders in key industries or occupations, as well for the effectiveness with which these collaborations were managed. Without exception, however, reviewers still offered recommendations and/or suggestions for additional classes of stakeholders with whom collaboration would be valuable, including contractors that work with relevant technologies, building owners and operators as well as other technology end users, and specialty retailers or distributors. Reviewers assigned lower scores to projects for which the additional recommended collaborators were perceived by reviewers as being essential to the project's success; for higher scoring projects, reviewers recommendations tended to focus on potential partnerships that could provide a value-add.

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

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 U.S. residential housing market is comprised of more than 118 million single-family homes, multi-family units, and mobile homes.[27] While approximately 3.8 million of these homes were built between 2010 and 2015, more than half were constructed prior to 1980.[28] Residential buildings account for approximately 22% of total U.S. energy consumption and 38% of all U.S. electricity consumption, costing consumers over $220 billion in natural gas and electricity bills each year.[29,30,31]

In FY16, the RBI Program's R&D efforts focused on identifying building integration technology areas and technical solutions that offer the potential for large energy savings, and then conducting research to resolve major technology and system integration challenges. This research creates the basis for private sector entities to voluntarily test new and improved energy-saving technologies, providing a theoretical foundation for building system design and generating field-based data that can inform the prioritization of future R&D. In addition to energy efficiency, the RBI Program also addresses other technology integration and installation issues that can affect total home performance, focusing especially on issues related to water heating and heating and cooling loads, durability, comfort, and indoor air quality and moisture control.

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

Field testing a moisture-managed, solid panel wall system.
Image courtesy of University of Minnesota.

Zero Energy Ready Home in Seattle, WA.
Image courtesy of TC Legend Homes

High-Level Summary of Reviewer Comments

At the 2017 BTO Peer Review, 17 Building America projects were presented and reviewed. Building America is the principal platform through which the RBI Program validates energy saving solutions for both new and existing homes by identifying and testing building science and engineering best practices through industry partnerships. Building America 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.

In late 2015, Building America completed a Research-to-Market Plan which detailed 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 17 RBI projects presented at the 2017 BTO Peer Review addressed each of these three technical challenges.

A high-level summary of scores for the 17 Building America projects can be found in Table 10 below; projects had a maximum potential score of four and a minimum potential score of one. Of the 17 projects, eight were initiated under the auspices of the Building America High Performance Housing Innovation Funding Opportunity for FY16, and had only begun work approximately six months prior to the date of the Peer Review.[32] The remaining nine projects had been active for a longer period of time—with the project terms for some effectively coming to a close—representing more mature research efforts with more

Residential Buildings Integration

results to report.[33] Consequently, project performers for the eight new FY16 projects were provided only 15 minutes to present on their projects and respond to questions from reviewers and other Peer Review attendees; most other performers at the Peer Review were provided with 30 minutes.

Table 10. High-Level Summary of RBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Building America	17	3.16	2.20	3.69
↳ *FY16 Projects*	*8*	*3.21*	*3.00*	*3.69*
↳ *Other Projects*	*9[(a)]*	*3.12*	*2.20*	*3.55*

[(a)] Three separate tasks led by Home Innovation Research Labs were reviewed together as part of a single presentation. The Project Count total reflects the total number of presentations delivered at the 2017 BTO Peer Review.

This section discusses high-level evaluation trends among the eight FY16 projects as well as the nine other projects presented.

Building America Projects Initiated in FY16

Reviewers assigned strong scores for the project approaches described by each of the eight FY16 projects. Projects for which relevant market actors and barriers were effectively identified scored relatively higher, while projects scored relatively lower if market barriers were not identified or were less well defined.

