U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2019 Buildings Technology Office Peer Review Report

APPENDIX

July 2020

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy

2019
Building Technologies Office
Peer Review Report

APPENDIX

April 15 – 18, 2019
Arlington, Virginia

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Notice

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Final List of Reviewers

The complete list of reviewers for Project, Portfolio, and Partnership reviews is presented below:

Aoki-Kramer, Michael
RDH Building Science, Inc.

Arbab, Mehran
PPG Industries

Ballesteros, Rita
Fannie Mae

Barnett, Tom
National Fenestration Rating Council

Bertino, Massimo
Virginia Commonwealth University

Bianchi, Marcus
Owens Corning

Bickel, Stephen
Liberty Homes

Bigham, Sajjad
Michigan Tech University

Blissard, Laureen
Green Builder Coalition

Boric-Lubecke, Olga
University of Hawai'i

Braham, William
University of Pennsylvania

Brown, Carrie
Resource Refocus and IBPSA-USA

Chudnovsky, Yaroslav
Gas Technology Institute

Costa, Marc
Energy Coalition

Deng, Song
Bee USA

Eger, Bill
City of Alexandria

Domitrovic, Ronald (Ron)
Electric Power Research Institute

Emrath, Paul
National Association of Home Builders

Fedie, Ryan
Bonneville Power Administration

Foss, Asa
U.S. Green Building Council

Gonzalez, Jorge E.
The City College of New York

Groppi, Mike
CBRE Group, Inc.

Hakkarainen, Pekka
Lutron

Hamilton, Ian
UCL Energy Institute

Hampsmire, Gail
U.S. Green Building Council

Hanifin, John
Thomas Jefferson University

Haramati, Mikhail
California Energy Commission

Hartman, Thomas
The Hartman Company

Healy, William
National Institute of Standards and Technology

Holdridge, Heather
Lake Flato Architects

Hopkins, Greg
Rocky Mountain Institute

Hilsey, Shannon
World Resources Institute

Hostler, Steve
Case Western Reserve University

Hungerford, David
California Energy Commission

Hwang, Yunho
University of Maryland

Hydeman, Mark
Google, Inc.

Jarzomski, Kevin
U.S. Energy Information Administration

Junglaus, Matt
Rocky Mountain Institute

Khounsary, Ali
Illinois Institute of Technology

Krarti, Moncef
University of Colorado at Boulder

Lechner, Norbert
Auburn University

Lilya, Dustin
DC Engineering

Lord, Richard
Carrier Corporation

Mansy, Khaled
Oklahoma State University
Markham, Phil
Southern Company

McPhee, Peter
Massachusetts Clean Energy Center

Medina, Mario
University of Kansas

Memari, Ali
Pennsylvania State University

Miller, Alexi
New Buildings Institute

Moghaddam, Saeed
University of Florida

Moriarta, Courtney
New York State Energy Research and Development Authority

Muenz, Ulrich
Siemens Corporation

Murphy, William
University of Kentucky

Musho, Terence
West Virginia University

Nadel, Steven
American Council for an Energy Efficient Economy

Nelson, Brent
Northern Arizona University

Nesler, Clay
Johnson Controls

Orosz, Michael
University of Southern California

Pate, Michael B.
Texas A&M University

Pavlak, Gregory
Pennsylvania State University

Payne, Vance
National Institute of Standards and Technology

Pegues, Jim
Carrier Corporation

Perlman, Jeffrey
Bright Power

Podorson, David
Xcel Energy

Poges, Shannon
Arizona State University

Powell, Kevin
U.S. General Services Administration

Previtali, Jon
Wells Fargo

Rahman, Muhammad
Wichita State University

Rainey, Teresa
EYP, Inc.

Rao, Sagar
Affiliated Engineers

Roth, Kurt
Fraunhofer CSE

Roy, Anthony
Earth Advantage

Sachs, Harvey
American Council for an Energy Efficient Economy

Sawford, Michael
EDSL USA, Inc.

Sbar, Neil (retired)
SAGE Electrochromics, Inc.

Shah, Bipin
WinBuild

Shen, Lester
Center for Energy and Environment

Simmons, Craig
Vermont Energy Investment Corporation

Smith, Amanda
University of Utah

Srebric, Jelena
University of Maryland

Srinivasan, Ravi
University of Florida

Stratton, Susan
Northwest Energy Efficiency Alliance

Tabares Velasco, Paulo Cesar
Colorado School of Mines

Thomas, Greg
Performance Systems Development

Ticona, Daniel
Freddie Mac

Vicent, Will
Southern California Edison

Viswanathan, Jeet
City of Alexandria Public Schools

Walser, Brian
Accenture Operations

Wang, Robert
Arizona State University

Weston, Theresa
DuPont Building Innovations

Wolfman, Howard L.
Lumispec Consulting

Worek, William
Texas A&M University

Final List of Presenters

The complete list of presenters for Project, Portfolio, and Partnership review sessions is presented below:

Alberi, Kirstin
National Renewable Energy Laboratory

Antretter, Florian
Oak Ridge National Laboratory

Armstrong, Andrew
Sandia National Laboratories

Baechler, Michael
Pacific Northwest National Laboratory

Bahar, Bamdad
Xergy

Baxter, Van
Oak Ridge National Laboratory

Bergmann, Harry
U.S. Department of Energy

Bernal, Willy
National Renewable Energy Laboratory

Biswas, Kaushik
Oak Ridge National Laboratory

Block, Jason
Steven Winter Associates

Bohac, David
Center for Energy and the Environment

Brown, Richard
Lawrence Berkeley National Laboratory

Campbell, Martha
Rocky Mountain Institute

Chandrasekhar, Prasanna
Ashwan-Ushas Corporation

Cort, Katie
Pacific Northwest National Laboratory

Curcija, Charlie
Lawrence Berkeley National Laboratory

Dames, Chris
Lawrence Berkeley National Laboratory

Davis, Robert
Pacific Northwest National Laboratory

Deru, Michael
National Renewable Energy Laboratory

Desjarlais, Andre
Oak Ridge National Laboratory

Demott, Jessica
Arkema

Dickey, Glenn
Allegheny Science & Technology

Fricke, Brian A.
Oak Ridge National Laboratory

Garrabrant, Michael
Stone Mountain

Geoghegan, Patrick
Oak Ridge National Laboratory

Gladden, Chris
Glint Photonics

Glickman, Joan
U.S. Department of Energy

Gluesenkamp, Kyle
Oak Ridge National Laboratory

Gong, Amy
Inventwood

Gorthala, Ravi
University of New Haven

Granderson, Jessica
Lawrence Berkeley National Laboratory

Gupta, Erika
U.S. Department of Energy

Hackel, Scott
Seventhwave

Hains, Bryant
Southface Institute

Huelman, Pat
University of Minnesota

Hun, Diana
Oak Ridge National Laboratory

Hunt, Walt
Pacific Northwest National Laboratory

Im, Pijae
Oak Ridge National Laboratory

Jackson, Roderick
National Renewable Energy Laboratory

Jiron, Amy
U.S. Department of Energy

Joshi, Pooran
Oak Ridge National Laboratory

Kaur, Sumanjeet
Lawrence Berkeley National Laboratory

Kinzey, Bruce
Pacific Northwest National Laboratory

Kochkin, Vladimir
Home Innovation Research Labs

Kohler, Christian
Lawrence Berkeley National Laboratory

Kosny, Jan
Fraunhofer CSE

LaFleur, Jason
Gas Technology Institute

Lamm, Douglas
Building Envelope Materials

Lee, Eleanor
Lawrence Berkeley National Laboratory

Leon, Felipe
Pacific Northwest National Laboratory

Levy, Emanuel
The Levy Partnership

Linteris, Gregory
National Institute for Standards and Technology

Liu, Xiaobing
Oak Ridge National Laboratory

Lstiburek, Joe
Building Science Corporation

Mahmoud, Ahmad
UTRC

Martin, Eric
University of Central Florida

Mathew, Paul
Lawrence Berkeley National Laboratory

McGehee, Michael
University of Colorado

Metzger, Cheryn
Pacific Northwest National Laboratory

Momen, Ayyoub
Oak Ridge National Laboratory

Moore, Mike
Newport Partners

Muehleisen, Ralph
Argonne National Laboratory

Munk, Jeff
Oak Ridge National Laboratory

Nawaz, Kashif
Oak Ridge National Laboratory

Patel, Viral K.
Oak Ridge National Laboratory

Petit, Michael
V-Glass

Pless, Shanti
National Renewable Energy Laboratory

Poplawski, Michael
Pacific Northwest National Laboratory

Puttagunta, Srikanth
Steven Winter Associates

Radermacher, Reinhard
University of Maryland

Regnier, Cindy
Lawrence Berkeley National Laboratory

Roth, Amir
U.S. Department of Energy

Roth, Kurt
Fraunhofer CSE

Sharma, Jaswinder
Oak Ridge National Laboratory

Shen, Lester
Center for Energy and Environment

Shrestha, Som
Oak Ridge National Laboratory

Singer, Brett
Lawrence Berkeley National Laboratory

Singla, Rupam
TRC Energy Services

Sofos, Marina
U.S. Department of Energy

Staats, Wayne
Sandia National Laboratories

Taylor, Ruth
Pacific Northwest National Laboratory

Tenent, Robert
National Renewable Energy Laboratory

Trentacost, Joseph
EA Membranes

Walker, Ian
Lawrence Berkeley National Laboratory

Wang, Nora
Pacific Northwest National Laboratory

Westfall, Brian
Trane

Wheeler, Grant
National Renewable Energy Laboratory

Wilson, Eric
National Renewable Energy Laboratory

Zhiming, Gao
Oak Ridge National Laboratory

Analysis Methodology

For all projects, reviewers were given five evaluation criteria and asked to score them on a 1–4 scale, with four being the highest. In addition to numeric scores, reviewers were asked to provide qualitative comments and feedback regarding the project's strengths and weaknesses, as well as recommendation for project improvement. Please refer to the Project Evaluation Form, Portfolio Evaluation Form, and Partnership Evaluation Form on pages 4, 6, and 8, respectively, for full evaluation criteria.

Scores were based on the following criteria and weights:

Score 1: Approach (30%) – Degree to which the project's approach contribute to overcoming barriers, technical challenges, and mitigating project risks.

Score 2: Impact (20%) – Assuming that the **project-specific goals** are met, degree to which the project is **expected to** contribute to **program goal(s)**.

Score 3: Progress (15%) – Based on current project efforts, degree to which the project has met **project-specific goals**.

Score 4: Collaboration and Coordination (20%) – Appropriate to the current project stage and level of development, degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

Score 5: Remaining Project Work (15%) – Degree to which the project has logically planned remaining work to meet the **project-specific goals**. This criterion is not applicable if a project has ended.

For each project, scores for the five criteria were used to calculate a weighted average using the equation shown in Figure 1.[1]

$$\left[\left(\frac{\sum_1^n Score\ 1}{n}\right)x(0.3)\right]+\left[\left(\frac{\sum_1^n Score\ 2}{n}\right)x(0.2)\right]+\left[\left(\frac{\sum_1^n Score\ 3}{n}\right)x(0.15)\right]$$
$$+\left[\left(\frac{\sum_1^n Score\ 4}{n}\right)x(0.2)\right]+\left[\left(\frac{\sum_1^n Score\ 5}{n}\right)x(0.15)\right]$$

(n equals the number of reviewers per scoring metric)

Figure 1. Equation used to calculate each project's weighted average score

- This analysis methodology is also used for the Portfolio and Partnership reviews conducted at the 2019 BTO Peer Review. Note that although the analysis methodology is the same for all three types of evaluations, the Portfolio and Partnership reviews employ different criteria and weights – the latter of which is reflected in their respective equations – as deemed appropriate for each type of evaluation.

[1] For projects that were already complete at the time of review, a weighted average score was calculated based on the first four evaluation criteria only.

Project Evaluation Form

This evaluation form was used by reviewers to provide ratings and comments for projects showcased at the 2019 Building Technologies Office Peer Review.

Evaluation Criteria: Building Technologies Office (BTO) Program Peer Review 2019

A. Approach (30%): Degree to which the project's approach contribute to overcoming barriers, technical challenges, and mitigating project risks.

1. Poor - The project's approach is **not likely** to contribute to overcoming barriers, technical challenges, and mitigating project risks.
2. Fair - The project's approach is **somewhat likely** to contribute to overcoming barriers, technical challenges, and mitigating project risk.
3. Good - The project's approach is **likely** to contribute to overcoming barriers, technical challenges, and mitigating project risk.
4. Outstanding - The project's approach is **highly likely** to contribute to overcoming barriers, technical challenges, and mitigating project risks.

Comments on Approach:

B. Impact (20%): Assuming that the project-specific goals are met, degree to which the project is expected to contribute to program goal(s). (Note: Program goal(s) were provided to reviewers separately.)

1. Poor - The project is **not likely** to contribute to the program goal(s).
2. Fair - The project is **somewhat likely** to contribute to the program goal(s).
3. Good - The project is **likely** to contribute to the program goal(s).
4. Outstanding - The project is **highly likely** to contribute to the program goal(s).

Comments on Impact:

C. Progress (15%): Based on current project efforts, degree to which the project has met **project-specific goals**.

1. Poor - The project has demonstrated **little or no** contribution to the project-specific goals.
2. Fair - The project has demonstrated **modest** contribution to the project-specific goals.
3. Good - The project has demonstrated **significant** contribution to the project-specific goals.
4. Outstanding - The project has demonstrated **excellent** contribution to the project-specific goals.

Comments on Progress:

D. Collaboration and Coordination (20%): Degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders. (Note: Projects should be scored appropriate to the current project stage and level of development.)

1. Poor - The project staff demonstrates **little or no** strategic collaboration or coordination with relevant stakeholders.
2. Fair - The project staff demonstrates **modest** strategic collaboration or coordination with relevant stakeholders.
3. Good - The project staff demonstrates **significant** strategic collaboration or coordination with relevant stakeholders.
4. Outstanding - The project staff demonstrates **excellent** strategic collaboration or coordination with relevant stakeholders.

