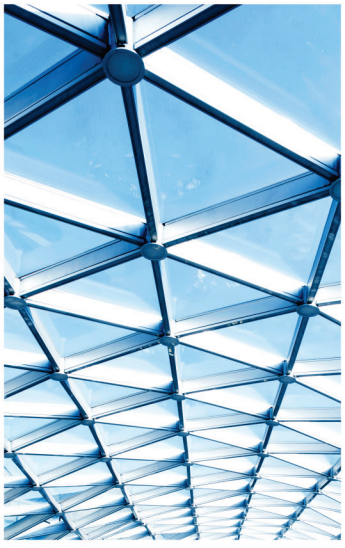
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

BUILDING TECHNOLOGIES OFFICE
Peer Review Report 2019



2019 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

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Cover photos courtesy of:

BTO 2019 Housing Innovation Award Winner (middle left), Gate Precast Company (middle right), and OLEDWorks (bottom right).

The U.S. fleet of 127 million buildings consumes the greatest amount of energy of any sector in the nation. Residential and commercial buildings account for 40% of the nation's total energy use and nearly 75% of its electricity use, resulting in an estimated annual national energy bill totaling more than $415 billion.[1,2,3] To improve the energy performance of the nation's building stock, the U.S. Department of Energy's (DOE's) Building Technologies Office (BTO) engages with universities, small businesses, and other private sector entities to partner with DOE's national laboratories to develop cutting-edge, affordable, energy-efficient solutions. BTO's long-term goal is to reduce the energy intensity of homes and commercial buildings by 50% or more (compared to 2010 levels) through the application of cost-effective efficiency technologies that improve energy productivity, thus yielding net economic benefits for homeowners, tenants, and building owners and operators, without sacrificing building occupants' comfort or the performance of equipment.

By reducing building energy use per square foot, or energy use intensity (EUI), BTO supports and enables efforts to 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 its regular programmatic work, BTO leads initiatives to advance the state of enabling technologies and systems that can facilitate step-wise improvements in building energy efficiency with cascading benefits in various other economic sectors. For example, by enabling the vision of Grid-Interactive Efficient Buildings (GEB), DOE can help buildings respond dynamically to electric grid conditions to shift and/or reduce overall electricity demand and decrease related stress on grid infrastructure, thus lessening the need for new electricity generation and transmission infrastructure. Separately, efforts in the Advanced Building Construction (ABC) initiative are aiming to further develop building construction technologies and deep energy retrofits to holistically address a combination of envelope, heating, cooling, water heating, and ventilation issues.

Figure 1. The Energy Sciences Building, a LEED Gold research facility at Argonne National Laboratory.
Image courtesy of Argonne National Laboratory

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

Mission and Goals

BTO's mission is to develop, demonstrate, and accelerate the adoption of cost-effective technologies, techniques, tools, and services. By leveraging innovative research and development (R&D), development of technology validation tools, information sharing, and utilization of regulatory authority, BTO can enable high-performing, energy-efficient, and flexible residential and commercial buildings in both the new and existing buildings markets. Furthermore, through coordination and engagement with industry and other key stakeholders, BTO can better understand user needs and direct technology development activities to deliver novel solutions 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 addition to saving energy, BTO technologies and activities are helping to improve energy affordability, increase the integration of energy technologies and systems into commercial and residential buildings, and expand the available suite of cost-effective options for energy storage.

As the only entity in the United States with responsibility and authority for R&D, technology validation, and regulation with respect to building energy efficiency, BTO employs a three-pronged strategy to advance its missions:

- R&D of innovative, next-generation building technologies, as well as their effective integration into efficient, resilient, grid-connected, and secure building systems
- Validation, verification, and integration 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
- Collaboration with industry and other stakeholders to test and implement statutorily mandated appliance and equipment efficiency standards, working with development bodies and providing analysis to states and industry organizations regarding building energy codes

Introduction

By carrying out this strategy and achieving its long-term goal, BTO can potentially help save over $200 billion annually in national energy costs. Based on current analysis of the building sector and BTO program planning, BTO has established a sectoral goal of reducing building EUI 30% by 2030.

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

To achieve these energy efficiency goals and improve energy affordability for homeowners and building owners and operators, BTO's activities are organized under five program areas:

- **Emerging Technologies (ET)** supports R&D and commercialization of high-impact building technologies with substantial potential for reducing primary energy consumption and greenhouse gases.
- **Commercial Buildings Integration (CBI)** helps improve existing and new commercial buildings by demonstrating cost-effective technologies that enhance building energy performance and operations, partnering with market leaders to increase technology adoption, and providing design and management tools and performance data to reduce perceived risks and address market barriers that have inhibited wide-scale uptake.
- **Residential Buildings Integration (RBI)** spurs greater energy efficiency in existing and new residential buildings through R&D and field validation of technologies; development and dissemination of best practices and tools; and partnerships with public and private sector stakeholders aimed at simultaneously improving efficiency, affordability, and comfort.
- **Building Energy Codes (BEC)** supports the evaluation, development, and implementation of commercial and residential building energy codes. BEC provides technical analyses to support regular updates of model building energy codes, as well as technical assistance and reports on the value of more advanced building energy codes to support states and municipalities through adoption.
- **Appliance and Equipment Standards** develops and regularly updates energy conservation standards for appliances and equipment, ensures the availability of reliable and effective test procedures, and enforces standards and labeling through product testing and compliance efforts.

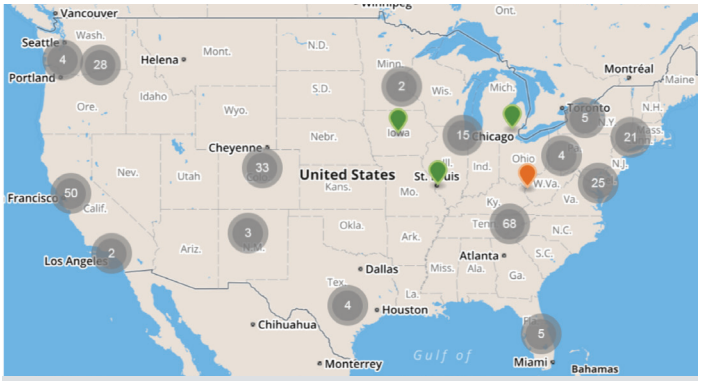

Figure 2. Snapshot of the BTO Project Map, an interactive tool for navigating all of the office's active project across the country. See more at energy.gov/eere/buildings/building-technologies-office-projects-map

Later sections provide an overview of each of these programs and any component sub-programs, including brief summaries of program and sub-program activities, scoring summaries for peer-reviewed projects, and key takeaways from reviewer comments on individual projects.

After the overview comes discussion of the 2019 BTO Peer Review objectives, process, and scoring criteria—including a comparison of the evaluation criteria for individual projects, portfolios, and partnerships—followed by summaries of scoring statistics and the reviewer comments for each of the portfolios and partnership activities that were reviewed at the 2019 BTO Peer Review.

2019 BTO Peer Review

The 2019 BTO Peer Review was held April 15–18, 2019, at the DoubleTree Crystal City in Arlington, Virginia. The review was attended by more than 570 participants and included presentations on 100 projects representing three of BTO's five technology programs. Of these projects, 98 were formally evaluated, broken down into the programs as below:

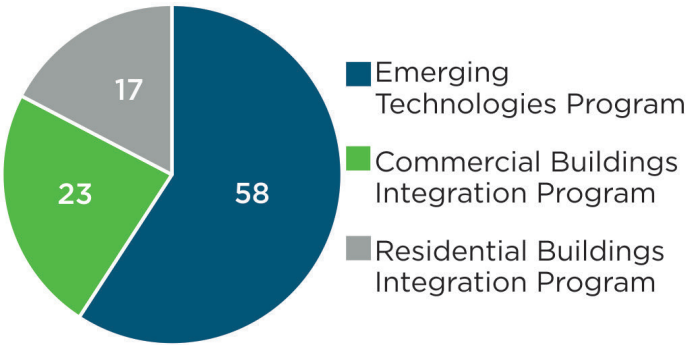

Figure 3. Summary of peer reviewed projects by relevant BTO program area.

The Appliance and Equipment Standards Program and Building Energy Codes Program are typically excluded from the peer review process, as the majority of their work and stakeholder input processes are statutorily mandated.[4,5]

The objectives of the 2019 BTO 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.
3. Demonstrate DOE's role in energy efficiency.

Independent reviewers were drawn from a variety of building-related backgrounds and included experts from industry, academia, government, and other stakeholder groups. Reviewers were screened for conflicts of interest and assigned to projects based on their interests and areas of expertise. Reviewers evaluated each assigned project according to five criteria—approach, impact, progress, collaboration and coordination, and remaining project work—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.

In 2019, BTO introduced portfolio and partnership reviews—covering six topic areas and encompassing over 60 projects—to evaluate groups of projects that are developing enabling technologies that target objectives in a common technology area and hence were deemed appropriate to be reviewed as a group of activities. Independent reviewers recruited for individual project reviews were also assigned as reviewers for portfolios based on their backgrounds and experience in relevant topic areas.

In addition to portfolio reviews, BTO conducted partnership reviews to evaluate its partnering efforts with various stakeholders through the CBI and RBI programs. Although the objectives of the portfolio and partnership reviews were the same as for individual project reviews, a different set of criteria and weights were used for evaluating portfolios and partnerships. Table 1 below outlines the key criteria and associated weighting for each type of review (see the appendix for detailed evaluation forms for each).

Table 1. Project, Portfolio, and Partnership Review Criteria and Weighting

Project Reviews	Portfolio Reviews	Partnership Reviews
1. Approach – 30% 2. Impact – 20% 3. Progress – 15% 4. Collaboration and Coordination – 20% 5. Remaining Project Work – 15%	1. Scope – 30% 2. Impact – 30% 3. Collaboration, Coordination, and Integration – 20% 4. Communication and Stakeholder Engagement – 10% 5. Metrics – 10%	1. Scope – 30% 2. Impact – 40% 3. Collaboration, Coordination, and Integration – 30%

BTO Peer Review Report

This report summarizes the scores and comments submitted by reviewers for the 98 projects, four portfolios, and two sets of program partnership activities that were formally evaluated at the 2019 BTO Peer Review. The following sections present an overview of the feedback on BTO's project, portfolio,

Figure 4. A Zero-Energy Ready home in La Grange, Illinois.
Image courtesy of BrightLeaf Homes

Portfolio R&D and Partnerships

and partnership activities as reviewed in 2019, objectives and activities for BTO's various technology program areas, a summary of project scores for each program, and a brief analysis of general evaluation trends and highlights for each program area or its constituent sub-programs. Individual project, portfolio, and partnership scores and comments, as well as BTO's response to reviewer comments, are available on the 2019 BTO Peer Review webpage or in the Appendix.