Spray foam insulation provides a conditioned attic space for heating and cooling ducts. *Image courtesy of Habitat for Humanity South Sarasota.*

Field testing aerosol envelope sealing in new residential construction. *Image courtesy of Center for Energy and Environment.*

Reviewers highly rated projects that demonstrated approaches which reviewers felt were logically sound, narrowly focused on a particular technology challenge, and grounded in solid building science fundamentals. In contrast, reviewers were critical of projects which prioritized lab tests over field-based validation, had perceived deficiencies in the dissemination strategy for research findings, or failed to provide clarity around certain project elements, such as technology evaluation criteria or specifics about a project's final deliverable.

A majority of FY16 projects were scored highly for the progress that each made during the opening months of their project terms. Reviewers generally felt that these well-rated projects appeared to be on track to accomplish their goals. To justify this assessment, reviewers pointed to projects' well-regarded project plans, as it likely too early in most cases for reviewer to focus on actual project accomplishments. Reviewers tended to assign lower scores when concerns were raised about a project's progress to-date or its eventual market impact, as well as when reviewers simply disagreed in their assessments.

Reviewer rated all FY16 projects well for their collaborations. The best rated projects were found to be collaborating with key, impactful, and/or strong partners, whom reviewers felt could contribute to the project's success. Most projects had assembled partnerships that were deemed to be at least appropriate for the task at hand, and several of the highest rated projects had partnerships that were explicitly flagged for being well-coordinated. Most projects were flagged by reviewers for having specific stakeholder groups whom reviewers would have liked to see integrated into the project team, including two projects for which reviewer recommended for intra-Building America collaboration with others team working on similar or related topics.

Other Building America Projects

Among the more mature Building America research efforts, the best scoring project was the one highlighted for its well-structured, technically-sound approach, which reviewers believed was focused on, and addressing, relevant market barriers. For several projects, a lack of collaboration with certain stakeholders was flagged when reviewers felt that such stakeholders could have yielded valuable advice, information, or market perspective that would have improved a project's approach. Reviewers also raised concerns for some projects about the ultimate usefulness of project outputs. The lowest performing projects were those where it was felt by reviewers that market barriers had been overlooked, such that the resulting technology would have limited utility.

In terms of project accomplishments, the best rated projects were perceived to be making progress toward their objectives and having accomplishments in line with or exceeding expectations. A lower score was assigned where reviewers felt that good progress was being made in some areas, but that progress lagged in others. The lowest rated projects were perceived by reviewers to have not made sufficient progress toward their goals to overcome key market barriers. Projects were also scored lower if reviewers expressed doubts or concerns about eventual market impacts.

Zero Energy Ready Home in Chicago, IL.
Image courtesy of Evolutionary Home Builders, LLC

Field installation of extended plate and beam wall system.
Image courtesy of Home Innovation Research Labs.

A majority of projects were well-regarded in terms of their collaborations. Among these projects, reviewers observed collaborations with key stakeholders that were well-coordinated and integrated with the project work, including several that drew from, and were building on, previous Building America research. For several projects, however, reviewers identified one or more classes of stakeholders whom reviewers felt it would be beneficial for the project to coordinate with. For the pair of projects that received low collaboration scores, reviewers felt strongly that one had not engaged in any meaningful collaborations or partnerships whatsoever, and the other raised questions among reviewers about whether identified partners were actively engaged with the project—or whether they were merely flagged for future outreach.

Building Energy Codes

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.[34]

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.[35] Building energy codes establish minimum energy conservation requirements for new construction residential and commercial buildings, as well as for additions or substantial renovations to these structures. In addition to significantly reducing energy use, these codes also substantially reduce consumer utility expenditures over the lifespan of buildings.

Because the energy code is frequently one of the least understood building codes, BECP played a critical role in FY16 by developing training curricula and providing software resources like REScheck™ and COMcheck™ to aid in demonstrating energy code compliance. BECP and its partners developed tools, state-specific analyses, and informational resources for use across the nation. DOE also contracted with national and regional energy efficiency organizations to provide additional technical assistance that is tailored to the needs of regions and individual states.

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.