Comments on Collaboration and Coordination:

E. Remaining Project Work (15%): Degree to which the project has logically planned remaining work to meet the **project-specific goals**. (Note: Not applicable if a project has ended.)

1. Poor - The project plans are **not likely** to meet the project-specific goals.
2. Fair - The project plans are **somewhat likely** to meet the project-specific goals.
3. Good - The project plans are **likely** to meet the project-specific goals.
4. Outstanding - The project plans are **highly likely** to meet the project-specific goals.

Comments on Proposed Future Work:

What are the project's strengths? Please be specific:

What are the project's weaknesses? Please be specific:

What are your recommendations to improve the project? Please be specific:

Portfolio Evaluation Form

This evaluation form was used by reviewers to provide ratings and comments for portfolios of projects showcased at the 2019 Building Technologies Office Peer Review.

Evaluation Criteria: Building Technologies Office (BTO) Program Peer Review 2019

A. Scope (30%): Degree to which the scope identifies and targets key barriers and technical challenges that are appropriate for the Federal Government to address.

1. Poor - The sub-program **does not** target appropriate barriers and technical challenges. **Many** significant barriers and challenges are ignored.
2. Fair - The sub-program **partially** targets appropriate barriers and technical challenges. **Some** significant barriers and challenges are ignored.
3. Good - The sub-program **mostly** targets appropriate barriers and technical challenges. **A few** significant barriers and challenges are ignored.
4. Outstanding - The sub-program **fully** targets appropriate barriers and technical challenges. **No** significant barriers or challenges are ignored.

Comments on Scope:

B. Impact (30%): Assuming that the **portfolio-specific goals** are met, degree to which the portfolio is **expected** to contribute to **program and BTO goal(s)**. (Note: Program goal(s) were provided to reviewers separately.)

1. Poor - The sub-program **does not** advance state-of-the-art, support industry, or contribute to BTO's energy savings goals.
2. Fair - The sub-program **somewhat** advances state-of-the-art, supports industry, and contributes to BTO's energy savings goals.
3. Good - The sub-program **moderately** advances state-of-the-art, supports industry, and contribute to BTO's energy savings goals.
4. Outstanding - The sub-program **significantly** advances state-of-the-art, supports industry, and contribute to BTO's energy savings goals.

Comments on Impact:

C. Collaboration, Coordination, and Integration (20%): Based on current portfolio efforts, degree to which its activities demonstrate **strategic collaboration or coordination** with relevant programs and partners.

1. Poor - The sub-program demonstrates **little or no** strategic collaboration or coordination with relevant programs and partners.
2. Fair - The sub-program demonstrates **some** strategic collaboration or coordination with relevant programs and partners.
3. Good - The sub-program demonstrates **moderate** strategic collaboration or coordination with relevant programs and partners.

4. Outstanding - The sub-program demonstrates **significant** strategic collaboration or coordination with relevant programs and partners.

Comments on Collaboration, Coordination, and Integration:

D. Communication and Stakeholder Engagement (10%): Degree to which the portfolio staff demonstrates integration of stakeholder input and effective communication of portfolio activity information.

1. Poor - The sub-program **does not** integrate stakeholder input and provide no useful information.
2. Fair - The sub-program integrates **some** stakeholder input and provides some useful information.
3. Good - The sub-program **moderately** integrates stakeholder input and provides a moderate amount of useful information.
4. Outstanding - The sub-program **significantly** integrates stakeholder input and provides a significant amount of useful information.

Comments on Collaboration and Coordination:

E. Metrics (10%): Degree to which the portfolio has identified appropriate metrics against which its performance will be measured.

1. Poor - The sub-program has **no impact metrics and/or performs poorly** on existing impact metrics.
2. Fair - The sub-program has **few metrics and/or performs fairly** according to those metrics.
3. Good - The sub-program has **appropriate metrics and performs moderately well** according to them.
4. Outstanding - The sub-program has **appropriate metrics and performs very well** according to them.

Comments on Metrics:

What are the portfolio's strengths? Please be specific:

What are the portfolio's weaknesses? Please be specific:

What are your recommendations to improve the portfolio? Please be specific:

Partnership Evaluation Form

This evaluation form was used by reviewers to provide ratings and comments for partnership activities showcased at the 2019 Building Technologies Office Peer Review.

Evaluation Criteria: Building Technologies Office (BTO) Program Peer Review 2019

A. Scope (30%): Degree to which the partnerships identify and target key barriers and technical challenges that are appropriate for the Federal Government to address.

1. Poor - The sub-program **does not** target appropriate barriers and technical challenges. Many significant barriers and challenges are ignored.
2. Fair - The sub-program **partially** targets appropriate barriers and technical challenges. Some significant barriers and challenges are ignored.
3. Good - The sub-program **mostly** targets appropriate barriers and technical challenges. A few significant barriers and challenges are ignored.
4. Outstanding - The sub-program **fully** targets appropriate barriers and technical challenges. No significant barriers or challenges are ignored.

Comments on Scope:

B. Impact (40%): Assuming that the **partnership-specific goals** are met, degree to which they are **expected** to contribute to **program and BTO goal(s)**. (Note: Program goal(s) were provided to reviewers separately.)

1. Poor – The sub-program **does not** advance state-of-the-market, appropriately support industry, or contribute to BTO's energy savings goals.
2. Fair – The sub-program **somewhat** advances state-of-the-market, appropriately supports industry, and contributes to BTO's energy savings goals.
3. Good – The sub-program **moderately** advances state-of-the-market, appropriately supports industry, and contribute to BTO's energy savings goals.
4. Outstanding – The sub-program **significantly** advances state-of-the-market, appropriately industry, and contribute to BTO's energy savings goals.

Comments on Impact:

C. Collaboration, Coordination, and Integration (30%): Based on current partnership efforts, degree to which its partnership activities demonstrate **strategic collaboration or coordination** within BTO/EERE and with relevant external stakeholders.

1. Poor - The sub-program demonstrates **little or no** strategic collaboration or coordination with relevant programs and partners.
2. Fair - The sub-program demonstrates **some** strategic collaboration or coordination with relevant programs and partners.

3. Good - The sub-program demonstrates **moderate** strategic collaboration or coordination with relevant programs and partners.
4. Outstanding - The sub-program demonstrates **significant** strategic collaboration or coordination with relevant programs and partners.

Comments on Collaboration, Coordination, and Integration: Reviewer Comment Summaries

Reviewer Comments Summaries and Raw Reviewer Comments

BTO solicits input on its projects via an annual Peer Review process to ensure that projects are relevant, effective, and productively assisting the Office in meeting its goals. Independent review is an important part of BTO's overall portfolio management process, as it provides alternative viewpoints from leaders in industry and academia on current project activities and strategies. Reviewers that participate in Peer Review evaluate projects and provide crucial, targeted feedback on progress-to-date as well as proposed future work. This feedback informs BTO's understanding of its portfolio's approach, effectiveness, and potential impact from current investments in technology research and development, validation and verification, and other related activities.

BTO Portfolio-Level Activities

Building Energy Data

Portfolio Review: Data Portfolio (Data Standards, Data Management and Analysis Tools, and Unstructured Data)

Presenter: Harry Bergmann, U.S. Department of Energy

Brief Summary of Reviewer Comments

In general, reviewers agreed that the scope identifies and targets key barriers and technical challenges that are appropriate for DOE to address. The initial technical barriers and challenges being addressed by this sub-program are appropriate for DOE to address and, when done in concert with the market, DOE is a critical catalyst in this area and can activate market channels. Overall, the Building Data subprogram is on-target with its scope. The stated goals align well with the overall BTO goals and are appropriate for a government role in the energy efficiency space.

Some reviewers expressed concerns about one overlooked barrier, the issue of cross-adoption within the industry. One of the biggest barriers in the building industry is the disconnect between building design and building operations. Another concern expressed was related to EDV and whether it is really solving a critical barrier in a direct way. There is skepticism that utilities will see enough value in the EDV approach to entice them to participate.

On the topic of the project's impact and the degree to which the portfolio is expected to contribute to program and BTO goals, the reviewers were split. Many reviewers agreed that the sub-program certainly advances the state-of-the-art (SOA) and the sub-program absolutely supports the industry. The BED portfolio advances the SOA by leveraging existing frameworks and accounting for future data needs or possible issues. Reviewers praised the industry stakeholders and partners involved. Examples of this include the use of the BEDES and BuildingSync, which specifically addresses a need to interact across different data sets, standards and software. The SEED platform also shows this support for industry, both large and small businesses, along with public organizations who are investing public funding in energy performance.

However, other reviewers disagreed, stating that the program does not seem to advance SOA or support industry as effectively as it could. Multiple reviewers suggested selling the value of some group of these initiatives to one or two adopters outside of the typical energy efficiency players (e.g., realtors, code officials, building inspectors, mortgage lenders). Reviewers also expressed other concerns, such as DOE continuing to offer free SEED hosting, an effort that is diminishing the overall support of making SEED a meaningful tool for the marketplace, and the program's ability to meet the end-goals listed on slide 6.

Overall, reviewers agreed that collaboration, coordination, and integration is a strength of this sub-program. Different projects within the BED portfolio complement one another and work in unison to ensure consistency, transparency, and quality. The portfolio coordinates among residential and commercial buildings and emerging technologies programs, allowing for consistency among the various related sectors. There also seems to be a very good use of channel partners, such as the API development licenses from the BPD and the integration of the SEED platform with other open and public system platforms, along with third-party hosting providers.

Many reviewers suggested additional outreach and collaboration with certain groups. There could be a stronger connection to GIS mapping organizations who produce what is considered to be open and closed data. Further outreach should be provided to property management firms and other entities with large building portfolios (e.g., universities with multiple campuses, multiple buildings, etc.). Some reviewers expressed that DOE could do a better job of leveraging channel partners.

Furthermore, reviewers generally agreed that the BED portfolio acknowledges the large variety of public and private stakeholders and works to continually identify relevant parties. Everyone from industry groups to public sector to NGOs and utilities are at the table. However, one reviewer did express skepticism if the identified stakeholders are active participants (such as Building America) versus folks who have agreed that the results would be useful if obtained quickly.

Most reviewers agreed that the webpages of all programs that are in operation are generally clear and provide good communication on updates as they evolve. From newsletters, partner announcements, and the structure of recognizing partner organizations, there is constant communication and those participating instantly know when success happens. A few reviewers expressed thoughts that the plan to communicate accomplishments and lessons could be strengthened.

As for metrics, many reviewers expressed uncertainty about what the progress and impact metrics were. As a result, it was somewhat hard for the reviewers to evaluate all the projects in terms of their performance across the chosen metrics. Although reviewers generally agreed that progress is being made, some reviewers suggested that the Building Data sub-program would be well served to develop some specific metrics (e.g., square footage entered into various tools, cumulative "size" of programs leveraging SEED, etc.) that they can begin to track.

Reviewers did identify some tracked metrics, such as unique logins to the tools, number of schema mapped, and number of buildings scored with Asset Score. Number of organizations adopting tools is a good starting point for a metric (e.g., 30 organizations have adopted BEDES). However, it would be helpful to have metrics that further determine the degree to which this has achieved the goals of standardization and interoperability of building energy data.

Weighted Average: 3.31 # of Reviewers: 8
Scope: 3.50 Impact: 3.38 Collaboration, Coordination, and Integration: 3.38 Communication and Stakeholder Engagement: 3.00 Metrics: 2.75

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning as appropriate.

A. Scope

This portfolio was rated **3.50** for the degree to which the scope identifies and targets key barriers and technical challenges that are appropriate for the Federal Government to address.

- At the crux of our collective challenges is data standardization. In the last three years, the DOE has immensely transformed the market in this respect. The team seems to fully understand the bottlenecks in the industry and has addressed them in a way that has given a "shot in the arm" to the industry. The challenges are understood as follows: agree on a data language, enable a way to share data across parties, provide use cases to make the standards tangible, and ingrain the standards across DOE subprograms. Through BEDES, BuildingSync, UBID, the BPD, Energy Data Vault, and by extension, SEED and Asset Score, the DOE has been succeeding at tackling the challenges, but there is still work that needs to be done for market transformation.

- The portfolio does a good job at "staking out the corners" of all the challenges. In addition to the technical challenges, which have been well-addressed, is the opportunity to further build the value proposition to the market. One obvious case of this is the UBID and the telecom adoption of the standard. However, for the other programs, while adoption has been steady, it seems that more resources (albeit small) are needed to make the portfolio of initiatives a stable success to the point where the sub-program can eventually reach a maintenance mode, and the DOE can move on to mapping out new challenges. This seems like it needs another 3-5 years of attention, which would greatly benefit not only the BTO but other offices.

- The sub-program is extremely comprehensive. It does seem that one overlooked barrier, not under control of BTO, is cross-office adoption or even simple awareness of the amazing work coming out of this team. The GEB team, or even SETO, OE, and perhaps the VTO could greatly benefit and save money by enhanced collaboration.

- The Portfolio is seeking to both improve on the data foundation from which real-world actions can be taken using reliable and well-described, observed data on building features and energy performance and the interconnections between that data foundation and tools that make use of this information. The objective is to ensure that businesses can take advantage of the opportunities allowed from data transparency and consistency. This is a particularly important undertaking from a federal government perspective because it reduces the risk of proprietary systems becoming entrenched and limiting market potential for taking actions for businesses and asset owners to invest in their buildings and saving energy. An example of this is the BuildingSync that provides that interaction between commercial and open access systems that need information on building performance but use different formats and standards of description. The BuildingSync acts as an interoperability codex, a place where these items are written down and can be translated across platforms. While a single proprietary system may have interest in developing such as a system for one or two of its collaborators, it would presumably limit this for competitors. Thus, these types of activities are squarely in the domain of the Federal government.

- The project portfolio does an exceptional job to address the identified barriers and technical challenges facing the users and producers of energy and building performance data. Namely, that the lack of common or consistent definitions, standards and guidance is a problem when producing and using building performance data, especially so over time and across jurisdictions and stakeholders. Projects such as BuildingSync offer to overcome this. Second, the access to information in a secure and usable format remains a challenge for developing comparison cases for buildings that are being evaluated. Projects such as BPDB offers a way to compare your building with hundreds and thousands that are similar or who have taken similar actions. Another is the concern around privacy and anonymity. The Energy Data Vault, as it is developed, should fit this need that organizations can securely analyze their data and develop a framework for security and privacy while not limiting access.