Portfolio R&D and Partnerships

The portfolio and partnership reviews conducted at the 2019 BTO Peer Review reflect the importance of strategically evaluating multiple activities working toward a common set of objectives. As such, these activities were evaluated and scored based on criteria different from the traditional project review criteria (see Table 1 above). Portfolios were reviewed and scored against five criteria: scope; impact; collaboration, coordination, and integration; communication and stakeholder engagement; and metrics. Partnerships were reviewed and scored against three criteria: scope; impact; and collaboration, coordination, and integration. See the appendix for detailed evaluation criteria and associated weights in the portfolio and partnership evaluation forms.

Building Energy Data Portfolio

Table 2. Building Energy Data Portfolio Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Building Energy Data	3.31	2.75	3.50

Reviewers of the Building Energy Data (BED) portfolio were interested in whether the scope identifies and targets key barriers and technical challenges that are appropriate for DOE to address, and praised the portfolio for addressing relevant technical barriers and challenges. However, some reviewers expressed concerns that the issue of cross-adoption within the industry was a barrier that was overlooked.

Project impact efforts were highly valued for advances to the state of the art (SOA) that leverage existing frameworks and account for future data needs, though some reviewers questioned the effectiveness of these efforts. Multiple reviewers suggested packaging and selling the value produced by these activities to adopters outside the energy efficiency space (e.g., realtors, code officials, building inspectors, mortgage lenders).

Feedback on the BED portfolio's collaboration, coordination, and integration efforts commended the different projects within the portfolio that complemented one another and worked in parallel to ensure consistency, transparency, and quality.

Reviewers praised the coordination among other BTO programs, and many reviewers suggested additional outreach to targeted stakeholders, with some specifying that DOE could better leverage its channel partners. In related criteria, communication and stakeholder engagement received high scores for acknowledging the variety of public and private stakeholders. Reviewers also valued the frequent communication to raise awareness of successes, though some reviewers noted that plans to communicate accomplishments and lessons learned could be strengthened.

The portfolio's metrics, however, received lower scores owing to uncertainty regarding the progress and impact metrics. Although reviewers generally agreed that progress is being made, some would have given higher scores if the Building Data sub-program had developed specific metrics (e.g., square footage entered into tools, cumulative "size" of programs leveraging SEED, etc.) that the sub-program can begin to track. Reviewers agreed that the portfolio would benefit from metrics to gauge progress toward standardization and interoperability.

Building Energy Modeling Portfolio

Table 3. Building Energy Modeling Portfolio Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Building Energy Modeling	3.49	3.20	3.70

In general, reviewers scored the Building Energy Modeling (BEM) portfolio highly for identifying appropriate technical challenges for the federal government to address. Reviewers also suggested numerous additional barriers that the sub-program should be addressing to improve its scope.

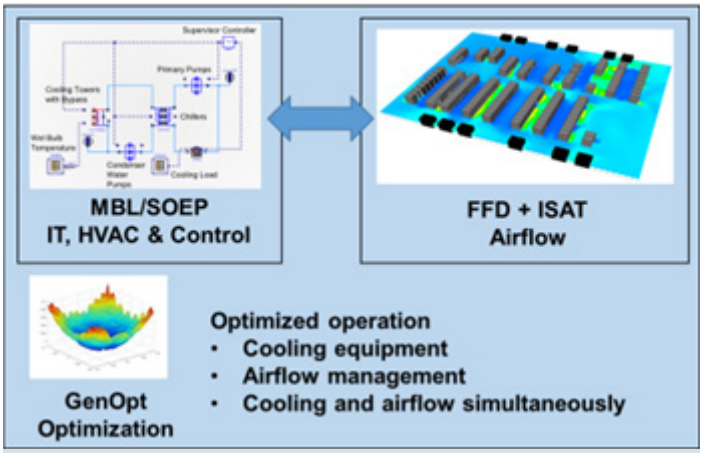

Figure 5. Overview of a unified cooling and airflow modeling and optimization toolkit for data centers. This toolkit helped realize energy savings of 30% in data centers in Cambridge, MA and Miami, FL.

In terms of project impact, reviewers praised the portfolio for advancing the SOA with its focus on more granular external tools in support of deeper analysis. However, some reviewers expressed concerns, including (1) industry's slow adoption of SOA practices, (2) disappointment in the non-vendor community with the portfolio's focus, and (3) vendor and end-user (energy modeler) errors when entering the complex inputs for EnergyPlus/OpenStudio. Reviewers also questioned whether the portfolio's impact on BTO's energy savings goals is sufficiently quantified and whether progress may be hindered in the short term.

With regard to collaboration, coordination, and integration, reviewers appreciated the sub-program's coordination within DOE across other offices, as the tools developed within this sub-program have been used extensively within DOE to support other DOE sub-programs and initiatives (codes, HVAC, etc.). Additionally, reviewers placed high regard on BTO's continued engagement with IBPSA-USA and ASHRAE. In separate but related results, communication and stakeholder engagement efforts scored higher for the sub-program's active integration of feedback from key stakeholders into the determination of barriers and initiatives to address them. Reviewers also agreed that the sub-program disseminated information in a timely manner and appreciated efforts to provide information at relevant events.

Empirical Validation and Uncertainty Quantification of Energy Simulation was the single BEM project separately reviewed at the 2019 BTO Peer Review. The project's goal is to *characterize and improve the accuracy of BEM engines* and, in turn, bolster the reputation and adoption of BEM tools. In general, the project was well-received, and reviewers approved of the team's approach to addressing these important issues surrounding uncertainty in energy modeling. Additionally, *reviewers stressed the value of empirical validation* and noted that the test data generated through this project would serve an important purpose within the energy efficiency community.

Although reviewers generally agreed that the portfolio is performing well against its chosen metrics, many reviewers suggested additional metrics for tracking, such as how DOE is supporting industry initiatives beyond the software it provides and how that support allows new users of BEM to emerge. Other proposed metrics included the actual cost of BEM per project, number of licenses sold, number of simulations run (for an online license), and number of software users. Reviewers also considered the current sub-program metrics and how they could be improved to better demonstrate the portfolio's impact.

Sensors and Controls Portfolio

Table 4. Sensors and Controls Portfolio Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Sensors and Controls	3.57	3.33	3.83

Reviewers were supportive of the Sensors and Controls (S&C) portfolio approach and remarked that the barriers are real and significant, noting that the barriers and technical challenges facing adoption of optimized building operation strategies are widespread problems that can be addressed only with a large-scale effort initiated by the federal government. Multiple reviewers also stressed the importance of technology-specific barriers, such as adoption of existing and evolving technologies.

The portfolio's impact received favorable scores as reviewers agreed that the sub-program advances the SOA, particularly in controls and benchmarking, and has an opportunity to lead in the emerging area of comfort sensing. Reviewers highly valued industry involvement through industrial advisory boards and the development of better S&C, particularly related to building–grid interactions and grid harmonization—critical elements in the pursuit of BTO's energy goals as the grid evolves and energy codes become more stringent. In contrast, some reviewers suggested more engagement with building owners and managers—key beneficiaries from both an energy savings and a user satisfaction point of view—and emphasized more engagement with private sector partners in deployment, particularly of pilot projects.

Reviewers were generally satisfied with the portfolio's collaboration, coordination, and integration activities, praising the effective leveraging of sub-program activities and clearly integrating with other offices across DOE. Reviewers

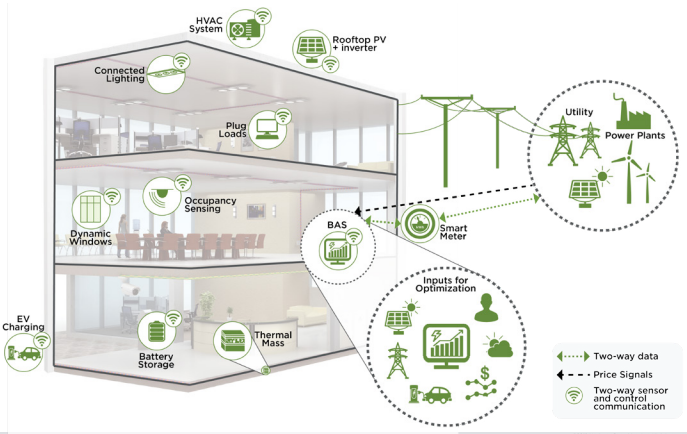

Figure 6. Vision for Grid-Interactive Efficient Buildings in the commercial sector. *Image courtesy of Navigant Consulting*

Portfolio R&D and Partnerships

commended the sub-program's coordination with public and private organizations through industrial advisory boards, though some reviewers provided suggestions for further coordination and collaboration with public and private entities outside the energy sector.

Communication and stakeholder engagement efforts were commended for integrating inputs from national labs, industry, and academia and for sub-program outreach to stakeholders, including building owners, managers, and end users. Reviewer consensus was that BTO's S&C activities are doing well at reaching out, engaging, and communicating with the proper stakeholders in both the public and private sectors. The reviewers also valued the portfolio's excellent efforts announcing funding opportunities and communicating project status and opportunities (publications, reports, announcements, etc.).

As for metrics, reviewers praised the sub-program for investing in benchmarking to help validate developed technologies and their potential impact for meeting energy savings goals and leading the definition of occupant-centric measures. Despite this praise, reviewers provided suggestions to validate the cost and efficiency predictions of Scout and to include alternative technologies, as well as those outside the BTO scope, to ensure that the developed technologies are successful in the marketplace. Reviewers also recommended a stronger focus on accelerating technology adoption.

Grid-Interactive Controls Portfolio

Table 5. Grid-Interactive Controls Portfolio Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Grid-Interactive Controls	3.00	2.45	3.36

Similar to the S&C portfolio, projects under the Grid-Interactive Controls (GIC) portfolio are widespread and require a large-scale effort initiated by the federal government. Reviewers noted that many of the barriers are related to challenges that span across states, industries, and various layers of the grid and building systems. Examples include communications protocols to enable buildings and devices to accept, and act on, grid signals. Many reviewers also noted market adoption is a major barrier.