To advance its mission, BECP evaluates the energy- and cost-saving impacts of changes to model building energy codes, and participates in the industry processes through which energy codes are developed, discussed, or approved.

BECP participates in industry processes to develop model residential building energy codes, including the International Energy Conservation Code and ASHRAE Standard 90.2

Appliance and Equipment Standards

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 testing and implementing statutorily-mandated 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.[36]

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.[37]

As required by statute, the Appliance Standards Programs promulgates energy conservation standards and test procedures through a rulemaking process whereby policy decisions are based on statutory criteria, including technical merit; economic analysis; the full consideration of impacts on consumers, manufacturers, and the environment; and stakeholder feedback. The Appliance Standards 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 requirements, the Appliance Standards Program works closely with a broad range of stakeholders, including manufacturers, states, utilities, energy efficiency advocates, consumer advocacy organizations, and other interested stakeholders. Each rulemaking process provides opportunities for stakeholder review and comment, and the Appliance Standards Program has established the Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) as another means of facilitating stakeholder engagement by allowing for negotiated rulemakings under the guidelines set forth in the Federal Advisory Committee Act.

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 efforts are expected to contribute to BTO's 2030 goal of reducing average energy use intensity in the buildings sector by 30% relative to 2010.

Standards implemented by the Appliance Standards Program cover a range of appliances and building equipment types, including commercial refrigeration equipment.

To meet statutory requirements, the Program implements 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:** Establish test procedures that capture innovative designs and are resistant to "gaming."
- **Standards Development:** Establish minimum standards that meet statutory obligations.
- **Enforcement:** Enforce certification and compliance with energy conservation standards and product representation requirements.

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.