- There is a question of how 'deep' one should go within the building, i.e., sub-meter, room level, appliance? And the type of smart data being generated that could be useful/influential to this program. The BRICK schema work will help to address this. There is a question of 'empirical' data and what that means. Does data generated using an algorithm (i.e., 30-minute intervals vs. continuous flow) count as empirical - presumably yes. This is not really a significant barrier, but one that might be reflected in some of the activities. Finally, the information on occupants and users of buildings is not very well addressed in this program. It is a common problem and not necessarily one that can be addressed here within the formulation of the program, but it might be helpful to see it within the Unstructured Data project as it develops.

- The mantra “You can’t manage what you can’t measure” is highly relevant to this sub-program. The barriers and technical challenges addressed by this program are real, significant, and appropriate for the federal government to address.
- Many stakeholders have a vested interest in reducing building energy consumption and demand due to the impact on building operating costs, the local and global environment, and the need for additional capacity and transmission from utilities. All of these stakeholders would have a greater ability to manage building energy consumption (whether for an individual building, a portfolio of buildings, buildings served by a utility, buildings that are part of a municipality, etc.). The DOE Data portfolio’s focus on standardization, interoperability, and publication of consolidated data to a broad audience helps each of these stakeholders better manage building assets relevant to building energy performance.
- Yes, the project portfolio appropriately addresses the barriers and technical challenges. It begins with standardization of the data through two data dictionaries (BEDES for building elements, and Haystack for control elements), the Unique Building ID that can be automatically generated for a large dataset, and Schema that allow a consistent methodology for structures and relationships related to this data.
- It also provides open-source tools for collecting this data, while not infringing on private-sector development. To the extent possible within data privacy constraints, the building performance database makes aggregated data regarding building performance available for comparison to customized peer groups.
- There is one major barrier that appears to be largely ignored by the program. The “ground rules” indicate that data is “measured, not modeled”. This is appropriate. However, one of the biggest barriers in the building industry is the disconnect between building design and building operations. There are case studies with measurement and verification that confirm that integrative energy design with building energy simulation informing the design process leads to higher performing buildings in operation. However, this energy simulation process is extremely time-consuming, and often includes manual re-entry of data multiple times for varying purposes (e.g., local code compliance, government incentive programs, etc.). Furthermore, basic information informing the energy model, such as default receptacle loads, default schedules, etc. have not changed in 40 years, and would greatly benefit if informed by measured data from buildings.
- The data standardization and interoperability that are being developed have many commonalities between measured and modeled information. Expanding the program to provide continuity of data from building design through operations would significantly increase the quality and quantity of data available and would increase the capability to manage building energy performance.
- The new construction process for high performance buildings includes iterative energy modeling to inform the design process, a basis of design and design intent document to inform the design process, a CD-phase model to confirm predicted energy performance vs. a baseline, the development of a Current Facilities Requirement (CFR) document and Sequences of Operation during building commissioning, and functional testing during commissioning to confirm the building performs as designed. Much of the information in these analysis and documents is the same information as is defined in the BEDES and Haystack data dictionaries. Intentionally expanding the sub-program to assure interoperability from design to building operations would significantly increase the value of the available data and would allow better transfer of relevant building information from the design professionals to the building operators.

- For example, BuildingSync and SEED could be expanded to receive information from the energy model to populate standardized forms used to demonstrate energy code compliance, to populate the Current Facilities Requirement document, to pre-populate information associated with an ASHRAE Level 2 audit based on the equipment present during commissioning, to link to standard commissioning tests provided by a 3rd party, etc.

- Assuming the data could be appropriately privatized and aggregated, this data could also be used to help identify the efficiency measures and control strategies incorporated during design that lead to the highest energy savings in various building types and locations, and the efficiency measures that lead to the greatest persistence of energy savings. Furthermore, data from building operations could be aggregated to provide better inputs to the energy models (e.g., default operating schedules, default receptacle and miscellaneous loads and schedules, etc.).

- Note: It’s possible the Energy Vault May be intended to address some of these details, but that wasn’t clear based on the presentation.

- Yes, I think, in particular, the challenges to data standardization and accurate performance information identified in the project plan for BuildingSync make sense. Assuming data cleaning and standardization is adequate (to address potentially unforeseen issues with the naming system), the project is well-designed to address the barriers.

- The Building Energy Data (BED) sub-program adequately acknowledges issues with data availability, quality and provenance, as well as the importance of and difficulty in standardizing language and approaches related to building energy data. These are real, significant concerns, and the Building Technologies Office is an appropriate group to address these issues.

- The variety of projects within the Building Energy Data program work to cohesively identify and address technical challenges. DOE already appears to have made significant headway in leveraging existing industry schema such as HPXML and developing consistent and coherent definitions and terminology via BEDES.

- Significant barriers appear to be addressed, though it is possible that new issues may arise as work progresses.

- The initial technical barriers and challenges being addressed by this sub-program are appropriate for DOE to address. Indeed, when done in concert with the market, DOE is a critical catalyst in this area and can activate market channels. When not done with the private market in mind, the sub-program limits its own potential effectiveness.

- It is very challenging to ‘evaluate’ this important program from the presentation, but that is all we have. Presentation has the feel of something pulled together last minute, rather than done in advance and reviewed by peers who have more experience with these reviews. Who is mentoring the fellows?

- To non-specialist building science and construction types of professionals, the first 20 or so slides had too many acronym gobbledygook bullet lists. One can think of lots of ways to organize a presentation for non-specialist reviewers trying make sense of things, to respond to the review goals enumerated on the slide 7.

- Too much detail in definitions, which takes away from grasping the position of each acronym component in the overall structure.

- By the time a reviewer sees slide 14, s/he is already lost in the alphabet soup. Emphasize what each acronym does for the others (slide 48) and level of maturity (perhaps colors to differentiate stages from proposed though available for commercial/real world application). Slide 22 is helpful.

- Please see notes below. The most important question about scope is whether this program and its ‘stretch’ exist because it can meet market needs, or help the market achieve the DOE/national goals versus whether it is an exercise in exploring data science capabilities. This wasn’t clear at all.

- Overall, the Building Data subprogram is on-target with its scope. The stated goals align well with the overall BTO goals and are appropriate for a government role in the energy efficiency space. EDV is the only specific component with uncertainty whether it is really solving a critical barrier in a direct way.
- Standardization: If it weren't for the Building Data subprogram, there would be little if any progress toward universal building data dictionaries or schema. This "inter-communicability" is an area where private industry repeatedly shows lack of initiative because they believe their interests are best served by monopolizing data. However, in order to achieve market-wide progression, standardization is critical and an appropriate role for government. So, the Building Data subprogram is right on target here.
- Tools/Analytics: Some aspects of exactly what SEED is are not as clear. But the building data tools (BPD, Asset Score/Audit Template) are found to be well-targeted and generally serving gaps that will help the industry improve buildings over time. It can be assumed that SEED is equally well-targeted and essential to pulling together "standardization" with these other elements.
- EDV: Getting interval data out into a space where analysis can be carried out is a major barrier. There is skepticism that utilities will see sufficient value in the EDV approach to entice them to participate. It might require there to be well-crafted and closely related regulatory requirements on the utilities for this to work.
- The Building Data work is impressive, and it will be good to see greater adoption.

B. Impact

Assuming that the ***portfolio-specific goals*** are met, this portfolio was rated **3.38** for the degree to which the portfolio is ***expected to*** contribute to ***program and BTO goal(s)***.

- The sub-program is at the bleeding edge of the market. In my ten years of being involved in the industry, I have not attended one event where I have learned so much new information. They have had major breakthroughs in the industry when it comes to data standards. They have laid the groundwork and have strategically partnered to begin initial deployments. Through their work, they have brought the market with them to build a fundamental understanding, or at least the catalyst/enabling elements to really make progress in the near term. The one piece of feedback is to better integrate AI/ML/DL (deep learning) into their work. Also, the work may need to be more accessible to the average user in the sense that some of the tools require a bit of coding experience. Plug and play software that auto-updates would be beneficial if that is the path the DOE wants to take.
- Not only has the sub-program supported the industry, it has created a whole new industry and opportunities. Because of SEED, for example a whole new batch of consultants have been able to thrive in the market. They have brought the labs with them and many industry stakeholders in volunteer opportunities, ad-hoc groups, as well as created avenues to further the industry because of the work they have done.
- Are there industry stakeholders that are not supported by the project portfolio? I really had to think hard about this, and I cannot think of an existing industry stakeholder that isn't either already involved or has an opportunity to be involved/benefit from this work.
- There is an absolute connection between this work and energy savings. When thinking about the lifecycle of an energy project, it all starts with data and understanding how a building, campus or even city uses energy. The portfolio offers ways to address each scale of these challenges. It enables policy to be made via Scout and the BPD, it enables practitioners to do audits and find savings, it enables programs to track and share data, and it allows the market to move at scale.
- The sub-program certainly advances the state of the art in terms of its focus on developing infrastructure and systems for supporting a strong building performance data foundation. The effort spent in developing translational products and systems for improving interoperability is really crucial to this foundation. In

looking elsewhere around the world, the program within the BTO on data is very strong. The BTO often sets the standard against which other activities in this area can be compared.

- It is clear from the collaborative partners across all the projects that industry is being supported. Examples of this include the use of the BEDES and BuildingSync, which specifically addresses a need to interact across different data sets, standards and software. The SEED platform also shows this support for industry, both large and small businesses, along with public organizations who are investing public funding in energy performance. The users of the BPD platform and developers of APIs from this platform also illustrate this collaborative support.

- An area that could be improved is the investors in energy performance of buildings. While there is a number of large organizations who would use the tools being produced and their information to access capital and apply for funds, one could imagine a stronger connection with those making decisions to provide funds on the ground. Examples of these might be public mortgage companies and other retail lenders.

- This program undoubtedly supports the BTOs energy saving goals, by addressing the weaknesses in the building energy performance data foundation, particularly the need for standardized and transferrable information sources, access to information for making decisions, and the need to address new and emerging areas of data. Together, these activities provide a strong foundation upon which one can measure and therefore manage energy use.

- The sub-program advances the state of the art in this industry. It still lags behind the state of the art in other industries, but for this industry, where there have been no major data firms that have focused on building energy efficiency, it provides better information than has previously been available.

- The most impressive examples within this program include:

    - SEED – It makes use of the most widely used energy benchmarking tool (Portfolio Manager) and creates linkages with the most widely used customer service tool (Salesforce).

    - Audit template – It standardizes a template for collecting building energy efficiency information in existing buildings, provides a method for transferring this information, and creates a suite of interoperable tools that connect this data together.

- Does the sub-program effectively support the industry? It effectively supports the existing building industry as noted in the response under Question 1 above. It currently provides the greatest value to municipalities and property managers/portfolio owners through the energy audit templates, BuildingSync, and SEED.

- The sub-program could be further augmented to create greater linkages between new construction and existing building operations. This would support building design and construction professionals, and lead to further development of data tools that would increase the ability of building facility managers to operate the building efficiently, and for the energy simulation industry to develop better default assumptions for building inputs.

- The SEED, Energy Audit Template, and BuildingSync collectively, paired with the Energy Asset Score, will contribute significantly to BTO's energy savings goals.

- Currently, the tools have the greatest impact on government buildings, and in locations that have local code requirements stipulating building energy tracking and ASHRAE Level 2 Audits for existing buildings. If there is more widespread adoption of the BEDES and Haystack data dictionaries, and related interoperable tools, the impact on the existing building industry relevant to operational improvements and low-cost energy retrofits will increase significantly.

- This impact will continue to grow as further development takes place for controls systems, miscellaneous systems, and data to enable grid-interactive efficient buildings.

- In terms of building data, the sub-program seems to fall among the advancing curve of building efficiency, neither leading nor following. The suite of tools is well-designed to support the construction, real estate, and efficiency industries.
- The BED portfolio advances the state of the art by leveraging existing frameworks and accounting for future data needs or possible issues.
- The program goals of standardizing building data and focusing on data quality/provenance supports the industry by increasing consistency and ensuring high-quality data and tools. This saves the industry processing and overhead time.
- The sub-program has identified industry, government, and non-profit organizations, but should ensure that groups that may be less energy-focused (e.g., realtors, code officials, building inspectors, mortgage lenders) participate in conversations so varying priorities and different industry cultures and standards are considered.
- The benefits of this program are somewhat more indirect than supporting development of specific energy-consuming technologies. However, the ability to improve the process efficiency and quality of data management allows industry stakeholders to focus more effectively on their core business practices.
- At the beginning of SEED development, DOE was advancing the state of the art by developing SEED. For this to have continued there was a need for SEED to be adopted by private developers. For private developers to become involved there needs to be a business motive. When DOE decided to continue offering free SEED hosting to cities that blocked an opportunity for private IT developers to create business relationships with cities and in turn likely delayed advancement of the SEED as a state-of-the-art tool.
- The program does not seem to support industry as effectively as it could. With SEED development, the program stated in mid-2014 that it wanted the market to take over SEED hosting, moving that work away from LBNL to cities or contractors. The enhancement of SEED was well managed and advanced the state of the art in our opinion. However, LBNL has not provided a firm timeline for the end of their SEED hosting. 5 years later the transfer to the market has not transpired. This leaves the potential industry partners with investments made but no way to capitalize on the investments and leaves SEED less impactful and used than it would otherwise be. If DOE felt that switching to private SEED hosting could not be done because there were not enough providers, a clear statement (or RFP/RFI) from DOE outlining the hosting opportunity would have spurred private market interest. In doing so a market opportunity would have been created and more SEED hosting providers would have entered the market. The slow process of switching from free SEED hosting, provided by DOE, to private hosting prevented adoption of SEED hosting by private actors. This in turn may have blocked the development of additional SEED functionality and SEED-related IT applications. If DOE activated market stakeholders more effectively in delivery of SEED services, they are more likely to come up with innovative uses of SEED and bring those ideas to cities using SEED. The development of more SEED use cases has the capacity to create more demand for use of SEED by cities. This is a classic case of DOE trying to insure they were being "fair" to the market, but instead they ended up hamstringing the greater adoption of the data management technology that they wanted to see adopted.
- See above comment. DOE thought they were supporting cities by continuing to offer free SEED hosting, but that effort diminished the overall support of making SEED a meaningful tool for the marketplace, meaning that DOE did not support business opportunities for private IT developers well enough.
- Do they contribute to energy savings goals? Cities with benchmarking policies have seen year over year energy reductions in the buildings being benchmarked.
- Nothing here gives assurance that the end goals (slide 6) are underlain by a deep understanding (from surveys, etc.) of who needs what, outside of the research community. For example, what would enable Level 2 auditors to use the time staved in one of the program goals to cross-check with a building model? How would this help

a designer changed with planning deeper retrofits? What data does she need, and how much time can she spend on it? What is it worth to the commercial real estate business, a goal of the EnergyStar Portfolio, which all know is imperfect?