Since controls is an area of immense need, reviewers highly valued that both S&C and GIC portfolios are advancing the SOA. The S&C sub-program is taking advanced methods into field tests and supporting novel control platforms that are seeking to change how the balance of supply and demand is achieved within the electric grid. However, multiple reviewers expressed concerns about the sub-program's support for industry,

Figure 7. BTO is developing a GEB strategy that aims to optimize across distributed energy resources to advance the role buildings can play in energy system operations and planning.

as the extent to which the industry members were participating in R&D, versus simply providing equipment, was not clear.

Both Controls portfolios received praise for being well-coordinated with the public and private sectors. The well-ordered collaboration was clear from the demonstration projects and partners involved in the industrial advisory boards. However, reviewers critiqued the GIC portfolio for its lack of internal cohesion and suggested efforts to bridge gaps between projects and pull lessons learned and tools developed from one project to the next. Similar to the S&C portfolio, reviewers praised the GIC portfolio for its external communication and publication of results, specifically for its excellent job of publication of results, specifically for its excellent job of announcing funding opportunities, communicating project status and opportunities, and relating sub-program accomplishments back to BTO-wide goals. Many reviewers suggested that utilities should be more involved in the GIC portfolio, particularly those that are explicitly interested in activating grid-enabled controls and transactive energy in their territories.

In terms of metrics, reviewers recommended more measures related to cost and efficiency predictions, financial goals, and technology market adoption. For the GIC portfolio specifically, most reviewers noted the lack of progress and impact metrics and tracking methods, since they were not covered in the presentation. Therefore, it was difficult for reviewers to evaluate performance based on the metrics provided.

Commercial Buildings Integration Partnerships

Table 6. Commercial Buildings Integration Partnerships Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Commercial Buildings Integration	3.30	3.22	3.44

Overall, reviewers highly regarded the Commercial Buildings Integration program's (CBI's) partnership activities for addressing key barriers and technical challenges facing energy-efficient technologies in the commercial building sector. Reviewers agreed that the scope and goals were appropriate for the federal government to address and led to significant advancements and a greater rate of market adoption. Similarly, most reviewers applauded partnership activities for being comprehensive and remarked on the variety of programs and outreach strategies utilized by the team. However, several reviewers recommended that CBI make clearer distinctions between program offerings so that stakeholders have more guidance before deciding on a solution.

As for the impact of partnership activities, reviewers complimented the contribution towards BTO's energy efficiency goals. The majority of reviewers highlighted that CBI's partnership efforts advanced the state of the market and successfully highlighted new technology opportunities for the commercial sector. Specifically, reviewers highly valued CBI's work as a clearinghouse and the program's early-stage R&D activities, field validation, and demonstration projects. Reviewers also noted that little overlap exists between BTO and other organizations working in the same space.

Reviewers generally found that CBI partnerships were well-integrated with each other and well-coordinated with existing external energy efficiency efforts. With regard to stakeholder engagement, most reviewers agreed that the team collaborates with all relevant groups and effectively leverages channel partners. On the other hand, reviewers recommended CBI coordinate with additional organizations on workforce development issues and collaborate more directly with state and local governments when possible. Reviewers were mindful that some of these stakeholders are difficult to reach and that resources are often a limiting factor.

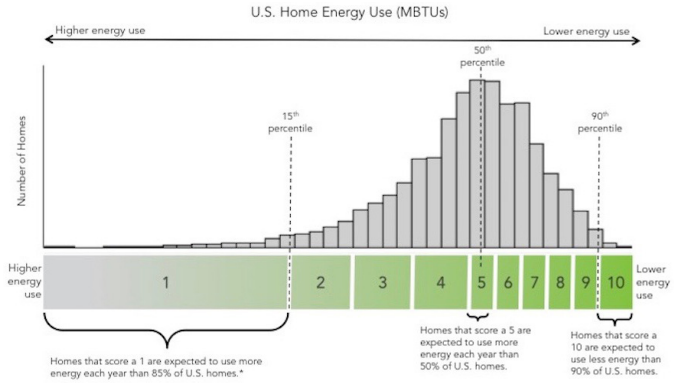

Figure 8. Overview of the scoring methodology for the Home Energy Score tool. Learn more here: energy.gov/eere/buildings/downloads/home-energy-score

Residential Buildings Integration Partnerships

Table 7. Residential Buildings Integration Partnerships Scoring Summary

Portfolio Area	Average Score	Low Score	High Score
Residential Buildings Integration	3.43	3.30	3.60

In general, reviewers were highly supportive of the Residential Buildings Integration program's (RBI's) partnership activities as well as several individual program components. The majority of reviewers agreed that the barriers identified by RBI were significant and appropriate for the federal government to address. Reviewers also appreciated the difficulty in overcoming these challenges in residential buildings but praised RBI for the team's progress, particularly with the dissemination of information to relevant stakeholder groups. While most reviewers commented positively on the scope of these efforts, some reviewers were critical of specific items and provided recommendations for improvement.

Reviewers valued the activities that demonstrated an impact and advanced the state of the market while coordinating closely with industry partners. Feedback highlighted the different strategies that RBI employed and complimented those that could provide a quick and lasting impact to the residential sector. However, some reviewers disagreed on how effectively RBI partnerships contributed, either directly or indirectly, to BTO's energy efficiency goals; nonetheless, reviewers approved of the team's increased focus and future resources for improving existing buildings.

Reviewers found collaboration, coordination, and integration to be key strengths of RBI's partnering efforts. Despite the challenges associated with stakeholder engagement in the sector, most reviewers lauded the team for their work in developing an extensive network of partners. In addition, reviewers remarked on DOE's role in keeping stakeholders well-informed and sharing lessons learned and best practices within the community. Reviewers suggested additional areas and activities to further improve engagement with groups across the country.

Grid-Interactive Efficient Buildings – Technical Report Highlights

GEB Overview Report

To help inform the building research community and advance BTO's R&D portfolio, BTO is publishing a series of technical reports evaluating the opportunities for grid-interactive efficient buildings (GEBs). The GEB Overview provides background on core concepts, details research gaps, and addresses how flexible building loads can be integrated and controlled to benefit consumers, building owners and operators, and the grid.

The GEB Overview report was reviewed at BTO's 2019 Peer Review. Reviewer comments and suggestions will be taken into consideration, and an updated version of the report will be published. Some significant changes that will be made to the report include the addition of, or further discussion on, the following topics:

- Clear scope of the GEB Overview report
- Interactive effects of GEB technologies
- Batteries and DC technologies
- Relative potential of each technical area
- Highest-potential technologies found in the four technical reports (see below)

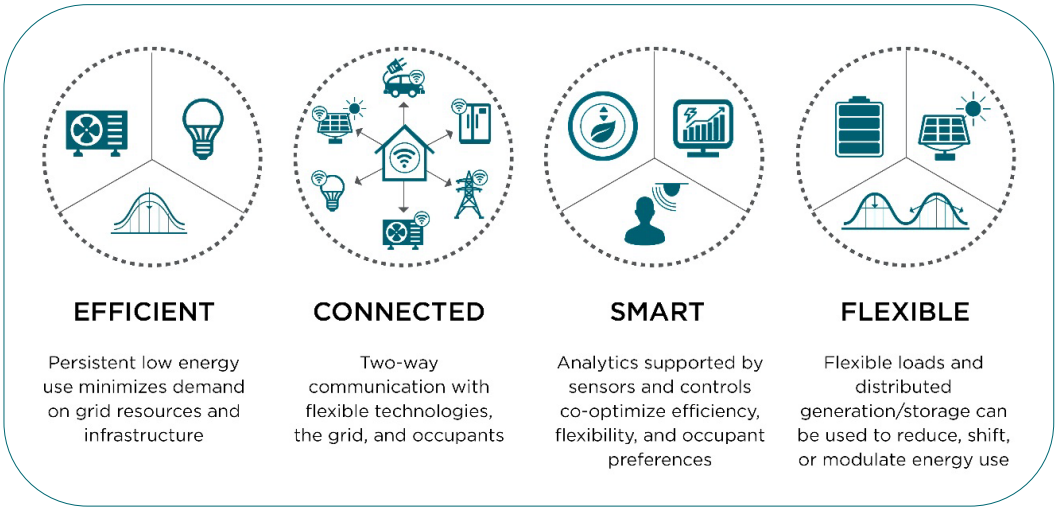

Figure 9. Characteristics of Grid-Interactive Efficient Buildings

GEB Technical Report Series

In addition to the GEB Overview report, four technical reports were reviewed at BTO's 2019 Peer Review. Brief summaries of the technology areas and prospective updates are presented below and on the following page.

1 Sensors & Controls, Data Analytics, and Modeling

Smart technologies for building energy management are necessary for implementing flexible, grid-interactive strategies. Analytics supported by sensors and controls can optimize energy use for occupant patterns and preferences, utility price signals, weather forecasts, and available on-site generation and storage.

Example Grid Service: ***Efficiency***
Enhanced communications regimes within buildings and between buildings and the grid avoid wasting energy

High-Level Topics to Expand on:

- The role of buildings in providing modulation and other grid services
- How to value occupant comfort and highlighting sensitivities around low-income communities

2 Windows and Opaque Envelope

Building envelope technologies have the potential to provide grid flexibility through passive high-performance technologies and novel active technologies. New advancements like those in phase change materials significantly increase thermal mass and load shifting capabilities of buildings.

Example Grid Service: ***Load Shifting***
Building uses its thermal mass with pre-cooling or pre-heating strategies to shift HVAC load to off-peak periods

High-Level Topics to Expand on:

- The importance of technologies' suitability for retrofits
- The importance of designing to avoid worst-case failure modes for technology category

3 Advanced Lighting Technologies

Novel lighting devices and systems can be utilized in buildings to shed and modulate load. An integrated lighting system must work to balance the benefits to the grid while maintaining occupant preferences and visual comfort levels.

Example Grid Service: ***Load Shedding***
Building dims lighting system by a preset amount in response to grid signals

High-Level Topics to Expand on:

- How current lighting technologies can provide grid services
- The benefits of lighting sensors to provide data to HVAC and other building systems
- The potential impacts on circadian rhythms

4 HVAC, Water Heating, and Appliances

With proper communication and controls, HVAC equipment and water heaters can provide benefits to the grid while also providing value to owners. Some of the grid services that these technologies can perform include shifting load or modulating electricity use.