End Notes

1. U.S. Energy Information Administration. February 2017. Electric Power Monthly. Accessed April 10, 2017: https://www.eia.gov/electricity/monthly/current_year/february2017.pdf.
2. U.S. Energy Information Administration. March 2017. Monthly Energy Review. DOE/EIA-0035(2017/03). Washington, DC: U.S. Department of Energy, March 2017. Accessed April 10, 2017: https://www.eia.gov/totalenergy/data/monthly/archive/00351703.pdf.
3. U.S. Energy Information Administration. "U.S. Natural Gas Summary." Accessed April 10, 2017: https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.
4. Moving forward, BTO's strategy will pivot toward early-stage R&D to advance a fundamental understanding of physical properties and phenomena relevant to buildings, building materials, and building equipment, enabling the various buildings technology industries to innovate novel technologies that ultimately improve the efficiency of energy services such as light and heat to consumers.
5. Private investment in R&D to improve building energy performance is minimal; while other private industry sectors invest 3 percent in R&D, construction R&D lags at 0.4 percent. Wolfe, Raymond M. (2016). Business Research and Development and Innovation: 2013 Detailed Statistical Tables. NSF 15-329. Arlington, VA: National Center for Science and Engineering Statistics (NCSES). Accessed May 11, 2017:https://www.nsf.gov/statistics/2016/nsf16313.
6. "2010 technologies" are defined as technologies available in 2010 that cost-effectively save energy in a typical residential or commercial building.
7. The Appliance and Equipment Standards Program 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.
8. BTO Multi-Year Program Plan: Fiscal Years 2016 – 2020. Accessed May 8, 2017: https://energy.gov/eere/buildings/downloads/multi-year-program-plan.
9. One envelope-focused CBERD project was reviewed at the 2016 BTO Peer Review as part of the Windows and Envelope Sub-Program.
10. One quad is a unit of energy equal to one quadrillion (1015) British thermal units (BTUs). The U.S. consumes approximately 100 quads of energy each year.
11. Supra 8; BTO Multi-Year Program Plan; Accessed May 8, 2017.
12. U.S. Energy Information Administration. Annual Energy Outlook 2017 with projections to 2050. Washington, DC: U.S. Department of Energy, January 2017. Accessed April 11, 2017: https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf.
13. Supra 13; Annual Energy Outlook 2017; Accessed April 11, 2017.
14. Supra 8; BTO Multi-Year Program Plan; Accessed May 8, 2017.
15. Supra 8; BTO Multi-Year Program Plan; Accessed May 8, 2017.
16. All BEM projects reviewed at the 2017 BTO Peer Review fall under the purview of the ET Program.
17. The Small Business Vouchers (SBV) program is administered by DOE Office of Energy Efficiency and Renewable Energy's Technology to Market program. SBV seeks to help small business overcome critical technology and commercialization challenges through prototyping, materials characterization, high-performance computations, modeling and simulations, and validation of technology performance. Small businesses operating in the clean energy sector can request assistance from a national lab, and if accepted, a voucher is issued. The voucher acts as a coupon and allows the applicant to access a unique skill or facility at a lab to bring clean energy technologies to market. Assistance from labs will vary depending on lab capabilities and the small business needs related to specific products and services. Vouchers are awarded on a competitive basis.
18. Fernandez N, S Katipamula, W Wang, Y Huang, and G Liu. 2012. Energy Savings Modeling of Standard Commercial Building Re-tuning Measures: Large Office Buildings. PNNL-21569, Pacific Northwest National Laboratory, Richland, Washington.
19. The project receiving the lowest assigned score for collaboration was a SBV project, which limited participation to the small business receiving the voucher.
20. GMLC supports research on (1) fundamental knowledge and technologies related to grid modernization, (2) individual grid technologies, and (3) crosscutting topics that impact multiple technology areas. All GMLC projects reviewed at the 2017 BTO Peer Review were specific to building technologies.
21. Fiscal year 2017 is the final year of CBERD Phase 1.0 and the second year of Phase 2.0 of CERC's Buildings Energy Efficiency Consortium.
22. Supra 13; Annual Energy Outlook 2017; Accessed April 11, 2017.
23. Supra 2; Monthly Energy Review. March 2017; Accessed April 10, 2017.
24. Supra 1; Electric Power Monthly. February 2017; Accessed April 10, 2017.
25. Supra 3; U.S. Natural Gas Summary; Accessed April 10, 2017.
26. Supra 13; Annual Energy Outlook 2017; Accessed April 11, 2017.
27. U.S. Energy Information Administration. Residential Energy Consumption Survey 2015, Housing Characteristics (Table HC2.1). Accessed May 16, 2017: https://www.eia.gov/consumption/residential/data/2015/
28. Ibid.
29. Supra 2; Monthly Energy Review. March 2017; Accessed April 10, 2017.
30. Supra 1; Electric Power Monthly. February 2017; Accessed April 10, 2017.
31. Supra 3; U.S. Natural Gas Summary; Accessed April 10, 2017.
32. Reviewers were instructed to account for the relative age of a project when completing their evaluations of projects' progress and accomplishments, and therefore the novelty of each of the eight newer projects can and should be considered when reflecting on the comments and scores that reviewers submitted.
33. One of nine older projects encompassed three separate tasks that were carried out by a single performer and initiated at the same time. The project review presentations for each of the three tasks were packaged together in a single session entitled "High Performance Building Envelope Assemblies."
34. BECP did not conduct any project reviews at the 2017 Peer Review.
35. Athalye, R.A.; Sivaraman, D.; Elliott, D.B.; Liu, B.; Bartlett, R. Impacts of Model Building Energy Codes. PNNL-25611 Rev. 1. Richland, WA: Pacific Northwest National Laboratory, 2016. Accessed April 10, 2017: https://www.energycodes.gov/sites/default/files/documents/Impacts_Of_Model_Energy_Codes.pdf.
36. The Appliance Standards Program did not conduct any project reviews at the 2017 Peer Review.
37. 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, 2017. Updated January 2017. Accessed April 10, 2017: https://energy.gov/eere/buildings/downloads/appliance-and-equipment-standards-fact-sheet.

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