- A cynic would observe that this program is a wonderful platform for rationalizing the kinds of research that laboratories like to do: reasonably challenging, pretty opaque for outsiders to assess, and guaranteed never to be completed. It will always need maintenance and enhancement of its facets in the never-ending search for something that someone else will use (note slide 21, which hints at similar situations).
- In contrast to firm strategy of making the Energy+ engine something that the private sector could use, I just don't see an actionable plan to reach the noble goals outlined on slide 6.
- More data won't support better inferences if the data is not the significant source of variability. Sensitivity analyses are not done to show what is critical. Let's drop back and look at each acronym's underpinnings and ask what data is likely to give better information.
- The use of UAVs (and ground-based mobile IR) is promising, as at least one firm is trying, but the reach to do data processing onboard the UAV doesn't seem like more than wish-list decoration. Who really cares if we do on-board processing or just remove a micro-SD card for on-ground processing?
- I think by nature the BTO programs are addressing big hurdles and impact will be inherently slow at first. It is impressive that the standardization and tool work has made its way into very big urban markets. On the flip side, it would be nice to see one or more examples outside of the top-tier ACEEE state rankings (e.g., California, New York, Massachusetts). But the fact that I am seeing the impacts within the day to day work that I do is a good sign. Again, I think the inter-communicability of various tools and data sets is a huge asset moving forward, and specifically the ability to connect various city disclosure and audit ordinances with tools like Asset Score/Audit Template and BPD I expect will have huge implications once the level of adoption increases.
- Overall, I think impact is good but has room for improvement. Selling the value of some group of these initiatives to one or two adopters outside of the typical energy efficiency players would go a long way to driving impact.

C. Collaboration, Coordination, and Integration

This portfolio was rated **3.38** for the degree to which its activities demonstrate strategic collaboration or coordination with relevant programs and partners.

- This is perhaps where the program excels the most. Its collection of programs seems to be a well-oiled machine and the inter-dependence of each sub-program on the others forces cohesion and performance. If BEDES or BuildingSync doesn't work, Asset Score won't work. If people don't benchmark or audit, the BPD doesn't get populated. There is a community of accountability because of the integration of the portfolio.
- The program is well integrated as stated before. The other offices (OE, SETO, etc.) could be more open to working with, adopting, and leveraging this team's work.
- As evidenced by the presentation, state and local governments are well integrated, industry organizations like ASHRAE and IBPSA are well integrated, and even some unique actors such as telecom have seen so much value in things like UBID that they are at the table. They have also been able to connect with policy makers to institutionalize the tools into the public sector, such as Asset Score, SEED, UBID, etc.
- The sub-program absolutely utilizes channel partners. The City Energy Project is one example. Another is working with ASHARE for BuildingSync and SPC 211 and audit standards. There are endless examples of industry involvement.

- There may be opportunities to launch new accelerators or re-launch the Case Competition to further connect with universities and the public sector for raising awareness and adoption of some of the tools.
- The sub-program has a goal of developing interoperable tools, collaborating with stakeholders, and providing products to help inform decision-making. Those projects that are included within this program are doing this by developing new products to connect between stakeholder, user, and producer of building performance data. Addressing issues like standardization is common among all the projects. Including this in the beads and building sink and building identification work is very clear. The new program on BEDES mapping manager and the development and BuildingSync will also help to improve interoperability to existing decision-making tools.
- There is a question about how integrated these programs are with other parts of the DOE. Examples where integration seems to be very thoughtful are the exchange between the energy plus and EnergyStar Portfolio manager, Asset score, and other API developers. The reality is, this program of projects seems to have evolved out of the clear lack of data infrastructure development that has been needed for the other programs and projects that are within the BTO and DOE programs. So, these seem to be inherently well integrated to these projects.
- There is good collaboration among both public and private organizations. An example of this is the energy data bowl, with both Open source developers such as EE open, public groups such as LBL flex lab, private organizations such as PG&E, and public government. These are the types of organizations who both demand and require better data infrastructure tools. They are also those who produce energy performance data in their day-to-day operations. Another example is the asset score program and its connection with different audit reporting programs and other tools.
- There seems to be a very good use of channel partners, such as the API development licenses from the BPD and the integration of the seed platform with other open and public system platforms, along with third-party hosting providers. There could be a stronger connection to GIS mapping organizations who produce what is considered to be open and closed data. But they are included in a number of instances like Google and the UBID methodology development. Overall, the collaboration community seems quite strong.
- The sub-program is well integrated and cohesive. The focus on standardization and interoperability of data, beginning with the Unique Building Identifier, then expanding to energy audits, and then further expanding to controls is the right approach.
- The sub-program is well integrated with some other sub-programs within the DOE and does a great job of leveraging the Energy Star Portfolio Manager data. I don’t have a full listing of DOE sub-programs, so it’s difficult to make the assessment of overall integration.
- However, it appears this sub-program could be uniquely leveraged to support both energy codes development, and the building energy modeling sub-program. See responses above for further information.
- The sub-program is ideally positioned and well-coordinated with relevant public sector organizations, particularly municipalities and the GSA. Coordination with public and private utilities is also making strong progress.
- Further outreach should be provided to property management firms and other entities with large building portfolios (e.g., universities with multiple campuses, multiple buildings, etc.).
- Does the sub-program effectively utilize channel partners? I don’t understand this question.
- The program appears to be internally cohesive, although I am not very familiar with DOE energy data more broadly. I would be interested to see more on how the data works to integrate with USGBC and other performance tools, but current partnerships appear strong.

- Different projects within the BED portfolio complement one another and work in unison to ensure consistency, transparency, and quality. The portfolio coordinates among residential and commercial buildings and emerging technologies programs, allowing for consistency among the various related sectors.
- The sub-program appears to be well integrated within BTO and EERE. However, it seems that the U.S. Energy Information Administration (EIA) is one part of DOE that could be further leveraged (given appropriate additional resources to participate). EIA functions to aggregate, analyze, and disseminate energy data in an unbiased way. It can lend a certain level of credibility and neutrality to the data, and its statistical and analytical expertise could complement that of BTO and EERE.
- The portfolio appears to coordinate well with relevant public and private organizations. It appears to have established effective channel partnerships to ensure that the standards and processes being developed by DOE are used and relevant to end users and stakeholders. Partnering with standards organizations such as ASHRAE and ANSI allows for broad reach in developing consensus. UBID leverages the publicly available Open Location Code, and consistent use of unique building identification connects data from various sources to be combined and analyzed by different stakeholders in a more effective and intuitive way than in the past.
- It appears that the there is good cross-department communication and coordination. We would extend that to the work with the national labs as well.
- We have seen this work, specifically with SEED hosting interrelating with Asset Score and to some extent with Home Energy Score.
- We believe that the program is well-positioned and coordinated with key city governments, such as New York City. We think that the program could better utilize relationships with private entities. For instance, in some cases there has been a development effort undertaken that replicates the work already completed by private partners. An example of this is the API that was built for SEED to make data available to MLS systems. The design of that API service is not state of the art for the MLS industry, especially when compared to those developed by partners. Also, the development of MLS connectivity is much more about business relationships and less about information technology. The generic ability of a SEED database to make data available does not enhance the capacity of two market actors to come to business terms for the delivery of home data to an MLS. This is an example where discussion with private partners could have saved the DOE time and effort.
- See comment above. We think that DOE could do a better job of leveraging channel partners. If DOE has a willing partner(s) with private industry, they should work very hard to understand the best ways they can support industry. This may require stepping back to review overall DOE goals in supporting a market.
- From the slides presented (e.g., slide 24), one infers that there is no market for the anticipated work product(s) except for public entities and a few utilities. Sure, there is some collaboration with an ASHRAE building energy quotient (bEQ) committee (which seems to compete with BPD), but where is deep involvement by entities like BOMA, IFMA, CoStar, etc.? Why does a program of this size not have an external advisor group, perhaps through a DOE lab (if easier to deal with agency rules)?
- This is clearly a big strength of the BTO and its sub-programs in general. I am consistently impressed with how various projects weave together and benefit from one another even between sub-programs. Kudos to the team.

D. Communication and Stakeholder Engagement

This portfolio was rated **3.00** for the degree to which it demonstrates integration of stakeholder input and effective communication of project information.

- As stated in the last section, everyone from industry groups to public sector to NGOs and utilities are at the table. So yes, the sub-program does integrate input from the proper set of stakeholders.

- One of the best things about this sub-program is the plethora of opportunities to jump on a webinar, provide candid feedback, reach out to the labs, test the tools, get involved in the development of the tools, etc. In the past, it has been difficult to connect with such new programs, but in the last few years, it has been very easy.
- Absolutely, sub-program accomplishments and results are communicated in the proper venues and in a timely fashion. From newsletters, partner announcements, and the structure of recognizing partner organizations, there is constant communication and those participating instantly know when success happens.
- The sub-program is engaging with a variety of stakeholders including public government, utilities, commercial organizations providing energy performance services, and international collaboration such as the Investor Confidence Project, along with a variety of emerging developers in the software sector. A potential stakeholder that is missing from this group could be building occupants and users. However, at the present, most users of buildings will not have the level of data requirements being offered from these types of programs. Those who are developing products and services for them, however, are a part of the stakeholder group.
- The program timelines are reasonably clear. The outputs of the projects are set out, though they could be presented more clearly when looking across the entire program (i.e., particular output dates where projects might require connections). Project webpages include more specific outcomes and delivery dates. For those programs that are emerging, such as the unstructured data project and brick scheme a structured meta-data, these should be setup similar to the others.
- The webpages of all programs that are in operation are generally clear and provide good communication on updates as they evolve. For those programs that are being developed, it is anticipated that those would have the same level of care and communication output.
- The sub-program integrates input from the proper set of stakeholders for work developed to date, focused on energy audits of existing buildings, and sharing building data at a macro-level.
- For future development, it is recommended that further input be sought from HVAC manufacturers, building energy simulation developers, and the commissioning industry.
- The website includes fairly robust information about its projects, activities, and plans. However, I don't think this information is nearly as widely disseminated as it could be. Finding more opportunities to reference this from commonly accessed sites (such as Energy Star Portfolio Manager) would be helpful.
- I don't have sufficient information to comment on if sub-program accomplishments and results are communicated in the proper venues and in a timely fashion.
- Yes, the stakeholder engagement and communication seem adequate.
- I think the plan to communicate accomplishments and lessons could be strengthened.
- The BED portfolio acknowledges the large variety of public and private stakeholders and works to continually identify relevant parties. It has piloted different projects with a variety of stakeholders, allowing for those different perspectives to shape the program.
- Communication and data sharing appear to be sufficient and timely.
- We believe that DOE has done a good job of listening to input from cities with benchmarking policies but has not done enough to push forward an agenda that expands the concepts of what this program could provide to the cities if private information technology developers were enticed to participate more actively in this space.

- I just don't find that the identified stakeholders are active participants (a la Building America) versus folks who have agreed that the results would be useful if obtained quickly.
- None of the words "Communications," "Engagement," or "Outreach" are used in the presentation. Does that reflect the importance of communications and stakeholder engagement to this sub-program?
- I believe the Building Data sub-program is on track to continue expanding its scientific and political influence. This sub-program should aim to maintain universality and ease of adoption. So far, it seems that stakeholder engagement is going well, and slowly but surely, more programs are hitching to the relevant data platforms. Although, internally, my home organization adoptions seem slow, it is encouraging to see tools being implemented in several large municipalities.
- I think the biggest opportunity moving forward is to branch out beyond the sort of typical group of early adopters. If the sub-program can sell the value proposition to one or two cities/states that are not typically seen as players in the energy efficiency space, then we'll start to have a platform for much broader adoption.

E. Metrics

This portfolio was rated **2.75** for the degree to which it has identified appropriate metrics against which its performance will be measured.

- It was impressive to see the tracked metrics in terms of unique logins to the tools, number of schema mapped, and number of buildings scored with Asset Score. These are great indicators and there have been upward trends in nearly all areas. It was impressive.
- Yes, the upward trends were promising. It would have been nice to have a bit more robust set of targets and scenarios of high/medium/low goal scenarios.
- In the presentation of the program, it was not entirely clear what the progress and impact metrics were. For some, such as the BPD, the metrics were associated with the number of users and the number of contributors to the platform. Another was the API licenses developed using the BPD. Other examples might be the SEED platform, which shows connections with existing programs such as Asset Score and Salesforce links, such as the San Francisco project. It is not clear, however, how many users (i.e., system developers) of BEDES there are. As platforms, SEED and BPD have impressive numbers of data points, but it is not clear how these have continued to develop overtime. More clearly setting out the goals of project performance would be particularly helpful for schema and translational projects like Building Sync. This would help understand the take up of these project outputs.
- As a result, it is somewhat hard to evaluate all the projects in terms of their performance across the chosen metrics. However, it is very clear that those projects that have a strong user base, such as the BEDES and BuildingSync, along with the SEED and BPD platform, and the upcoming Energy Data Vault project, are performing well in terms of collaborators and users. At this point, these give a good degree of confidence that the projects are useful and are being used.
- Number of organizations adopting tools is a good starting point for a metric (e.g., 30 organizations have adopted BEDES). However, it would be helpful to have metrics that further determine the degree to which this has achieved the goals of standardization and interoperability of building energy data.
- The adoption metrics provided for evaluating BuildingSync do a better job identifying the degree to which the goals of standardization and interoperability of building energy data affect market transformation and show this tool works well relevant to the metrics. Multiple workflows using BuildingSync have been identified and many of these workflows currently affect, or have the ability to affect, a large number of building users (e.g., FEMP CTS, SEED Platform, Audit Template Tool, LL87, etc.).