Example Grid Service: ***Modulating Load***
Building responds to external grid signals through connected water heater

High-Level Topics to Expand on:

- The relationship between load shedding and shifting for HVAC
- Load shifting performance under extreme weather events
- Seasonal demand response and flexibility

End-Use Load Profiles for the U.S. Building Stock Project

The lone GEB-related project evaluated at the 2019 Peer Review aims to **develop specialized energy models** that are customized for particular uses to produce a set of **highly resolved, data-driven, electricity end-use load profiles** for all the major building types and climate zones that constitute the U.S. building stock.

Overall, reviewers commented positively on the team's approach and progress towards achieving their project-specific goals as well as the project's potential impact on wider BTO objectives. Reviewers also noted the team's **extensive collaboration and coordination with partners and other stakeholders** and highlighted the established technical advisory group as a key strength of the project.

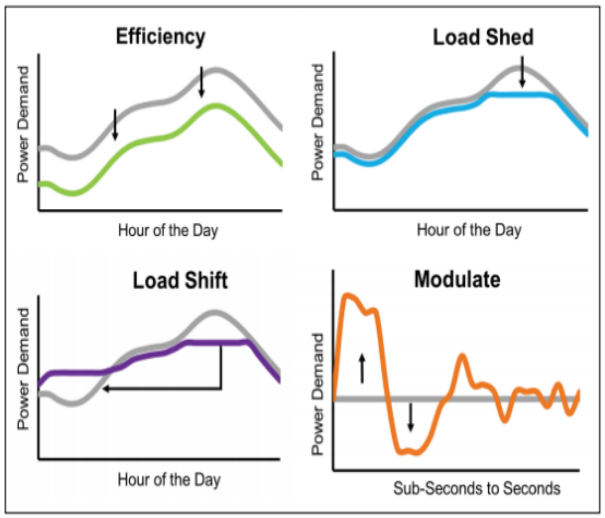

Figure 10. Building Flexibility Load Curves
The gray curve in the graphs represents an example baseline building load. The colored curves (green, blue, purple, orange) show the resulting building loads when implementing methods to enable flexibility.

Partnership Spotlight: Connected Neighborhoods

In 2019, BTO unveiled a new connected neighborhood, Altus at The Quarter, which will serve as a living laboratory to evaluate how homeowners use energy in a real-world, smart home environment. The Altus neighborhood consists of a set of townhomes in Atlanta, GA outfitted with solar photovoltaic panels, batteries, and state-of-the-art, grid-connective, energy-efficient building components and appliances. These components will be managed and optimized by a novel, grid-interactive control system that Oak Ridge National Laboratory developed with support from BTO.

This research, along with Reynolds Landing (pictured at right), is part of BTO's Connected Neighborhoods project. Other DOE partners on this project include Georgia Power, Southern Company, Electric Research Power Institute, and Pulte Group Homebuilders.

Figure 11. Reynolds Landing Smart Home Neighborhood in Hoover, Alabama.

Emerging Technologies

The Emerging Technologies (ET) program contributes to BTO's goals by funding applied R&D activities in industry, academia, DOE national laboratories, and other research institutions that advance technologies and tools for cost-effective building energy efficiency and flexibility.

ET also supports R&D for advanced sensors and controls and communications technologies and systems that can enhance the building's energy efficiency and occupant comfort as well as improve demand flexibility to provide grid services. This work is central to BTO's Grid-Interactive Efficient Buildings (GEB) Initiative. The GEB vision is the integration and continuous optimization of distributed energy resources for the benefit of building owners and occupants, as well as the grid. A GEB utilizes analytics and controls to optimize energy use for occupant patterns and preferences, utility price signals, weather forecasts, and available on-site generation and storage. This added connectivity enables buildings to be *efficient, connected, smart,* and *flexible*. Building energy loads can be to dynamically shaped to reduce utility bills by shifting peak load costs and to reduce stress on the grid.[6] Three GEB-related portfolios—Sensors and Controls Portfolio, Building Energy Modeling Portfolio, and Building Energy Data Portfolio—were evaluated at the 2019 BTO Peer Review, and several GEB-focused reports are discussed in the preceding sections (see the Grid-Interactive Controls Portfolio feedback on page 6 and the GEB Technical Report Highlights vignette on pages 9 and 10).

In addition to the activities reviewed within the portfolios, the ET program's individual projects focus on three major technology areas to execute its strategy:

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

The HVAC, water heating, appliance, and SSL technology areas represent approximately two-thirds of the delivered energy consumed in commercial and residential buildings today. However, the 2019 Annual Energy Outlook projects that this proportion will decline to 57% by 2050, indicating a significant source of potential efficiency gains over the next few decades.[7] Advancements in sensor and control technologies and energy modeling platforms and tools can further improve the base efficiency of these other building technologies, both in design and operation, and enable concepts such as GEB.

High-Level Summary of Reviewer Comments

The peer review included assessment of 58 ET projects across three sub-programs: HVAC, Water Heating, and Appliances; Windows and Building Envelope; and Solid-State Lighting. This section discusses the high-level evaluation trends by technology area.

Table 8 provides a high-level summary of project scores broken out by sub-program. Projects had a maximum potential score of 4.0 and a minimum potential score of 1.0. For individual project scores and comments, please visit the 2019 BTO Peer Review webpage or see the appendix.

Table 8. High-Level Summary of ET Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Overall	58	3.15	2.00	4.00
↳ *HVAC, Water Heating, & Appliances*	28	3.17	2.00	4.00
↳ *Windows and Building Envelope*	21	3.10	2.17	3.80
↳ *Solid-State Lighting*	7	3.18	2.33	4.00

*Note: Two ET projects evaluated during the 2019 BTO Peer Review are not included in this table because each was a single activity associated with BEM and GEB, respectively. They are each briefly summarized in call-out boxes within their respective portfolio summary sections.

HVAC, Water Heating, and Appliances

HVAC, water heating, and appliances account for an estimated 24 quads of primary energy consumed in the United States, with HVAC representing the largest energy end use in both residential and commercial buildings.[8,9] The HVAC, Water Heating, and Appliances sub-program seeks to accelerate the development of technologies that have the potential to save significant amounts of energy. This includes conducting R&D on novel heat exchanger designs and manufacturing techniques; researching and evaluating alternative refrigerants and developing compatible HVAC and refrigeration (HVAC&R) systems; and researching thermally driven compressors used in fuel-fired applications, including natural gas or propane. In the long term, the sub-program seeks to develop next-generation technologies that "leapfrog" existing technologies and result in dramatically improved energy efficiency. Next-generation technologies currently being researched by the sub-program include HVAC&R and water heating systems and appliances that utilize magnetocaloric, thermoelectric, and electrochemical materials and processes.

Each of these research thrusts were represented among the 18 projects reviewed under the HVAC, Water Heating, and Appliances sub-program at the 2019 BTO Peer Review. HVAC&R projects represent the largest category of reviewed

projects in this sub-program with 25; these projects are further segmented into Advanced HVAC Technologies (7 projects) and Assorted HVAC&R Technologies (18 projects) for better disaggregation of evaluation trends. The remaining 3 projects under this sub-program are divided between appliances (2 projects) and water heating technologies (1 project). Each of these technology areas and sub-areas are discussed in the sections that follow.

Table 9 provides a high-level summary of project scores; projects had a maximum potential score of 4.0 and a minimum potential score of 1.0.

Table 9. High-Level Summary of HVAC, Water Heating, and Appliance Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
HVAC, Water Heating, & Appliances	28	3.17	2.00	4.00
↳ *Advanced HVAC Technologies*	7	3.02	2.00	3.67
↳ *Assorted HVAC&R*	18	3.15	2.20	4.00
↳ *Appliances and Water Heating*	3	3.58	3.00	4.00

Advanced HVAC Technologies

HVAC systems presently represent the largest energy end use in buildings, requiring over 16 quads of primary energy annually, or approximately 38% of all energy used in U.S. commercial and residential buildings.[10] Given this energy usage, as well as the harmful environmental impacts of conventional refrigerants used in traditional vapor-compression equipment, BTO is working with several partners to develop advanced HVAC technologies that improve energy performance while transitioning away from the use of conventional refrigerants and toward low- or zero-global warming potential (GWP) alternatives. Advanced vapor compression projects aim to reduce the cost and improve the energy performance of air conditioning systems in buildings using low-GWP refrigerants that have minimal effect on the global environment. Non-vapor compression projects seek to develop innovative new classes of highly efficient HVAC technologies that do not use refrigerants and can achieve cost-effectiveness in the long term.

Seven advanced HVAC projects were reviewed at the 2019 BTO Peer Review. Reviewers had mixed reactions to Advanced HVAC Technologies project approaches, though projects with sound and reasonable strategies received praise from the reviewers. Reviewers scored projects lower whose project approach had limitations that may affect the project's impact, such as the project's being only a temporary solution, practical efficiency limitations, and lower projected impacts. When conducting their evaluations, reviewers also considered whether the technologies have market adoption potential.

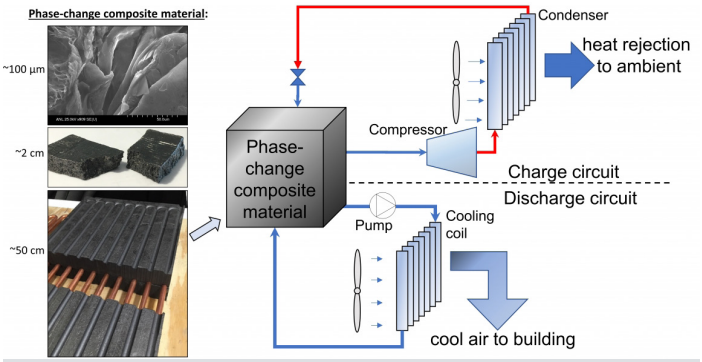

Figure 12. Left: High-conductivity, shape-stable graphite and wax composite. Right: Dual-circuit phase-change composite heat exchanger integrates seamlessly with an air conditioner with minimal additional components. *Image courtesy of Said Al-Hallaj, NETenergy, and Jason Woods, National Renewable Energy Laboratory*

Many of the reviewers praised the projects for their potential to have a significant impact on maximizing energy efficiency. Reviewers issued higher ratings for projects that are more cost-effective and expressed the importance of industry acceptance for success, particularly for ammonia-and natural gas-related applications. Technologies that run the risk of low commercial potential received lower scores.