- Yes, the impact tracking methods are good.
- Metrics include rate/level of adoption and incorporation of tools into programs and policies. The broad number and type of stakeholders, from local governments to industry partners to standards organizations, provides many opportunities for adoption of BED portfolio outputs. However, communication is key in tracking that growth and identifying areas that need to be improved. So far though, that appears to be going well. The number of partnerships and adoption appear to be increasing, and time saved by implementation of BED tools is quantifiable (if anecdotal).
- It was unclear from the presentation slides what metrics are being used to quantify success and progress.
- The term metrics is used only as a sub-program goal. No metrics were found except things like users (without reference to potential market size). Therefore, I can’t evaluate it on this yardstick.
- I haven’t seen documentation of the “hard” metrics being used to assess progress. Qualitatively, I would agree that progress is being made and as a practitioner, I am just beginning to see the fruits of this work in some of the projects I work with. However, I think the Building Data sub-program would be well served to develop some specific metrics (square footage entered into various tools, cumulative “size” of programs leveraging SEED, etc.) that they can begin to track. Even if it takes a few iterations and some trial and error to find meaningful metrics, it would be good to start thinking about and tracking this progress in a more specific way.

F. Additional Comments and Recommendations

1. Project Strengths

- The sub-program's biggest strength is that it has developed a market almost from scratch and has been effective. Also, the cohesion of all aspects of the efforts across labs and finding the right expertise at each lab to meet the unique challenges of the market is fantastic. The sub-program has recognized the root cause of industry challenges, and this has been a fundamental catalyst to meeting those challenges. Often, in the public sector, there is a narrow focus on proximate strategies to saving energy. The vision and forethought embedded into each effort of this sub-program is its strength and more programs at DOE offices could learn from this.
- The program strengths include a thoughtful approach to a major problem that faces all building performance analysts and investors, which is the lack of a strong data foundation. The program addresses this by seeking to build tools that provide translation between existing products, BEDES, secure environments for data testing and analysis, and Energy Data Vault, with resources that offer comparison and exchange of activities.
- The sub-program projects also explore new and emerging areas in this field. An example is the unstructured data, as well as the building identification project. These are challenges that will only be addressed by being proactive in their use.
- The method for identifying the unique Building ID consistently and automatically generating UBIDs was an important start to allow standardization and interoperability.
- The sub-program started by leveraging data and developing Data Dictionary terms for DOE data already available (i.e., the Energy Star Portfolio Manager), and then focused on standardization and interoperability for the existing building energy audit process. This was an important starting point and has the greatest potential for market transformation. The sub-program appears to focus on incremental steps to leverage building energy data, and then builds on those based on stakeholder feedback. This leads to robust tools which can be used by an increasingly broad set of stakeholders.
- The BuildingSync tool paired with the Energy Asset score and Audit templates appears to be the best development by the sub-program to date.

- The Building Performance Database also appears to be a very useful tool (though it doesn't seem to have been marketed adequately to date).
- The strengths of the sub-program are in identifying a strong and appropriate niche for federal government tool provision amidst the private sector offers.
- It is also a thoroughly researched program that sets appropriate measurable goals and fills an identified need.
- DOE and the national labs already have a track record for creating effective tools for building energy analysis (e.g., ResStock, CommStock, EnergyPlus, DOE-2/eQUEST), which lends credibility and expertise to its current focus on standardization and quality as part of the BED portfolio. It can leverage its wide variety of long-term partnerships to ensure that stakeholders are represented in whatever tools, processes, or standards are developed. Because the BED portfolio is relevant across BTO programs (residential buildings, commercial buildings, and emerging technologies), consistency and transparency have that much more effect.
- Project strengths include the initial vision of introducing consistent standards and tools, plus the national lab capacity to initiate work in both areas. The private market was not taking care of this on its own.
- The sub-program also clearly has a broad array of priorities and numerous new projects. The disparate types of topics staff are trying to impact could end up being a weakness for the program overall.
- This is a very strong exercise in the interconnection of disparate data sets.
- This is a very strong, experienced team that will produce.
- The goal of making it possible for users to seamlessly access and use all this data is noble.
- Municipalities with benchmarking requirements (and/or incentives) would potentially consider this project's results.
- This program is doing extremely well at establishing one set of data definitions and a consistent platform for the use of that data. Also, integrating this work with the other tools/software of other sub-programs is impressive and appreciated. It's easy to envision a near future where data flows relatively easily from disclosure information to audit to asset score to even an energy model if needed.

2. Project Weaknesses

- There are no glaring weaknesses, but the accessibility of the tools and solutions were mentioned previously. One aspect is having executable tools (which seems like they are on the horizon), and the other aspect is how to widely deploy the solutions. Since this is cutting edge research, it is often challenging to invest in the current state of a solution when it's likely to change rapidly and private sector dependence on the DOE and labs is almost obligatory. Perhaps more thought can go into solving this challenge to lower the adoption risk and first mover 'disadvantage' when working with novel programs.
- The sub-program weaknesses fall into two categories. The first is how long-term performance of these projects could be evaluated. This seems to be a fairly straightforward fix, which is to set out a clear vision with project planning timelines. I suspect these probably do exist, but it could help inform the user community and audience by presenting them.
- Another area of potential weakness in the program is the focus on building occupants and users. From a data standards and management perspective, the ability to monitor and describe this category of building performance is particularly challenging. I would welcome the DOE's efforts in attempting to better create standards, guides, and innovative approaches to describing real world activities and behaviors.

- It’s unclear the extent to which the BEDES Data dictionary and Haystack have been marketed to/extended to the building industry, particularly for organizations that work significantly with building data. It would be helpful to more broadly focus on buildings from design through construction (see details in the Barriers response above for more thorough recommendations on this issue).
- No comment.
- Identifying issues with the sub-program will partly depend on fostering broad adoption to the BED portfolio. Most importantly, BTO will need to effectively adapt to user issues and ensure that tools and program outputs are well-documented and usable to maintain relevance.
- Once the initial standards and tools were developed, there was not enough focus on moving utilization to the private market. Instead, there was inertia to keep development inside the program.
- There does not seem to have been adequate advance work to see what potential customers, particularly in the private sector, would value from the effort. Like many other programs, it really needs early and ongoing contributions from an outside stakeholder advisory group.
- It's not clear that enough thought has gone into considering what privacy protections need to be baked in early to protect those who would apply this information by integrating it with proprietary data (e.g., local tax assessments).
- There could possibly be a more aggressive position toward achieving adoption of these standards, particularly in regions that are not as progressive in their adoption of "energy efficiency" as a worthwhile goal in and of itself. As an industry, we need to be better at communicating broader value propositions (e.g., resilience, flexible grid resources, etc.) and this sub-program is clearly in a position to affect that effort. Having standardized data sets and intercommunication between tools will allow for better management of many municipal and utility resources beyond just energy.

3. Recommendations

- See previous question for recommendations.
- In terms of recommendations going forward, focusing on the new and emerging unstructured data is very important. Presenting work on these emerging projects as soon as there are sensible outputs to share would be very helpful. There is a lot of interest in new areas of building data collection and many potential dead ends and risks. Helping to inform the user base and audience of these as they emerge, and to seek their feedback, would be particularly useful.
- One of the biggest barriers in the building industry is the disconnect between building design and building operations. There are case studies with Measurement and Verification that confirm that Integrative Energy Design with building energy simulation informing the design process leads to higher performing buildings in operation. However, this energy simulation process is extremely time-consuming and often includes manual re-entry of data multiple times for varying purposes (e.g., local code compliance, government incentive programs, etc.). Furthermore, basic information informing the energy model, such as default receptacle loads, default schedules, etc., have not changed in 40 years and would greatly benefit if informed by measured data from buildings.
- The data standardization and interoperability that is being developed has many commonalities between measured and modeled information. Expanding the program to provide continuity of data from building design through operations would significantly increase the quality and quantity of data available and would increase the capability to manage building energy performance.

- The new construction process for high performance buildings includes iterative energy modeling to inform the design process, a basis of design and design intent document to inform the design process, a CD-phase model to confirm predicted energy performance versus a baseline, the development of a Current Facilities Requirement (CFR) document and Sequences of Operation during building Commissioning, and functional testing during commissioning to confirm the building performs as designed. Much of the information in these analysis and documents is the same information as is defined in the BEDES and Haystack data dictionaries. Intentionally expanding the sub-program to assure interoperability from design through building operations would significantly increase the value of the available data and would allow better transfer of relevant building information from the design professionals to the building operators.

- For example, BuildingSync and SEED could be expanded to receive information from the energy model to populate standardized forms used to demonstrate energy code compliance, to populate the CFR document, to pre-populate information associated with an ASHRAE Level 2 audit based on the equipment present during commissioning, to link to standard commissioning tests provided by a third party, etc.

- Assuming the data could be appropriately privatized and aggregated, this data could also be used to help identify the efficiency measures and control strategies incorporated during design that lead to the highest energy savings in various building types and locations, and the efficiency measures that lead to the greatest persistence of energy savings. Furthermore, data from building operations could be aggregated to provide better inputs to the energy models (e.g., default operating schedules, default receptacle and miscellaneous loads and schedules, etc.).

- I recommend an extensive training and outreach program to push for standard use and adoption.

- As mentioned before, investigate how BTO can work with EIA to leverage its expertise and statutory data protection (i.e., CIPSEA) and dissemination roles.

- Start immediately looking for ways to promote this work to private industry and move management of data standards outside of DOE itself. If the standards and tools remain within DOE program structure, they will become obsolete and not useful for new market purposes.

- Prepare review presentations more thoughtfully, considering what the reviewers need to understand and what their own interests in this work might be.

- Bring in outside advisors to guide the program to be useful. Advisors should include outside data architects (Google?) but also include potential users.

- I think the primary weakness is in outreach to ensure that various entities and programs leverage the efforts of the Building Data sub-program so that they can easily take advantage of other DOE tools and initiatives as they gain the skills and knowledge. For those "in the know," these data efforts are indispensable, but there are gaps in the outreach and education to ensure broader adoption of common data standards across building energy programs and initiatives.

BTO Portfolio-Level Activities

Building Energy Modeling

Portfolio Review: Building Energy Modeling

Presenter: Amir Roth, U.S. Department of Energy

Brief Summary of Reviewer Comments

Overall, reviewers agreed that the sub-program is successfully addressing an array of barriers and technical challenges. Reviewers generally agreed that the challenges identified are appropriate for the Federal government to address and, as one reviewer pointed out, there are numerous precedents for Federal government involvement in user interfaces and tools, as evidenced by the EPA ENERGY STAR Portfolio Manager (ESPM).

Reviewers also suggested additional barriers that the sub-program should be addressing. It was recommended that BTO also focus on improving BEM's value proposition for the design teams themselves and greater clarity may be needed on explicitly defining the long-term role of each "tool" in the ecosystem. Furthermore, reviewers suggested that the sub-program also address the lack of local authority awareness of how to specify appropriate BEM tools and their ability to review the results.

In general, reviewers agreed that this sub-program is contributing to advancing the state of the art and clearly supports BTO's energy saving goals. Some reviewers expressed concerns that it may hamper current industry operations due to industry lagging behind in state-of-the-art practice adoption - there is disappointment in the non-vendor community with this shift. Additionally, one reviewer noted that vendors and end-users (energy modelers) can easily commit errors when entering the complex inputs for EnergyPlus/OpenStudio. Reviewers stated that the sub-program does contribute to BTO's energy savings goals by providing quality tools for modeling energy savings, but some reviewers expressed that this relationship is not thoroughly quantified.

Multiple reviewers suggested filling the industry gap in the meantime with tools that are simpler and faster than EnergyPlus/Modelica that make BEM more accessible to the general public. Another reviewer suggested that education programs and updated information repositories and certifications can help mitigate the gap by providing guidance and assurances to stakeholders and industry. As identified in the report, a shortage of trained energy modelers is another bottleneck that could be addressed through DOE projects.

With regards to collaboration, coordination, and integration, reviewers agreed that the sub-program is well integrated and cohesive internally and well-positioned in relation to and well-coordinated with relevant public and private sector organizations. Reviewers praised 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 (e.g., codes, HVAC, etc.). The sub-program includes a wide portfolio of fundamental and ubiquitous tools and some reviewers found it difficult to keep track of the tools within the program.

Reviewers specifically mentioned BTO's continued engagement with IBPSA-USA and ASHRAE as most beneficial. DOE has provided support for projects like IBPSA-USA's Project StaSIO, which aims to raise awareness of ASHRAE 209 and provide good visual examples of data presentation to allow more conversations around BEM, its uses, and the specific questions it can answer. Reviewers generally agreed that initiatives are coordinated well with other public and private organizations such as AIA, gbXML.org, USGBC, and other NGOs, as well as tool vendors and equipment manufacturers.

Reviewers commented positively on the sub-program's communication and stakeholder engagement, agreeing that the sub-program actively integrates feedback from key stakeholders into the determination of barriers and initiatives to address them. These feedback loops are well-appreciated by the industry. Most reviewers also agreed that the sub-program disseminates information in a timely manner and quickly responds to user feedback and issues with new releases.

Reviewers appreciated the sub-program's efforts to provide information at relevant events. Sub-program efforts are often presented at conferences and this is very helpful for non-lab folks to know more about what is going on. BTO actively participates and engages in BEM industry events such as SimBuild and California's Software Symposium. Updates are also available at other venues such as IBPSA meetings, IES meetings, etc.

Reviewers generally agreed that the sub-program is performing well according to its chosen metrics, but most reviewers had suggestions for additional metrics that the sub-program should be tracking. Metrics could look at how DOE is supporting industry initiatives beyond the software it provides and how that support allows new users of BEM to emerge. Another metric to be considered could be the actual cost of BEM per project (e.g., BEM cost per square foot or BEM cost per total project cost). Reviewers also suggested metrics such as number of licenses sold, number of simulations run (for an online license), and number of software users.

Reviewers also provided feedback for some of the sub-program's current metrics. One metric identified the percentage of new construction projects with energy models as reported in the AIA database (as well as type of software used). This is a good source of data that identifies buildings that have been modeled, but it doesn't necessarily show a true cross-section of commercial new construction in the US. Other reviewers commented that tracking the number of people downloading certain software doesn't necessarily capture the impact of the program.

Weighted Average: 3.49   # of Reviewers: 10
Scope: 3.70   Impact: 3.40   Collaboration, Coordination, and Integration: 3.40   Communication and Stakeholder Engagement: 3.60   Metrics: 3.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning as appropriate.

A. Scope

This portfolio was rated **3.70** for the degree to which the scope identifies and targets key barriers and technical challenges that are appropriate for the Federal Government to address.

- The presentation and draft "Roadmap" do a good job of clearly identifying target areas and their respective barriers and initiatives. The 6 overall topics extensively cover barriers and technical challenges that the industry is currently facing. I found the table in the Executive Summary to be extremely useful to quickly understand the big picture. Overall, it seems to cover just about everything that I can think of. One area that could use more attention is quantifying carbon through BEM. (I did see this listed once in the stakeholder feedback section.) Currently, there is a lot of interest specifically in zero carbon buildings, as opposed to zero energy. In the coming years, I think there will be a demand to quantify carbon at a level much more detailed than the standard flat conversions for electricity and gas. The document does note: "BEM tools are missing advanced capabilities in areas such as occupant behavior modeling, urban-scale modeling, and grid modeling." and "Develop standard methods for deriving future weather data from current climate and weather projection models." If projects are already considering urban-scale, grid modeling, and future looking weather, it seems a natural fit to add carbon to the research list as well.

- There are numerous precedents for the federal government involvement in user interfaces and tools, as evidenced by the EPA ENERGY STAR Portfolio Manager (ESPM). This is a shining example of a clear need and response by the federal government to spur action in the private sector through the use of public funding. It has resulted in billions of square feet of gross floor area to be captured and has provided benefit to all sectors. Similarly, the DOE BTO, now more than ever, has the responsibility to continue this work into the BEM space. In a complex world of energy efficiency, and federal, state and local goals, BEM is at the crux of the decision-making process to proceed with energy savings activity with a quantified risk. In the absence of a free and open source tool such as an audit interface analogous to ESPM, it will challenge the BTO to think hard about how to satisfy the market, despite a small group of disgruntled market actors stifling the market and depriving young and/or disadvantaged populations to have fair and equitable access to tools derived from federal funding. As such, the BEM portfolio has recognized these challenges and has made great strides in providing multiple pathways to addressing these critical needs.

- Through core projects, competitive projects and support, the sub-program is addressing an array of challenges. They address both the physics-based energy modeling challenges, and the logistic challenges in a market that is inevitably consolidating the supply and demand side of energy. Expanded analysis for MPCs via Spawn and Modelica tremendously help as well as macro scale challenges in urban analysis.

- The program seems to have hit most all barriers known at this time.

- The barriers and technical challenges identified by the sub-program are real and significant:

  - BEM is not used sufficiently as a tool to inform the design process due to the cost of energy modeling, the time-intensive requirements for BEM (BEM is not able to keep pace with schematic design and early design development timelines), and insufficient data proving the contribution of BEM to high-performance buildings.

  - Predictive accuracy of BEM is misunderstood, leading to misconceptions that the use of BEM is not informative to the building design and construction process.

  - BEM is not able to model occupant behavior modeling, urban-scale modeling, and grid modeling

  - EnergyPlus/OpenStudio BEM is slow (note that other BEM engines are not as slow, so the barrier should be made more specific to EnergyPlus/OpenStudio).

    - BEM engines are not well integrated with design and operation tools, leading to manual effort for inputting data.
    - Modeling of code baseline is not consistently automated.
    - DOE Data for CBECs and RECs is insufficient to support benchmarking of end-uses
    - Detailed equipment performance data used in simulation tools is outdated.
- The following barriers are effectively addressed either by the current portfolio, or by the initiatives identified:
    - Value proposition - Develop and document compelling evidence that use of BEM for design and operation leads to robust energy savings. Document the costs associated with BEM. Develop case studies highlighting the value of BEM. Leverage reporting programs to track use of BEM.
    - Core Modeling capabilities (Note: With the exception of speeding up the engine, I think a lot of the emphasis should be placed on other initiatives that will increase the usability of energy modeling to inform the design process, and limit user-input errors.)
    - Data Ecosystem – The initiatives identified are good. However, I would recommend even more of a focus on the design-through-construction workflow, and further leverage/augment BTO data projects for energy modeling, commissioning – including verification of design efficiency measures, standardized building information documents that can be passed from designers to the building operators, etc. Note that I would recommend leveraging the data available to support the value proposition as noted below.
    - Process standardization – The initiatives identified are good, particularly online resources. However, process standardization will have limited impact until some of the other initiatives are addressed.
- The following barriers are addressed by the portfolio (either in past development or future initiatives). However, the priorities for addressing them might be better if re-prioritized:
    - Barrier – Predictive accuracy: Supporting empirical validation of BEM using test facilities is unlikely to have a significant impact on the predictive accuracy of the models. The biggest issues affecting predictive accuracy are related to:
        - Inadequate details for building occupancy, building schedules, “unregulated” energy usage pre-design.
        - Inadequate data linking predicted modeled site energy/source energy/cost/GHG savings versus benchmarked performance on a macro-scale.
        - User errors made by energy modelers and inadequate QA checks by energy modelers.
        - Initiatives that focus on the following could significantly improve predictive accuracy:
            - Provide monitoring studies (or reference existing monitoring studies that have been done in utility incentive programs, etc.) to update the default ASHRAE 90.1 schedules and equipment loads (not updated since 1989) and expand the schedules to be specific per space function (not just building function). For receptacle loads in offices/schools, provide more than one option for defaults.
                - Data research study at a macro level that links percent better than ASHRAE 90.1 or other energy standards such as Title-24, Seattle Energy Code (using any metrics available – site EUI, source EUI, cost, GHG emissions) versus

        benchmarked energy performance. The hypothesis for the study would be that relative savings predicted track with benchmarked performance.

        - Develop a tool that receives exported data from the energy model (using BEDES Data dictionary terms), auto-processes the results, and helps the modeler perform QA on the model (note: this would also be a good way to provide standardized inputs in a trackable data format, which can be used for other uses as well).

    - Barrier – Workflow Integration/Task Automation

        - Promoting the use of OpenStudio Measures and other frameworks for task and workflow automation is the best initiative identified for addressing this. Actual development of measures by DOE focusing on the most time-consuming and/or repetitive labor tasks reported by end-users would be a good way to promote its use.

        - Working with design authoring tool vendors to improve consistency, robustness, and analyzability of design model exports is a good focus. However, actually developing a data framework for these exports, and automating the checks would further improve this effort.

        - Promoting certification for automated BEM tasks is an important initiative, and the role the Energy Modeling Portfolio takes in this will play a significant role in whether this succeeds. Note that certification should also be for modeling the most common baseline HVAC system types and controls.

- Does the sub-program ignore any significant barriers? - Yes, "Limited market usage of EnergyPlus/OpenStudio" barrier. The majority of energy models in the U.S. are conducted using either Trace 700 or eQUEST. Trace 700 tends to be used by HVAC engineers who are familiar with the interface and output format for loads calculations, and who use the energy model for both energy simulation and loads analysis. eQUEST tends to be used by energy modelers, most of whom are not directly responsible for the HVAC Design. It is selected because it is freely available to users, includes an intuitive Graphical user interface with a fully searchable help function, facilitates quick modeling through the wizard interface during schematic design, parametric run functions which can be used for detailed design, and interchangeable txt file which can be used interchangeably with the GUI.

- The barriers and technical challenges identified by the program are real and significant. It is appropriate for the government to work to address these challenges. But it should always do so in close collaboration with relevant public and private stakeholders and channel partners to maximize impact and effectiveness.

- The barriers and challenges are being addressed by the portfolio through the very large number of highly useful initiatives being undertaken.

- Yes, the technical challenges identified are significant and appropriate for the federal government to address.

- BTO's investments to quantify the value proposition of BEM to building owners is well-appreciated because it empowers them to demand a more sophisticated approach to building design. However, in addition to this, it is suggested that BTO also focus on improving BEM's value proposition for the design teams themselves. Project Managers are primary advocates who facilitate the use of BEM on design projects. Therefore, it is suggested that this sub-program continue to address challenges that preclude modelers from simultaneously being accurate, nimble, and consistent; thus developing them into assets for Project Managers.

- Does the project portfolio address identified barriers and technical challenges? - Yes, it does. However, greater clarity may be needed on explicitly defining the long-term role of each "tool" in the ecosystem. A clear distinction is needed between data formats; simulation engines; software development platforms; and applications; and their respective short-, medium- and long-term plans.

- Does the sub-program ignore any significant barriers? - There is a fundamental change underway in nature of analyses that are performed to inform design. Going forward, trends indicate that we will see many more data-driven, web-focused, inter-disciplinary studies and stochastic analyses. The data infrastructure to support this data exchange does not currently exist (outside of the BTO projects, such as BEDES, etc.). With a proliferation of custom data schemas, file formats, etc. an IOT-like situation resulting in a reactionary data exchange protocol may become the need of the hour for BEM users. This may be a research area for BTO to support - beginning with data translation from BIM. This is key to achieving true process automation for our industry.

- Sub program addresses barriers of the limitation of current market for BEM tools. However, it may create barriers to more widespread adoption in the current market due to move to more complexity (with Modelica).

- As the DOE is focused on creating a leading simulation engine relying on third parties to create usability, the DOE must support vendors who are making BEM easy to access whether that is to EnergyPlus directly or via interoperability. Perhaps the support could come in the form of a list of qualified tools (similar to the 179D Qualified Software list) but just for tools that pass certain standards (new ASHRAE 140-1) and maybe a subset of those tools that meet further requirements. This promotes BEM from the DOE directly, having this list provided by any other organization, private or non-profit, would undermine the credibility of the list.

- Another barrier is a lack of local authority awareness of how to specify appropriate BEM tools and their ability to review the results. Perhaps, if a list like the one described above existed then local authorities could look to reference that, or the subset of tools that meet the requirements for ASHRAE 90.1 Appendix G 2.2, for example. Also a standard form of results reporting (such as EN1 for NY) could be used to allow assessors to only review one type/format of report from all modelling software.

- Debunking a barrier: Example barrier given for automated workflows, automation of the generation of 90.1 PRM baseline models (geometry/HVAC/efficiencies), was not a barrier for EDSL, as these tasks have been automated in our software. What we would like guidance on is if the automated models comply with the intended interpretation of the rules.

- Effort Barrier: Main barrier, once BEM has become part of the discussion, is the effort needed to use BEM. The scope for EDSL is to reduce the effort needed to use BEM in a robust and efficient manner. EDSL focuses on providing a solution that simplifies the process for using BEM day-to-day for 99% of projects while maintaining a link to the EnergyPlus through IDF so users can still leverage the state-of-the-art in building simulation software when that extra level of complexity is needed, for example from the future capabilities that Modelica will provide.

- Two most important topics: Lots of the targeted focus areas intersect; value, predictive accuracy, and education being three main ones that intersect heavily. The most important focus areas are education and value, as without those the rest never become important, though some value may be derived from predictive accuracy and having the DOE publish a list of tools that meet certain qualifications/approval processes.

- 7 most important barriers:

    - 1) Topic 1, Table III-1: Value - Clients (usually) invest in BEM (only) when it is mandatory. Performance Attribution (B.) and Communication (C.)

    - 2) Topic 6, Education, Table VIII-1: Standards and Credentials (A.) for BEM - ASHRAE Standard 209 is not widely referenced or required. Education (D.) - Few architectural or engineering programs offer BEM.

        - EDSL has made Tas software free for academic and research purposes and has also made a free to all noodle video-based online training course so that students have the training material available when they need it to support education and research. The Tas two-way link to EnergyPlus allows faculty to teach either EnergyPlus or Tas and transition seamlessly to the other tool.

    - 3) Topic 4, Table VI-2. Workflow Automation - Geometry translation (A.) - Engines are not well integrated with design and operation tools resulting in unnecessary manual effort to transfer data.

        - EDSL has put significant effort into healing gbXML import and providing merge features for updated gbXML models.

        - DOE could create a BEM gbXML schema that mandates for high fidelity geometry models with the data needed for BEM work (Revit too much detail; Rhino too little detail).

    - 4) Topic 4, Table VI-2. Workflow Automation - BEM input interoperability (B.)

        - EDSL has also put effort into BEM-2-BEM data transfer, particularly using IDF with EnergyPlus to support a point-to-point data exchange. The EnergyPlus data exchange should allow users to perform analysis in Tas and, from time to time, when the level of detail Modelica provides is needed there would be a way for users to connect the data entered in Tas into the SPAWN (EnergyPlus/Modelica) workflow. The barrier for general input information will increase with the move to Modelica.

    - 5) Topic 4, Table VI-2. Workflow Automation - BEM output interoperabilty (C.)

        - Would benefit from a standard report form, such as the EN1 form used for NY that could be accepted as an output from all modelling software for submission to local authorities

- No technical reason for barrier: Topic 4, Table VI-2. - Baseline generation automation (D.)

    - Workflow automation - mechanical modelling tasks such as generation of the code-baseline model from model of proposed are not automated.

        - EDSL has chosen to automate the 90.1 PRM (appendix G.) baseline model (geometry and HVAC) due to demand (LEED/Code). EDSL can make these tools for users and allows users to make their own tools in vb.net/vba/c# using the automation interface to script their own tools. I believe BTO has the same options with the OpenStudio Measures and the OpenStudio SDK.