With regard to project progress, reviewers agreed that most projects demonstrated good progress if they were meeting performance targets and were on track to meet project goals. Reviewers recognized that many of the projects are still in early stages but are meeting performance targets thus far, although reviewers noted that some projects appear to be behind schedule. Some projects were given high scores if they had already made progress on securing commercial certifications, since reviewers placed high importance on progress of commercialization activities.

Overall, reviewers praised the projects' collaboration and coordination with relevant stakeholders, particularly with manufacturers. Reviewers also provided suggestions for the projects to improve their collaboration and coordination, such as more stakeholder engagement with original equipment manufacturers, experts, and end users. Projects that scored lower did not clearly describe their stakeholder engagement efforts or were not able to reveal certain aspects of the project's achievements, so stakeholder involvement was not clear.

In terms of remaining project work, reviewers scored projects highly where remaining work was clearly identified and the projects were on track and meeting performance targets,

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while other projects scored lower if they were delayed or had a significant amount of work remaining. Many projects were noted as well-planned, with remaining work clearly defined for reviewers, but some projects' remaining work may present challenges and obstacles that the team did not properly plan to mitigate. Reviewers suggested that projects include the manufacturing process and accuracy analyses as a part of their remaining work, with very clear targets and timelines for the rest of the project.

Assorted HVAC&R Technologies

Components such as heat exchangers (HXs), dehumidification and ventilation systems, and sensors and controls can heavily influence energy consumption and performance in common HVAC&R equipment. BTO seeks to take advantage of unrealized opportunities to increase the efficiency of HVAC&R equipment by improving the design and engineering of individual system components, as well as the integrated performance of such components within packaged HVAC and refrigeration equipment.

Eighteen projects reviewed at the 2019 BTO Peer Review were focused on assorted HVAC&R technologies, including those addressing refrigerant leak detection and flammability evaluations, novel HX designs and manufacturing processes (i.e., additive manufacturing or 3D printing), and joining techniques. Reviewers often applauded the approaches of projects that showed the promise of disrupting or revolutionizing their respective applications or that addressed a major barrier to market adoption. Reviewers also commented positively on projects that proactively identified mitigation strategies to address project risks, streamlined manufacturing processes, and utilized a combination of modeling and experimental approaches. Reviewers expressed concern for projects that had an approach that was too broad in scope, as well as projects with technical issues or challenges that may limit progress moving forward.

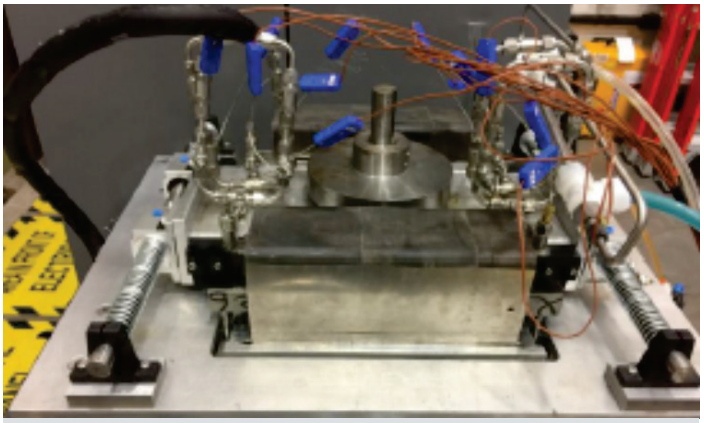

Figure 13. Solid-state magnetic cooling prototype. *Image courtesy of Oak Ridge National Laboratory*

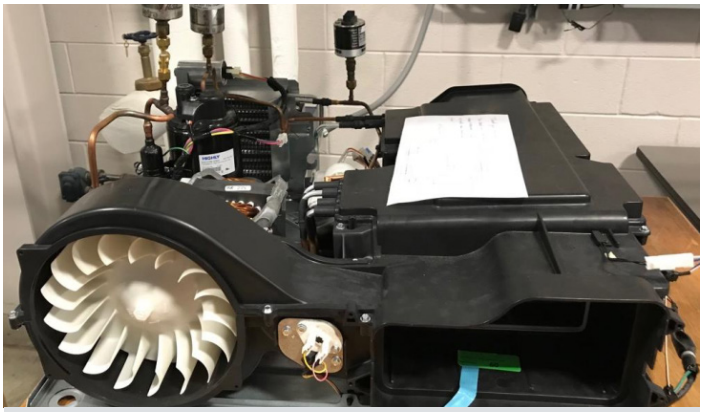

Figure 14. Modified heat pump dryer system. *Image courtesy of Oak Ridge National Laboratory*

Reviewers applauded projects that aim to achieve energy savings while also appealing to industry through potential lowered costs or ancillary benefits such as reduced refrigerant leakage or broader applications. For many projects, however, reviewers worried whether the research effort would provide a commercially viable product, particularly for projects with complex approaches.

Reviewers generally agreed that the projects were making good progress toward their outlined goals and scheduled milestones. For several projects, reviewers expressed concern about specific components or technical processes of the project and often made recommendations toward addressing these concerns. In a few projects, the reviewers made recommendations that the project teams engage with stakeholders earlier in the project life cycle.

Overall, reviewers noted some issues with the projects' remaining work. One of the most common critiques regarding the remaining project work was whether it is feasible to complete on time and whether it is clearly aligned with project goals. Often the reviewers identified specific components or steps that need to be addressed.

Reviewers gave high marks to projects with strong collaboration with industry, especially partners with manufacturing and market adoption capabilities and expertise. For projects that did not receive high collaboration scores, reviewers frequently recommended continued industry partnerships to facilitate and ease manufacturability or to provide additional expertise in a particular field.

Appliances and Water Heating

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 nearly 21% of residential building primary energy consumption.[11] Appliances used in commercial buildings for cooking and refrigeration are another potential source of energy

savings, especially for buildings such as grocery stores and hotels. Water heaters, which provide buildings with continual sources of hot water, currently account for approximately 9% of primary building energy consumption.[12] BTO's appliance research focuses primarily on refrigerators, freezers, clothes washers, and dryers, which have the most opportunity for energy savings, while BTO research on water heating seeks to improve the efficiency of new water heaters for both residential and commercial buildings.

Three appliance and water heating projects were reviewed at the 2019 BTO Peer Review, including one focused on heat pump water heaters and two addressing clothes drying technologies. The projects were well-regarded for their technical approaches. Although reviewers made specific technical suggestions for how to improve the projects (i.e., using the correct form factor in the water heater), they applauded the projects' well-formulated and well-thought-out approaches to innovative high-performing appliances and water heaters. However, reviewers expressed concerns for projects without clear paths to commercialization.

As a whole, reviewers felt that the appliance and water heater projects reviewed could have substantial impacts and could be revolutionary for the market. Although the scores were high, reviewers noted concerns about technology adoption, particularly for the dryers, as consumers may not pursue energy efficiency for that application.

Reviewers agreed that the projects in this technology track were progressing well, achieving project milestones, and operating on schedule. The planned future work of the appliances and water heater projects were well-received by the reviewers. Again, reviewers did caution project teams about upcoming challenges for even the highly rated projects, including issues with field deployment, and time management for upcoming project phases.

Figure 15. Project staff with a novel ultrasonic clothes dryer. *Image courtesy of Oak Ridge National Laboratory*

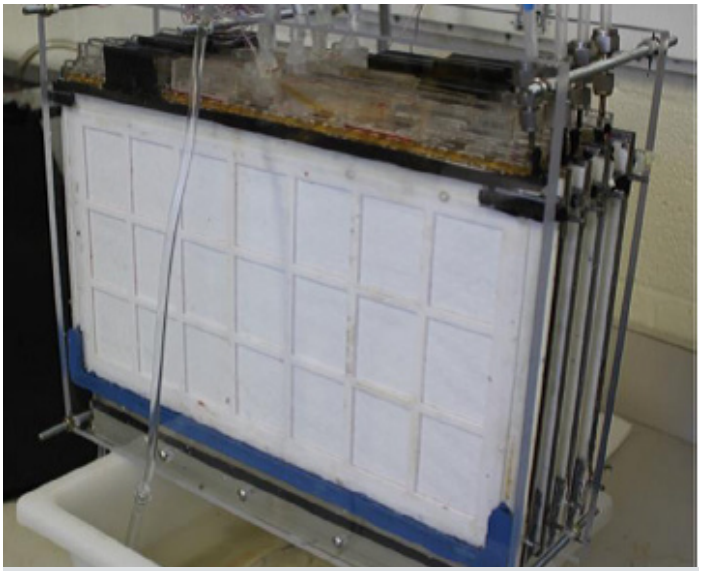

Figure 16. Membrane-based prototype heat pump water heater absorber component. *Image courtesy of the University of Florida*

For all projects in this category, reviewers found the project teams had collaborated and coordinated well with stakeholders and industry partners. Reviewers particularly appreciated the linkages made with adopters and manufacturers and established means of disseminating information.

Windows and Building Envelope

Space heating and cooling represents roughly 34% of the primary energy consumed in residential and commercial buildings;[13] the building envelope forms the main thermal barrier between interior and exterior spaces. When it fails to adequately control the transfer of heat and moisture between these spaces, the building envelope can greatly impact how much energy is required to heat or cool the interior to meet occupant preferences.

To reduce the energy required to heat and cool a building, the Windows and Building Envelope sub-program supports the development of next-generation residential and commercial building technologies that reduce the unintentional amount of air and moisture that is exchanged, and the thermal energy lost and gained, through windows and the building envelope. Specific R&D areas of interest include high-R insulation materials, air sealing technologies, and smart building materials.[14,15]

Twenty-one projects were reviewed under this sub-program at the 2019 BTO Peer Review. Table 10 provides a high-level summary of scores among Windows and Building Envelope projects; projects had a maximum potential score of 4.0 and a minimum potential score of 1.0.

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Table 10. High-Level Summary of Windows and Building Envelope Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Building Envelope and Windows	21	3.10	2.17	3.80
↳ *Building Envelope*	14	3.02	2.17	3.71
↳ *Windows*	7	3.26	2.20	3.80

Overall, reviewers found that the Windows and Building Envelope projects contributed to overcoming technical and market barriers through comprehensive approaches. In general, the projects that were well-received addressed the most pressing technical needs for building envelope technologies. Reviewers commended projects that presented a realistic path toward successful market adoption and noted when projects failed to consider the cost, convenience, or durability of the technology. Reviewers were most critical of approaches that contained major unaddressed issues without providing risk mitigation strategies.

In terms of project impact, reviewers generally valued the windows and building envelope projects that, if successful, would contribute greatly to BTO's energy reduction goals. While reviewers commented that several projects would not directly affect energy savings themselves, they also highlighted that these projects would enable the advancement of other envelope technologies. Many of the most well-regarded projects addressed both new construction and existing buildings, furthering the potential impact.

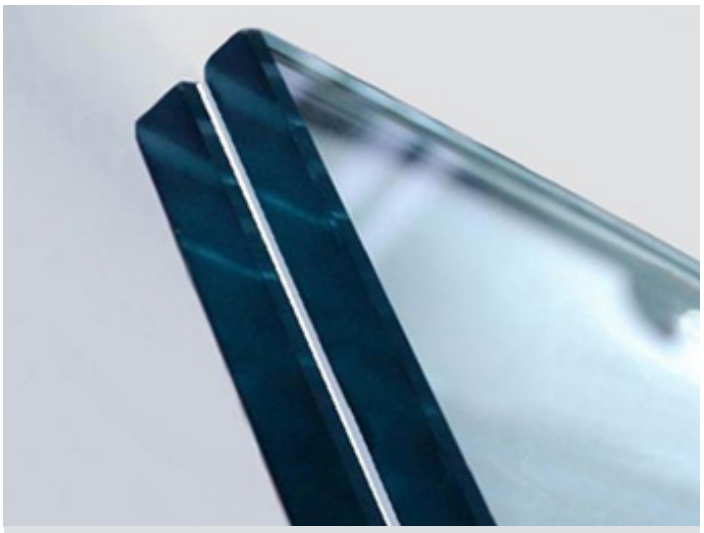

Figure 17. Representation of a vacuum-insulated glass unit used in highly energy-efficient windows. *Image courtesy of V-Glass*

Figure 18. Installation of a fiber-reinforced polymer panel manufactured by Kreysler and Associates for the San Francisco Museum of Modern Art. *Image courtesy of Kreysler and Associates*

Reviewers applauded projects that clearly demonstrated progress toward the stated project-specific goals. The majority of reviewers looked unfavorably on projects with delayed tasks but made positive remarks when the presenter offered a solution to get the project back on schedule. For projects that identified upcoming challenges, reviewers provided recommendations for overcoming those barriers. Reviewers were particularly complimentary of projects that presented a well-thought-out plan to address technical and market adoption concerns.

The highest scores for collaboration and coordination were awarded to projects with broad and thoughtful stakeholder engagement. Projects with strong industry partnership generally received the highest scores, while many of the other projects were critiqued for omitting important groups. For these projects, reviewers suggested potential organizations with ties to the windows and building envelope industry that could improve the projects' impact and overall chance of success.

With regard to future work, reviewers awarded high marks to projects that had a clear plan with detailed steps to overcome the identified barriers. Reviewers gave the lowest scores when they had concerns that the planned schedule left insufficient time to complete the remaining work or that the project goals were considered unattainable.

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 roughly $40 billion.[16] The efficacy of LED light sources has already surpassed that of incandescent, halogen, high-intensity discharge, and linear fluorescent lamps and continues to improve. However, continued innovation and breakthroughs in materials, processes, control systems, and manufacturing are still needed to realize the technology's full potential. SSL also presents a significant opportunity to improve the performance and value of lighting through enhanced controllability, new functionality, application-specific lighting performance, novel form factors, and targeted improved well-being and productivity.

Seven projects were reviewed under the SSL sub-program at the 2019 BTO Peer Review. Table 11 provides a high-level summary of scores among SSL projects; projects had a maximum potential score of 4.0 and a minimum potential score of 1.0.

Table 11. High-Level Summary of SSL Project Scores

Technology Area	Project Count	Average Score	Low Score	High Score
Solid-State Lighting	7	3.18	2.33	4.00

In general, the reviewers agreed that the SSL project approaches contribute to overcoming barriers, addressing technical challenges, and mitigating project risks. Reviewers praised projects that addressed barriers to adoption and included plans to minimize the risk of failure. Many reviewers thought that some of the project approaches were too optimistic and expressed concerns that some of the projects would not be able to adequately complete the scope or achieve all the outcomes in the allotted time. Some reviewers suggested focusing on one item more than the others as the project progresses, especially if there is still much work to be completed.

In terms of addressing program goals, reviewers generally agreed that the projects will have a high impact on achieving

Figure 19. Example of an OLED Panel. *Image courtesy of Digital Trends*

BTO's goals. Reviewers provided multiple specific examples, such as impacts on electric lighting in buildings, accelerated adoption of industry standards, and meeting the non-visual needs of building occupants. Reviewers also recognized that some projects may not have as much of an impact because of other factors such as slow progress.

Generally, the reviewers commented that all the SSL projects are on track and showing good progress. Reviewers recognized that these projects are all still in early stages, so progress is limited, but many of the projects have completed background work, have identified improvement opportunities, and have already started to achieve some results. However, reviewers pointed out that some projects may be lacking progress since they are addressing topics that do not have much existing literature, particularly horticultural lighting.

With regard to the projects' collaboration and coordination, reviewers praised projects that involved collaboration with a variety of stakeholders, including manufacturers, designers, subject matter experts, researchers, universities, and end users. Reviewers rated projects highly that went the "extra mile" with collaboration and coordination, such as including a project advisory group, public presentations, and/or experimental testing in realistic settings. Reviewers stated that some of the projects did not have enough collaboration, particularly with industry.

Overall, reviewers commended projects that have remaining work that is on track and ambitious while recognizing the challenges in this complex environment. Although reviewers praised many of the projects for their organization of the remaining work, they also provided suggestions for additional future work that each project should undertake, including assessing metrics and measurement methods in real-world field evaluations, promoting adoption by end users, and overcoming issues related to implementation.

Commercial Buildings Integration

BTO's Commercial Buildings Integration (CBI) program performs research, development, and validation activities that make commercial buildings more energy-efficient by accelerating the deployment of high-performance building technologies. The commercial buildings sector accounts for over 90 billion square feet of floor space in the United States.[17] This footage includes a variety of building sizes, ages, and construction types, located in all climate zones, and used for a broad range of purposes such as commercial and government offices, education, health care, retail, datacenters, warehouses, and large multi-family buildings. Together these buildings represent 18% of total U.S. energy consumption, over 36% of U.S. electricity consumption, and nearly $174 billion in electricity and natural gas bills each year.[18,19,20,21] The sector also grows annually and is expected to add more than ten billion square feet over the next five years.[22]

CBI's efforts focus on highly innovative energy-saving measures—solutions that promise the most impactful energy savings within cost-effective thresholds. To accomplish its goal of reducing the EUI of U.S. commercial buildings, the CBI program implements three central strategies:

- Improving understanding of the technical and structural barriers to greater energy efficiency in commercial buildings, and identifying R&D requirements based on existing dynamic operational conditions
- Verifying and validating the energy performance and cost savings of building technologies and systems, informing R&D based on laboratory and field validation outputs
- Developing cost-effective systems-based solutions, focused on optimizing whole buildings or multiple buildings (rather than improving and optimizing individual building components such as lighting) through original R&D activities

Figure 20. Commercial buildings represent over 90 billion square feet of floor space, a significant opportunity for reducing energy waste.

High-Level Summary of Reviewer Comments

Reviewers provided feedback on 17 projects within the CBI program during the 2019 BTO Peer Review. These projects are divided among three program areas: Energy Performance & Tools, Field Validation & Data Frameworks, and Technology Systems & Packages. Table 12 provides a high-level summary of CBI project scores; projects had a maximum potential score of 4.0 and a minimum potential score of 1.0.

Table 12. High-Level Summary of CBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Overall	17	3.00	1.80	3.75
↳ *Energy Performance and Tools*	2	3.31	3.00	3.50
↳ *Field Validation and Data Frameworks*	8	2.96	1.80	3.75
↳ *Technology Systems and Packages*	7	2.95	2.50	3.75

Energy Performance & Tools

The CBI program works to develop data infrastructure and frameworks that can be used for a variety of purposes by building owners and operators, utilities, scientists, manufacturers, architects/engineers, and policymakers. This research focuses on collecting, managing, and analyzing "apples to apples" information about buildings' energy performance; informing and implementing energy efficiency programs and policies; and better understanding the potential for, and impacts of, energy efficiency investments.

At the 2019 BTO Peer Review, two projects under the Energy Performance & Tools track were reviewed. In general, reviewers strongly approved of the approaches to CBI's two Energy Performance & Tools projects. For both projects, reviewers noted the importance of accomplishing the project-specific goals and addressing key challenges in the commercial buildings market. While reviewers rewarded one project with high marks, several reviewers still highlighted potential limitations with the team's underlying assumptions about behavior change in the United States compared to Europe.

Reviewers applauded the potential impact of the projects, awarding high scores for the range of benefits that the tools would contribute. In particular, reviewers appreciated one

project's focus on developing a cost-effective method to reduce energy use in multi-family buildings. On the other hand, reviewers of the other project remarked on the difference between direct and indirect energy savings. However, comments were positive, and reviewers commended the project for supporting decision-makers in the industry and its important role in R&D.

Reviewers were generally supportive of the collaboration and coordination efforts of the Energy Performance & Tools projects. Both projects cited broad stakeholder engagement and interest from private organizations, and both were well-received. Reviewers also appreciated projects that considered a variety of perspectives and pro-actively provided recommendations for new partners when they identified gaps in industry engagement.

Projects that demonstrated clear progress toward accomplishing stated goals according to schedule were positively rated. Reviewers were more critical of a project that they perceived was falling behind schedule and expressed concerns about the project's pace of installations. In terms of future work, reviewers preferred projects that provided more detail on the planned next steps. Where uncertainty remained, reviewers offered suggestions and posed questions for the project teams to consider when moving forward.

Field Validation & Data Frameworks

One of the CBI program's main activities is to validate technology performance by working with building owners, engineers, and operators to conduct third-party, objective evaluation of energy-efficient technologies and practices under dynamic conditions, collecting real building performance data and taking into account human interactions. The information generated by these efforts provides a feedback loop that can help answer critical R&D questions, while also informing decision-making by sharing technology performance, installation, commissioning, operation, and maintenance requirements.