- Reasons for problem:

    - Knowledge of OpenStudio SKD among EnergyPlus vendors

    - Knowledge of ASHRAE 90.1 and all sub rules

        - Vendors may not be able to recreate the rules imposed by ASHRAE 90.1 automatically

        - Train the EnergyPlus vendors in the use of the OpenStudio SDK

- 17 most important Initiatives:

    - Topic 1. Value (TableIII-1) Initiatives 1. 4. 5. 6. 8. 9. & 10. Develop and document compelling evidence that use of BEM for design and operation leads to robust energy savings. Document the costs associated with BEM.

- See EDSL case study - post occupancy performance modelling case study: One New Change example (https://www.edsltas.com/technical-briefings/#onc). This case study is also applicable for Topic 2. Predictive Accuracy (TableIV-1), Initiative 5.) I will be glad to provide more details about the post-occupancy performance case study.
- Regarding BEM guides in Communication, initiative 10. The RMI "BEM for Owners and Managers" guide needs updating before promotion (old EERE Energy Tools directory website still listed and older tools are listed in table 3, leaving out newer tools.)

- New suggestion: Create and promote a list of qualified/approved (140-1) tools (replacement/in-addition to 179D Qualified Software list), requiring tools to submit their results and model files and to have those results and model files easily accessible online in standard compressed file formats(.zip, for example).
  - Also, create a subset list of the 'approved/qualified tools list' for tools that meet further proposed certifications (90.1 PRM baseline models) to allow local authorities to reference the tool list when specifying new code requirements using BEM. It must be an EERE/DOE website for credibility.
  - EDSL would participate in certification for automated PRM baseline model generation if such a website was created, providing credibility to the validation/approval and certification process.
- Topic 2. Predictive accuracy (TableIV-1) Initiative 1. & 2. Support empirical validation of BEM engines.
  - See above.
- Promote certification for automated BEM tasks such as baseline model generation.
  - Topic 4. Workflow Automation (TableVI-2) initiative 7. BUT code minimum is NOT sufficient to meet DOE energy reduction goals - should at least be appendix G PRM baseline models. See above also.
- Education Initiatives (TableVIII-1) 1. 2. 3. 5. 6. & 7. Promote ASHRAE 209, encourage academic use of BEM.
  - DOE could outline curriculum for BEM use, teaching certain Energy Efficiency Measure's (EEM's) that could be incorporated into vendor software training curricula.

- I think the overall program is focused in the right place, driving the technology "under the hood" to be picked up out in the market. The current projects are generally well-aligned with market trends (e.g., moving towards a controls focus and increased automation).
- Yes, the barriers and technical challenges mentioned are real, significant, and appropriate for the government to address. The project portfolio addresses many identified barriers, and some technical challenges. The sub-program does not ignore significant barriers, although the ones identified are substantial.
- The BTO focused roadmap is an excellent idea and appropriate strategic shift. DOE has a major role to play in the development of energy modeling as a critical technology for improving energy efficiency of buildings – both new and existing ones. In recent years, the energy modeling technology significantly advanced in a large part due to DOE and Labs' involvement. The technology is still requiring major developments and systemic work of researchers at universities and national labs to create both novel fundamental capabilities and ecosystem to support dissemination of best practices/software.

- The current focus on AIA 2030 commitment is appropriate as architects are both users and customers for energy modeling technology. If this community fully embraces energy modeling as a tool to steer decisions in building design, the rest of the engineering firms and consultants will have easier time in communicating the value of energy modeling results. Therefore, the focus on the architectural community is appropriate and one of the major barriers that can unlock opportunities for other participants in the building energy efficiency marketplace. I think that the existing AIA engagement is excellent, but there could be other opportunities to support dissemination of energy modeling technology in the architectural community. The critical component of any kind of dissemination has to be on accuracy of results, because a large-scale misuse of energy modeling can create trust issues for the energy modeling technology that is still under development.
- Barriers and technical challenges are identified and apparent as part of this portfolio plan. Overall, treating Building Energy Modeling (BEM) like an energy efficiency measure – as is proposed by the mission statement and the quantitative goals – is a great idea. This will help to put BEM on the same playing field as other reputable energy measures, such as high-efficiency HVAC and lighting equipment. This direction will help overcome a major barrier currently in the market: the value proposition. Many design firms are reluctant to invest in tools and processes that encourage the use of BEM because they are not certain that doing so will result in more profit, better design, or better buildings. The portfolio mission statement is set up to address and champion this issue, by highlighting the value proposition as a foundational element. This type of overall focus, taken by the DOE, will help to bolster other BEM initiatives happening nationally.
- At a deeper level, the portfolio's metrics seem to be focused on building square footage of projects using BEM tools, in particular in the new construction arena. For example, moving GSF of BEM for new construction from 47% to 70%. I think this is a helpful metric. My suggestion would be to consider additional types of metrics that are more broadly inclusive of a national constituency. The quantitative goals currently could, in theory, all be met by ensuring the few biggest firms use BEM (such as Gensler, AECOM, etc.), thereby leaving many of the smaller firms, and some software vendors/developers, out of the discussion. Some metrics that come to mind are: number of design firms using BEM tools, average savings per square foot by using BEM, and RMSE and CV (RMSE) for assessing accuracy of energy models (to support efficiency persistence).

B. Impact

Assuming that the ***portfolio-specific goals*** are met, this portfolio was rated **3.40** for the degree to which the portfolio is ***expected to*** contribute to ***program and BTO goal(s)***.

- I understand that your goal is to serve vendors, not end users, and that you are continuing to transition GUI-type work to 3rd party. However, your offerings have been supporting end users for some time and we have grown accustomed to it. I don’t think there’s really a solution here that satisfies everyone, but I just want to note that there is disappointment in the non-vendor community with this shift.
- The subprogram clearly supports BTO’s energy saving goals by increasing “the use and effectiveness of BEM in the design and operation of commercial and residential buildings with the goal of achieving persistent reductions in total and peak energy use.”
- The sub-program is moving at blazing speed and creating the state of the art in ways that were not possible even a few years ago. It has moved to a point, such as in the Standard 140 talk, which was impressive in that we are so confident in the modeling techniques that we are measuring the smallest impacts on the model to place a high confidence and validate the work to date on BEM. That work surely makes us reflect on how far we have come and can help satisfy any laggards in the industry.
- The sub-program has given every effort to be an enabling element in the industry. At this point, the only feedback is to focus on the outreach and awareness aspects of the valuable tools that have been created. More

user support and getting the tools commonplace in the market is needed. More "light bulbs" need to go off for the average user in order to make the sub-program tools as commonplace as ESPM.

- As of now, all stakeholders are represented. When ready (Modelica/Urbanopt/Spawn) could use some specific use cases by local governments, load serving entities, IRP practitioners and regional planning actors.

- Perhaps BEM is the driving force behind the BTO energy savings goals. Without it, goals and targets could not be set, site-level decisions could not be made, and most importantly energy savings cannot reasonably be found or tracked.

- The EnergyPlus/OpenStudio engine enables detailed calculations of interactive building energy systems, with highly accurate results. If the vendor/end-user gets the inputs right, it is probably one of the most accurate tools available. However, the program as designed is both complex and complicated. EnergyPlus/OpenStudio uptake in the market has been slow in spite of a long history of development, suggesting that the program is not as good as it could be based on investments to date.

- The decision to generate an engine, and to depend on independent vendors to use this engine to develop GUI's/energy simulation tools, has probably led to some of the issues. State-of-the art software programs include very close coordination between the developers of the engine and the GUI by software developers. This program has too much of a disconnect between the engine development and the GUI development to reach the "state-of-the-art" level.

- Related to this, it is very easy for the vendors and end-users (energy modelers) to err when entering the complex inputs for EnergyPlus/OpenStudio, and based on the output reporting, it can be much more difficult to identify the cause of the errors in EnergPlus/OpenStudio than in other tools. With that said, the sub-program has been very effective supporting certain functions:

    - Code development: The prototype modeling and efficiency measure analysis for ASHRAE 90.1, California Title-24, Seattle Energy Code, and others has been performed using the EnergyPlus and/or OpenStudio engine.

    - Academic research: Academic research for building efficiency has greatly benefited from these tools.

- The program contributes in meaningful ways to advancing the state of the art. The program effectively supports industry in many ways. To mention a few of the many impactful initiatives:

    - Collaborating with and supporting vendors building tools around the EnergyPlus engine via the OpenStudio Software Development Kit facilitates delivery of advanced, accurate engines to a wider segment of the HVAC design community.

    - Collaborating with tool vendors to add or improve features of EnergyPlus delivers continually increasing value to design engineers.

    - Efforts over the last 10 years to improve speed of EnergyPlus make it feasible to use EnergyPlus for production design and energy modeling applications to improve buildings.

    - The current EnergyPlus "10x" project will also play a critical role in enlarging the application of energy modeling for design. As speed increases it will become possible to evaluate a larger array of design options within tight project schedules to better optimize energy use of buildings. It will also facilitate wider use of parametric studies.

    - The empirical validation initiatives are extremely useful both for validating engines and maybe more importantly for understanding the proper application of the models (such as convection and radiation properties and models) to ensure accurate application results. This allows tool vendors to supply defaults and guidance to engineers to channel them into appropriate use of algorithms and thus to generate meaningful results.

  - Support of gbXML.org work to develop test suites designed to improve the quality of geometry data exported by BIM tools for use in design and BEM tools. If the quality of geometry exports improves, the cost of energy modeling can be drastically reduced due to the reduction in engineer labor to create virtual models of buildings.
  - Support for ASHRAE Standard 205 which will contributes to wider dissemination of HVAC equipment data and therefore more accurate energy modeling results.
  - Development of prototype building models, which aid on conceptual demonstration of the effectiveness of energy conservation measures outside the context of design of specific buildings.

- Yes, the sub-program has been making significant contributions to advancing state-of-the-art. Its research on topics such as GIS-based urban energy modeling, uncertainty quantification, high-resolution climate/weather predictions, and many such projects are extremely significant but financially not viable for the industry to pursue. In most cases, the infrastructure required is exclusively available at the national labs, so these past investments made by the sub-program have proven to be very beneficial.
- Yes, the sub-program effectively supports the industry. BTO's open-source projects are necessary for majority of the industry. They have served the advanced user well, but their future success is contingent on how the imminent internal disruptions to the platform(s) are managed, while also supporting third-party solutions that are currently being developed outside the BTO system.
- Its support for initiatives such as "Unmet Hours" has helped modernize the informal training platforms for novice, intermediate, and advanced users. Also, its contribution to students' travel grants, credentials for modelers, etc. help raise the bar for quality for the entire industry.
- Are there industry stakeholders that are not supported by the project portfolio? - Not currently, but given the increased emphasis on the OS platform and the impending transition of the OS application, it seems like BTO's future strategy may see a shift from its past approach of helping the end-user (utilities' incentive programs, the practitioner, etc.) directly, to helping vendors develop paid applications on top of BTO's BEM infrastructure. Depending on how this evolves in the coming years, it could alienate some end-users who may see this as BTO subsidizing the development of paid tools.
- Does the sub-program effectively contribute to BTO's energy savings goals? - Yes, it certainly does. Most of BEM is either driven by energy code compliance requirements and/or demonstration of beyond-code performance. EnergyPlus plays a vital role in enabling analysts to quantify the energy saved from meeting these requirements. For high-performance buildings especially, it would be almost impossible to analyze certain advanced systems and control sequences necessary to achieve project goals without the use of sophisticated simulation engines such as EnergyPlus and Radiance.
- Sub-program advances state of the art by shifting focus to more granular, external tools in support of deeper analysis. It may hamper current industry operations due to industry lagging behind in state-of-the-art practice adoption. For example, the majority of building analysis will not require the granularity of tools such as Modelica in the near future. When construction processes become more efficient, automated, and data-centric, this shift will help accommodate those changes.
- Tools that are simpler and faster than EnergyPlus/Modelica could fill the gap for the industry in the meantime. Similar to the AutoCAD-to-Revit transition, while the DOE is going from BEM to aerospace-level BEM via Modelica, how does a company not currently doing BEM go straight to aerospace-

level BEM? Productive, robust, fast tools are needed to fill the gap. This is EDSL's focus with Tas - improving productivity while maintaining the same level of accuracy.

- Does Sub-program contribute to BTO's energy saving goals? - It depends on the timeline under discussion. Short term, it may hamper goals due to added complexity of workflows currently in practice, and lengthen simulation times. These drawbacks may lead to a decline in BTO-based BEM tools. Long term, computation speed and performance may compensate and reduce or eliminate the short-term drawbacks. Alternatively, users will adopt the last version of EnergyPlus/OpenStudio before Modelica introduction, leading to a gap between current BTO research and industry adoption.
- Education programs and updated information repositories and certifications can help mitigate the gap by providing guidance and assurances to stakeholders and industry. This will contribute significantly to BTO's energy saving goals without the need for software development.
- From where I sit it is hard to understate the impact of the BEM sub-program. Particularly EnergyPlus and OpenStudio (and several vendor tools that leverage them) have truly transformed how our organization applies BEM to energy efficiency problems. It has also transformed where the BEM market is headed and the effectiveness with which BEM analysis can be incorporated into all sorts of analytical workflows. I think that BEM would literally be largely frozen in time (with a few exceptions) if not for some of these efforts. For many practitioners it is frozen in time, but I think that has more to do with human resistance to progression. The work of the BEM sub-program has made it possible to see how in a few years we could be in a place where day to day BEM is finally much more standardized and therefore trustworthy.
- The sub-program does advance state of the art, although not always in a way that is accessible to practitioners or those without experience in particular programming languages and computer skills.
- The sub-program effectively supports the industry; in my opinion the sub-program provides too much assistance and deference to industry.
- I am not aware of industry stakeholders who are not supported by the project portfolio.
- The sub-program does contribute to BTO's energy savings goals by providing quality tools for modeling energy savings; however, this relationship is not thoroughly quantified. I am not sure this is reasonably possible.
- The program advances state-of-the-art, especially with its transition to Spawn. The opportunity to capture dynamics of building behavior with either DOE software applications or proprietary ones is a nice step forward as it will allow equipment and controls manufacturers to take advantage of E+ capabilities and in a long run would allow development of component-level responses to not only building loads but also the grid loads.
- As identified in the report, a shortage of trained energy modelers is another bottleneck that could be addressed through DOE projects. If universities with required participation of graduate and undergraduate students are given a larger role in the DOE portfolio of projects, DOE would produce not only novel technological breakthroughs, but also workforce ready to fill open positions in building industry, architectural firms, utilities, national laboratories, and universities.
- The sub-program effectively advances the state of the industry. Recognizing that the DOE is one of many actors in the BEM industry – albeit a leading one – in my opinion the outlined program supports two of the most important needs of the BEM industry at a foundational level: value proposition and the continuous development of public domain core simulation capabilities. These two areas appear to be at the right level of impact for the DOE and will help the rest of the energy industry pursue energy savings goals.