At the 2019 BTO Peer Review, eight Field Validation & Data Framework projects were reviewed. When evaluating the approaches, reviewers highly regarded Field Validation & Data Framework projects that simultaneously addressed both technical and market challenges. Reviewers awarded top scores to projects that were scalable and had the potential to expand to additional building types and climate zones. On the other hand, reviewers were critical of projects when the approach was misaligned with the research questions and project goals. Reviewers generally looked favorably upon projects that would lead to cost-effective, user-friendly, and technologically viable solutions.

Figure 21. Participants in an Energy Treasure Hunt with the help of DOE at the University of Maryland Medical Center (UMMC). Representatives of DOE, UMMC, and American Society for Healthcare Engineering—a Better Buildings Alliance Affiliate—identified energy-saving opportunities and best practices for UMMC facilities. *Image courtesy of the Better Buildings Initiative*

Reviewers generally found the projects in this track to have great potential to contribute to BTO's energy efficiency goals. Projects demonstrating the opportunity to make a lasting impact, either directly through energy savings or indirectly by providing a foundation for future research, were well-received. However, reviewers scrutinized projects that failed to address barriers to market adoption or overlooked the importance of social research. In addition, reviewers criticized projects that provided unrealistic estimates for energy savings figures.

In terms of progress and future work, reviewers positively commented on projects that remained on schedule, on budget, and aligned with the project-specific goals. Reviewers rated projects higher if they clearly demonstrated success, as reviewers speculated that they would likely continue to make progress and complete the remaining work. Reviewers tended to give lower scores to projects that presented an inadequate plan for future steps. For several projects, reviewers recommended improving the teams' proposed strategies in order for them to successfully disseminate results and best practices.

Commercial Buildings Integration

Reviewers tended to approve of projects with broad stakeholder engagement and good collaboration with industry. Reviewers noted projects with identifiable gaps in partnering efforts and opportunities for improved outreach with other stakeholder groups. In addition, reviewers encouraged project teams to foster continued coordination with established peer networks and maintain awareness of real-world challenges with energy efficiency measures even after project completion.

Technology Systems & Packages

CBI supports systems integration and optimization R&D to access additive multi-system/multi-end-use energy savings in commercial buildings (e.g., combining solid-state lighting, dynamic windows, sensors, and advanced lighting controls in one room to maximize overall daylighting benefits and energy savings). Preliminary research shows that—relative to component-based retrofits—integrated systems-based retrofit packages can yield additional energy savings of greater than 50%.[23]

At the 2019 BTO Peer Review, seven projects were reviewed under the Technology Systems & Packages track. Generally, reviewers found that the Technology Systems & Packages projects addressed key market barriers to the adoption of energy-efficient technologies in commercial buildings. Reviewers favored projects that considered other industries in their design, such as real estate or advanced manufactured construction. While projects with the highest-rated approaches inherently had close collaboration with industry partners, projects with lower scores tended to have a limited number of field sites or difficulty finding suitable partners for demonstration activities.

Reviewers highly regarded projects that aligned strategically with BTO goals and, more specifically, focused on improving energy efficiency in existing buildings. On the other hand, reviewers were critical of projects that had less defined impacts on energy savings and offered suggestions on areas to improve those projects. Reviewers also highlighted projects that successfully balanced technological advancement with market viability.

In terms of collaboration, reviewers applauded projects that developed strong partnerships with relevant stakeholders including national labs, academic institutions, private companies, and other private sector organizations. Reviewers stressed the importance of coordination with industry and noted when project teams would benefit from additional partners or field validation sites. Several projects were also commended for working with utilities to test and develop incentive programs for commercial buildings, as reviewers stated this would lead to higher levels of energy savings in more commercial buildings.

Figure 22. Better Buildings Data Center partners showcase the integration of various building energy efficiency technologies, including server rack blanking panels, LED lighting, separate computer room air handler (CRAH) aisles, and advanced metering utilizing data analytics and artificial intelligence to enable near-real-time system optimization. *Image courtesy of the Better Buildings Initiative*

Overall, reviewers valued projects that demonstrated substantial progress and criticized teams without a clear plan for future work. In addition, reviewers credited the projects for presenting potential strategies to address any limitations identified up to that point in the project schedule. The majority of reviewer concerns were related to the project team's ability to complete the project-specific goals within the remaining timeframe.

The Residential Buildings Integration (RBI) program collaborates with a variety of stakeholders in the residential building industry to improve energy performance of existing and new homes. The U.S. residential housing market comprises more than 120 million single-family homes, multi-family units, and manufactured houses (also known as mobile homes). While nearly four million of these homes were built between 2010 and 2015, more than half were constructed prior to 1980.[24,25] Residential buildings account for approximately 20% of total U.S. energy consumption and nearly 40% of all U.S. electricity consumption, costing consumers over $240 billion in electricity and natural gas bills each year.[26,27,28] Furthermore, analyses have shown that residential buildings also have disproportionate impacts on electricity peak demand: in Texas, residential buildings comprise up to 50% of both summer and winter demand peaks.[29]

The RBI program leverages its partnerships with state and local governments, utilities, and others to identify stakeholder needs and deploy advanced building technologies and tools. Applied R&D efforts focus on identifying opportunities to cost-effectively integrate emerging technologies into residential building systems. In addition to energy efficiency, the RBI program's R&D activities address other technology integration and installation issues that can affect total home performance, including issues related to durability, comfort, indoor air quality, and moisture control. Building America is one of the principal platforms through which RBI conducts this innovative research on home energy performance and related issues. For more than 20 years, Building America has researched, developed, and validated innovative residential energy-saving solutions in partnership with expert building science research teams.

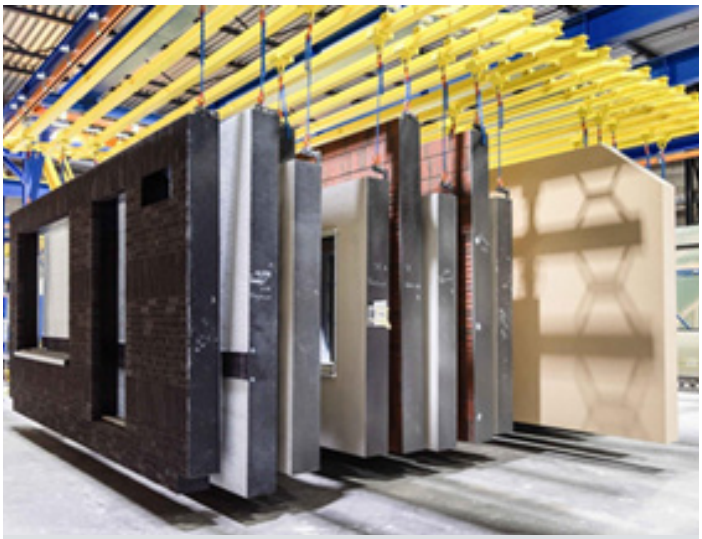

Figure 23. Pre-fabricated integrated panels can reduce system performance risk, installation times, and ultimately, cost. *Image courtesy of the Rocky Mountain Institute*

RBI is also helping lead a new initiative called Advanced Building Construction (ABC) that brings together multiple facets of BTO to tackle challenges hindering energy efficiency across new and existing residential and commercial buildings.

In part, ABC aims to facilitate the integration of energy-efficient technologies and practices as part of the overall transformation of the construction industry that is underway across the globe. In collaboration with researchers, industry, and state and local governments, ABC is funding R&D projects focused on delivering new technologies and approaches that can be applied broadly to existing and new construction. ABC projects will cover the spectrum from modular construction and off-site manufacturing of panels to improved on-site installation techniques and computer software that seamlessly ties together all parts of a project from building design to construction and operation. In addition to sponsoring R&D, ABC is forming a collaborative to convene the array of stakeholders needed to tackle pressing challenges related to workforce training, business models, market adoption, and service delivery. At the heart of ABC is a focus on developing solutions that deliver deep energy savings while being attractive, scalable, affordable, and durable in both new and existing buildings.

The RBI program also seeks to improve the energy efficiency of new and existing homes through other pathways, leveraging and learning from strategic partnerships to achieve impact on a national scale. For example, the Solar Decathlon offers students an opportunity to develop real-world skills by creating cost-effective, market-ready building designs—or actual constructed buildings—that meet DOE's Zero Energy Ready Home program requirements. RBI provides another examples in its Home Energy Score, which the program developed and continues to improve. Home Energy Score is an assessment tool that allows for consistent comparison of the energy performance of single-family homes. The Score helps consumers easily understand and evaluate a home's energy-related systems and comes with tailored recommendations for how to cost-effectively improve the home's efficiency.

High-Level Summary of Reviewer Comments

At the 2019 BTO Peer Review, 23 RBI projects were presented and reviewed, including 18 under the auspices of Building America and 5 representing other residential research initiatives or residential building topics, including Home Energy Score and integration of advanced residential building technologies (i.e., windows and wall panels). A high-level summary of scores for the 23 RBI projects can be found in Table 7 below; projects had a maximum potential score of 4.0 and a minimum potential score of 1.0.

Residential Buildings Integration

Table 13. High-Level Summary of RBI Project Scores

Sub-Program	Project Count	Average Score	Low Score	High Score
Overall	23	3.33	2.50	4.00
↳ *Building America*	18	3.35	2.5	4.00
↳ *Other Residential Research*	5	3.27	2.75	3.75

Building America

Among the eighteen Building America projects reviewed, reviewers generally praised the projects' approaches for successfully overcoming barriers, addressing technical challenges, and mitigating project risks. High-scoring projects exploited other technologies that already exist, such as communicating thermostats or other Building America projects. Reviewers also praised projects that had approaches that were straightforward, with an experimental design.

Related to the projects' impacts, reviewers commended projects that are likely to have far-reaching impacts, such as impacts on the development of standards and codes. Reviewers also praised projects that are critical in understanding how home operations are performing and in ensuring that very tight, energy-efficient homes have good indoor air quality. Reviewers criticized some projects for having smaller impacts because of limitations on the climate zone in which the technology will be successful, which limits the potential energy savings.

Overall, the reviewers praised the projects for being on track and showing great progress thus far. Reviewers noticed that some projects were experiencing hampered progress because of difficulties in finding target homes to participate in the projects. Reviewers also expressed some concerns about projects that may not be able to finish all the remaining work by the deadlines that were presented.

Reviewers scored projects higher if they collaborated with a wide variety of stakeholders from industry, such as manufacturers and utilities, as reviewers emphasized that stakeholder collaboration is a key strategy in a project's overall success in achieving real market impact. Reviewers praised projects that showed strong coordination and collaboration with partners that are large businesses, such as Mitsubishi or Broan. Reviewers suggested that multiple projects should include collaboration with the Home Energy Rating System rater community.

With regard to remaining project work, reviewers praised projects that demonstrated that the remaining work is on track to be completed by project deadlines. Reviewers also commended projects that show that remaining work includes a clear path to commercialization and market adoption for the technology. However, reviewers scored some projects lower if they did not allow time in the project timeline for the field testing and standards processes, as these are usually the most time-consuming steps.

Other Residential Research Initiatives

Reviewers highly rated the project approaches for residential research projects not associated with Building America, rating projects particularly highly if they addressed technical challenges and mitigated project risks. Additionally, reviewers positively rated projects that harmonized well with existing energy efficiency tools (i.e., Home Energy Score, HERS Index Score). Although most approaches were highly rated, reviewers did question whether some of the projects adequately considered potential barriers (i.e., cost, safety, design, manufacturing) prior to starting.

Overall, reviewers found the projects worked toward BTO's goals, especially projects that had a high potential for energy savings at a low cost. Reviewers stressed the value of affordability. Lower scores were awarded to projects that had not fully addressed the potential market or that had too narrow a scope.

Reviewers were more critical of the progress being made in this group of projects. Reviewers noted it was difficult to properly evaluate the progress of projects that were in such early stages, and the low scores reflect this. More positively, reviewers praised projects that had made early progress in real-world testing and expanding audiences and applications. Overall, reviewers were pleased with the projects' outreach and collaboration with relevant stakeholders and industry partners. The projects that received the highest marks typically had a large breadth of partners across industry, government, national labs, and academia. However, reviewers consistently recommended further engagement, often within specific industries that could help enable market adoption (homebuilders, manufacturers, etc.).

In most instances, reviewers expressed confidence in the projects' remaining work, finding that the next steps were well-thought-out and appropriate. Again, reviewers reiterated that it is difficult to assess the remaining work for such early-stage projects.

Through the Building Energy Codes Program (BECP), BTO actively supports the development, adoption, and implementation of building energy codes in the United States. DOE is statutorily directed to provide technical assistance at each stage of the code-making process. By supporting industry code development organizations, BECP helps ensure that newly developed building codes result in practical, cost-effective, and energy-efficient buildings that are safe and healthy for occupants. BECP also provides technical assistance to state and local governments throughout the adoption and implementation phases of their energy codes.

Building energy codes establish minimum efficiency requirements for new buildings, additions, and major renovations. By advancing energy codes, BTO helps improve building energy efficiency leading to a substantial reduction in energy consumption for both residential and commercial construction. Today's building energy codes enable new buildings to cost-effectively use 30% less energy compared to typical codes that were in place less than 10 years ago.30 In addition to helping ensure satisfactory levels of energy use, contemporary codes substantially reduce consumer utility expenditures over the lifespan of buildings. They also create the opportunity to incorporate successfully commercialized and proven energy-efficient technologies into standard design and construction practices.

BECP plays a central role in the industry processes to develop, discuss, and update the national model energy codes. The process is predominately administered by the following two private sector organizations:

1. ASHRAE: Standard 90.1, the Energy Standard for Buildings Except Low-Rise Residential Buildings
2. International Codes Council: International Energy Conservation Code (IECC)

When these model codes are formally updated, DOE analyzes the energy- and cost-saving impacts and provides guidance to states that are considering updating their codes for residential and commercial buildings.[31]

A key focus of BECP's mission is supporting building energy code implementation, as the benefits associated with codes are realized only when successful levels of compliance are achieved in practice. For example, DOE develops training curricula and compliance resources for use by states and local building departments. Tools like the REScheck™ and COMcheck™ software are popular with the design and construction community and help demonstrate compliance with energy codes and reduce the enforcement burden on local building departments. In addition to these tools, DOE provides each state with a range of technical analyses and assistance tailored to that state's specific energy code, including energy and cost impact analysis. BECP and its partners have also developed research methods to assist states in assessing their code's implementation status, tracking the influence of technologies and key energy efficiency measures, estimating the associated impacts, and identifying opportunities for industry workforce education and training programs.

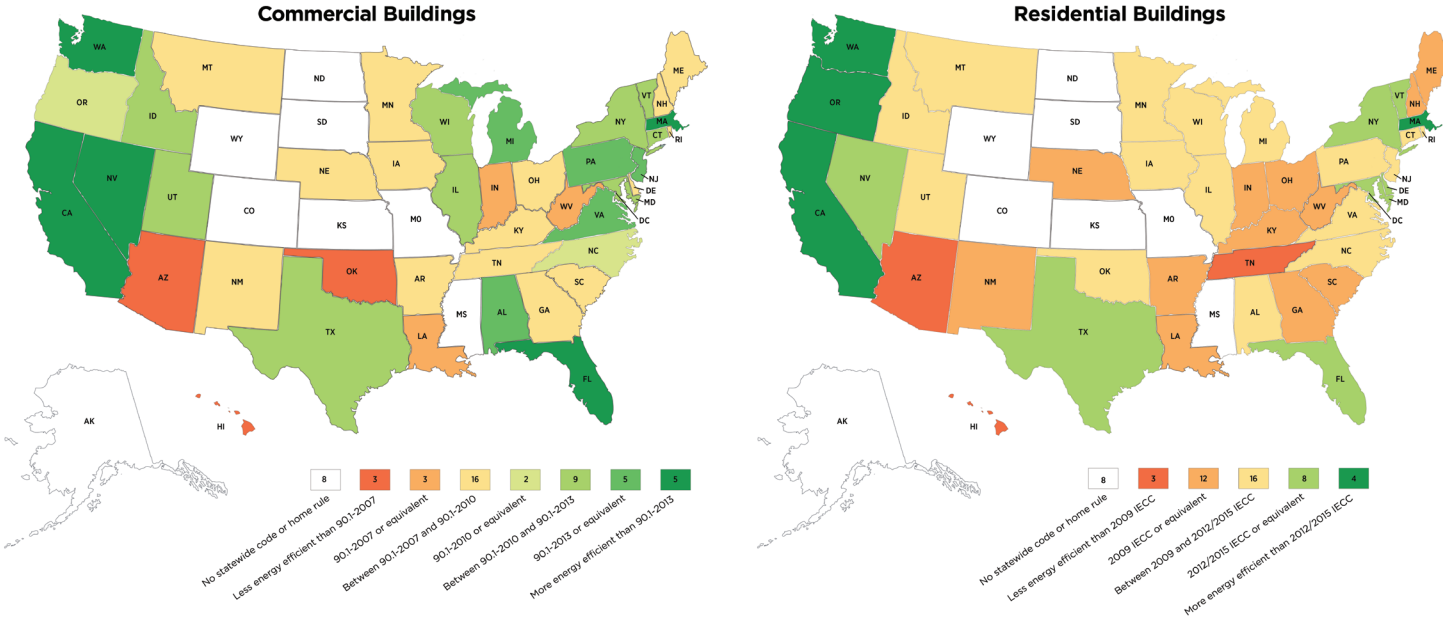

Figure 24. DOE tracks the adoption of energy codes across the United States for commercial and residential buildings. Building energy codes will save U.S. home and business owners an estimated $126 billion and 841 million metric tons of avoided carbon dioxide emissions through 2040. Learn more at the Building Energy Codes Program website: https://www.energycodes.gov/

Appliance and Equipment Standards

The Appliance and Equipment Standards Program (Appliance Standards Program, or Program) helps consumers save 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. In this capacity, DOE currently implements energy or water conservation 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.[32]

In accordance with statutory requirements, the Appliance Standards Program promulgates energy and water conservation standards and test procedures in a rulemaking process in which decisions are based on technical merit; economic analysis; the full consideration of impacts on consumers, manufacturers, and the environment; and stakeholder feedback. The Program also works with 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 marketplace, the Program can consider them as the basis for future standards.

In fulfilling its statutory responsibilities, the Appliance Standards Program works closely with a broad range of stakeholders, including manufacturers, states, utilities, energy efficiency advocates, and others. Each rulemaking process provides opportunities for stakeholder review and comment, and the Program has established the Appliance Standards and Rulemaking Federal Advisory Committee as another means of facilitating stakeholder engagement by allowing for negotiated rulemakings under the guidelines set forth in the Federal Advisory Committee Act.

To meet statutory requirements set forth in EPCA, as amended by several other laws including the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007, the Program initiates:

- **Test Procedures Development:** Establish test procedures that are representative of average use that capture innovative designs and are resistant to "gaming."
- **Standards Development:** Establish minimum energy and water conservation standards.
- **Enforcement:** Enforce certification and compliance with energy and water 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.

Figure 25. Standards implemented by the Appliance Standards Program cover a range of appliances and building equipment, including consumer products like dishwashers, microwaves, ovens, and refrigerators.

End Notes

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3. U.S. Energy Information Administration. "U.S. Natural Gas Summary." Accessed September 15, 2019: eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.
4. The Appliance and Equipment Standards Program works closely with a large range of stakeholders to ensure its energy conservation standards, test procedures, and certification and compliance regulations are based on technical merit. Decisions are also made based on economic analyses, and the consideration of impacts on consumers, manufacturers, and the environment.
5. The Building Energy Codes Program works with established industry development bodies and participates in the industry processes through which energy codes are developed, discussed, or approved.
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8. One quad is a unit of energy equal to one quadrillion (10^{15}) British thermal units (BTUs). The U.S. consumes approximately 100 quads of energy each year.
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10. Ibid.
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12. Ibid.
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14. The R-value is a measurement of a material's capacity to resist heat flow from one side to the other (i.e., the effectiveness of insulation).
15. Smart building materials are materials or systems that can dynamically adjust or control the transfer of heat, air, or moisture through the building envelope in response to ambient conditions, occupant preferences, or some other control signal.
16. BTO Multi-Year Program Plan: Fiscal Years 2016 – 2020. Accessed September 15, 2019: energy.gov/eere/buildings/downloads/multi-year-program-plan.
17. U.S. Energy Information Administration. Commercial Building Energy Consumption Survey 2012, Table B1. Accessed August 15, 2019: eia.gov/consumption/commercial/data/2012/.
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22. Supra 17; Commercial Building Energy Consumption Survey 2012. Accessed August 15, 2019.
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31. DOE is directed by statute to participate in industry model code development processes and to review updated editions of model codes for residential and commercial buildings (42 USC 6833).
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