- If the DOE wishes to more broadly support the industry, I see opportunity for DOE to lead by investing in tools and standards that make BEM more accessible to the general public – growing the BEST Directory comes to mind as a good example. Also, I have observed a massive need for the development of BEM model specifications templates or a standard. This would be most impactful coming from the national level. In the same way that we have ASHRAE level 1, 2, and 3 audits, model specification templates could be used to describe the minimum BEM inputs and outputs to be necessary to be considered industry standard practice.

C. Collaboration, Coordination, and Integration

This portfolio was rated **3.40** for the degree to which its activities demonstrate strategic collaboration or coordination with relevant programs and partners.

- It was helpful to hear about the mix of the long running core projects and shorter competitive projects – they seemed very well integrated and in line with overall BTO goals. And there is support for other BTO and DOE projects (Asset score, HES, 90.1, etc.). However, lacking an extensive background in the overall DOE structure and current priorities, it's a little bit harder to assess whether the BEM efforts are well coordinated with DOE as a whole. Conference sponsorship is both highly valuable to stakeholders and provides a venue for further coordination with stakeholders.

- Is the sub-program well integrated and cohesive internally? – Yes. With EnergyPlus/Spawn at the center of the sub-program, it is amazing how many other efforts have dependencies on it and have matured to satisfy the market need. From private sector derivatives to SDKs to entire platforms, there is a strong thread and body of knowledge that goes into the sub-program.

- Is the sub-program well-integrated within BTO, EERE, and DOE? – As evidenced by multiple labs using the core programs, there is quite a bit of integration between DOE work, labs on standardization, tools and analysis. As a reviewer for the majority of the Peer Review, is was apparent that BEM is the glue that holds all the efforts together. Aside from some of the GEB work and how some of the labs use RC models, nearly every other project has been involved in, or benefited from BEM.

- Is the sub-program well positioned in relation to and well-coordinated with relevant public and private sector organizations? – It is well positioned and coordinated with other private sector organizations. With is solid positioning, the time is now to capitalize on it and engage more in marketing, education and outreach. Perhaps more accelerators, case competitions and 'hand-holding' can help with scaling up the market share of not only the tool, but percent of building stock modeled. It would be interesting to see more load profile work and "Ikea style" startup resources to help spur the market.

- Does the sub-program effectively utilize channel partners? – This is a tough area for BEM with such a wide portfolio of fundamental and ubiquitous tools to develop channel partners. Nonetheless, see previous comment.

- Are there coordination, integration, and partnership opportunities that the program does leverage? – As mentioned before this sub-program does serve as a bonding agent to many, many other programs as well as across other offices. However, the other offices really need to wake up and adopt the good work coming out of BEM.

- The tools developed within this sub-program have been used extensively within the DOE to support other DOE sub-programs and initiatives (e.g., codes, HVAC, etc.). The Asset Tool program developed with EnergyPlus as the engine is an excellent addition to the Data Portfolio, and has the ability to affect market transformation through informing energy retrofits of existing buildings. The sub-program is also well positioned relative to universities and research organizations relevant to building energy efficiency.

- It can sometimes be difficult to keep track of the tools within the program as an outsider occasionally looking in. For example, EnergyPlus used to be the Engine for the Open Studio Application, which was a free GUI. Now, the Open Studio application will no longer be directly supported by the program, and OpenStudio SDK is an engine; and EnergyPlus is a separate engine. Also, Spawn is an engine parallel to EnergyPlus for a while, but eventually intended to replace EnergyPlus. It's not clear why there are three separate engines, or why these should function distinctly from one another, or what varying functions each performs. However, the sub-program has consistently kept the goal in focus – to develop and utilize energy modeling to realize energy savings in new construction, building operations, and major retrofits.

- Looking across all of the program initiatives, they appear cohesive and integrated to support wider use of building energy modeling to achieve the DOE goals of reducing building energy use. Initiatives are coordinated well with public and private organizations such as ASHRAE, IBPSA, AIA, gbXML.org, USGBC, and other NGOs, as well as tool vendors and equipment manufacturers. Through this coordination key stakeholders are well connected.

- Is the sub-program well integrated and cohesive internally? – Yes, it certainly is. EnergyPlus, OS, SOEP, Modelica, BEDES, BuildingSync, Asset Score, and many others are perfect examples of a cohesive development strategy.

- Is the sub-program well positioned in relation to and well-coordinated with relevant public and private sector organizations? – Yes and no. As would be expected, for the private sector entities working closely with BTO or jointly developing projects, they are well-coordinated. However, there are numerous efforts underway in the private sector that build on DOE's existing BEM infrastructure that may potentially be rendered incompatible if these developers do not buy into BTO's OS platform. It is strongly recommended that a more inclusive approach be utilized to carry along as many existing user groups as possible. There are some very innovative solutions coming out of these quarters and the industry would stand to lose from seeing them perish along the way.

- Does the sub-program effectively utilize channel partners? – Yes, it does. However, the industry would benefit from a more extensive and open collaboration between BTO and targeted stakeholders. A specific area for greater collaboration is a deeper partnership with equipment manufacturers for timely publishing of performance data while also integrating it into the BEM ecosystem for users. BTO is almost uniquely positioned to solve this longstanding issue.

- Are there coordination, integration, and partnership opportunities that the program does leverage? – The one that is the most beneficial is BTO's continued engagement with professional societies such as IBPSA-USA, ASHRAE, and others that help move along the need for greater inclusion, training, and cross-pollination.

- Sub-program could be more visibly aligned with the AIA, reinforcing the importance of BEM to the architectural & architectural sustainability communities.

- DOE has provided support for projects like IBPSA-USA's Project StaSIO, which aims to raise awareness of ASHRAE 209 and provide good visual examples of data presentation to allow more conversations around BEM, its uses, and the specific questions it can answer (full disclosure - I am on the organizing committee for IBPSA-USA's Project StaSIO).

- I have slightly less knowledge on this aspect of the subprogram. However, judging the people I interact with and that are involved in these efforts I judge that the collaboration is good. There is clearly occasional friction with the vendor world, but I think that is well balanced by the examples of vendor collaboration (Sefaira, Trane, etc.). The internal coordination is superb and it is impressive to have so many different groups behind the scenes delivering something on the surface that appears well ironed out.

- The sub-program does seem well integrated and cohesive internally. The sub-program does seem well-integrated with our related sub-programs within BTO. It does seem to leverage other sub-programs and support them.

- The sub-program is well positioned in relation to relevant public organizations. The sub-program has made extensive efforts to be well-coordinated with private sector organizations. I do not know exactly what "channel partners" means, but the sub-program does seem to be working with the appropriate partners.

- Yes, the program does leverage coordination, integration, and partnership opportunities.

- From the presented materials, it appears that the program could benefit from internal prioritization of topics. It might be that the order of topics already indicates priorities. Similarly, the engagement of other sub-programs could be prioritized with descriptions of mutually shared goals that are more granular than 30% energy savings by 2030. This strategic layer seems to be a next logical step based on the presented program materials.

- Overall, considering the complexity of the subject matter, I believe the BTO is collaborating, coordinating and integrating well. Similar to my response to the previous question, I see DOE as a national leader in this space. One way I can see DOE's influence going even further would be to really focus on the accessibility of BEM. This means possibly focusing on fewer products that are high-quality (as mentioned in the presentation). I understand BEM to be a tool for the building design community. In that light, I see designers struggling every day to keep up with the latest tools, platform ecosystems, and developments of BEM. Modeling a complex building system should be hard, deciding which tool to use should not be. I realize DOE wants to facilitate a transparent platform that allows unstifled proliferation of 3rd party products and services, but I would argue that the continually growing complexity of the "Software Philosophy & 'Constitution'", to some degree, inhibits the overall goal of increasing effective use of BEM.

D. Communication and Stakeholder Engagement

This portfolio was rated **3.60** for the degree to which it demonstrates integration of stakeholder input and effective communication of project information.

- The list of stakeholders consulted is impressive: BEM practitioners such as architects, mechanical engineers, sustainability consultants, energy auditors, and code and rating officials; BEM clients such as building owners, EE program administrators, and policy makers; BEM software developers; HVAC equipment manufacturers; researchers; and educators.

- Since one of the key metrics is GSF modeled, more outreach to commercial developers could be helpful.

- Sub-program efforts are often presented at conferences and this is very helpful for non-lab folks to know more about what is going on. However, it would be helpful if this material could be easily found on the website with the projects.

- Does the sub-program integrate input from the proper set of stakeholders? – Absolutely. Between ASHRAE, IBPSA and many other organizations that benefit from the work, there is a fairly robust set of stakeholders working on both the core products and competitive products. Having seen the SBIR proposals, it is quite clear that the market has a very diverse set of interested and active stakeholders.

- Does the sub-program provide sufficient and timely information about its projects, activities, and plans? – Being centered around open-source programs, the information, roadmaps, bugs, user feedback and releases are instantaneously known. So yes, they do a good job. Also, the roadmaps are very helpful to understand longer term visions for the sub-program.

- Are sub-program accomplishments and results communicated in the proper venues and in a timely fashion? – Yes, along the lines of the last answer, it does. Perhaps more case studies and recognition can be done for power users and outstanding results can be done if budget and resources allow.
- The sub-program has regularly sought and integrated feedback from a variety of stakeholders. It is also clear that the sub-program has made deliberate efforts to reach out to stakeholders and understand why BEM is used as little as it is, and what could lead to its further use.
- Stakeholder feedback was directly incorporated into the determination of barriers and initiatives to address them.
- The program is very good at communicating its projects, activities and plans. The Draft "Research and Development Opportunities for Building Energy Modeling" provided in advance of this workshop communicates detailed information about the planned activities for the program.
- The program actively integrates feedback from key stakeholders. The April 2019 "DRAFT Research and Development Opportunities for Building Energy Modeling" is a highly useful summary of the program's objectives and initiatives. The wider this can be circulated, the more good it can do. There is a lot of good work being done across the program. It is not always easy to keep tabs on the output/results of the work. This may be a matter of me not looking in the right venues for communication. Possibly greater placement of articles in trade press could help.
- Does the sub-program integrate input from the proper set of stakeholders? – Numerous channels currently exist, both formal and informal. These feedback loops are well-appreciated by the industry. A simple example is the EnergyPlus GitHub Issues log that crowdsources feature request and informs feature development. That said, a more formally structured and evenly balanced group of external stakeholders meeting frequently to inform the planning for BTO projects may be even more beneficial. The formal admission of external voices would greatly improve transparency, facilitate dialogue, and further ensure the elimination of echo chambers.
- Does the sub-program provide sufficient and timely information about its projects, activities, and plans? – Yes, the BTO and subprogram web pages are well-maintained and there is timely distribution of newsletters. Updates are also available at other venues such as IBPSA meetings, IES meetings, etc. However, I personally represent the experience of a well-informed, well-funded volunteer who is an active participant at numerous society events. This experience may be different for a new entrant to the industry, students, or emerging professionals.
- Does sub-program integrate input from proper set of stakeholders? – The BEM Draft R&D document outlines stakeholders, most of whom are already involved with and advocate BEM. If the BTO is looking to identify barriers and develop solutions we suggest including those outside this circle who are not currently engaging with BEM. Also, while building owners were included in the stakeholder list, building developers and managers are noticeably absent. The BEM guide "BEM for Owners and Managers" is out of date by 6 years.
- Does sub-program provide sufficient, relevant, and timely information? – Information is relevant, but due to the pace of the BTO initiatives and their scope, can sometimes be less than timely.
- Certainly the BEM specialists are well-informed and engaged. There could be some room for improvement in educating the broader building community about the extent to which BTO is impacting building energy and analysis. I'm sure it is difficult given the highly technical work being done, but the broader public could be better informed on the progress in this field and the impacts BTO is having in the market. Work like the validation work could also help some of the market penetration of BEM if it is communicated more broadly.
- The sub-program does integrate input from the proper set of stakeholders.

- The sub-program provide sufficient and timely information about its projects, activities, and plans. It does seem that sub-program accomplishments and results are communicated in the proper venues and in a timely fashion. The sub-program director is also open to adjusting the proper venues according to what the BEM community uses.

- Considering the size of the program and its annual budget, its reach is pretty wide and visible. For example, the number of research projects that use E+ significantly increased in the past five years, as evidenced by the published literature. Further, the stakeholder focus groups and program manger's R&D opportunities present a well-defined areas for major developments in coming years.

- The use of energy modeling in the industry is more widespread even for software that does not use E+ due to the program's activity in disseminating knowledge on usefulness of energy modeling for energy efficiency in buildings.

- I highly appreciate that the BTO actively participates and engages in BEM industry events such as SimBuild, IBPSA-USA, and even California's Software Symposium. This is of tremendous value to other industry participants and I hope that DOE continues to engage with the industry in this way. In my experience, programmatic input to BTO is taken seriously, and when applicable, is used to better the sub-program. At the same time, the sub-program's intent and updates are very helpful and timely at elucidating DOE's direction and developments on BEM.

E. Metrics

This portfolio was rated **3.20** for the degree to which it has identified appropriate metrics against which its performance will be measured.

- Prioritizing GSF over number of users makes sense since it is a clear energy metric. It sounds like you are already making the most of what is available through the AIA 2030 design data exchange coordination on stats/project reporting. However, from the discussion, the estimations on GSF sounded very approximate. I don't have a good suggestion on how else to track it, but perhaps more easily quantified metrics should also be considered.

- It was interesting to see the tracked downloads and total percent of floor area that was modeled. It would be great to see one day the goal be 100% modeled, and even break-out metrics for percent calibrated, percent field verified, etc.

- The upward trend and meeting or exceeding of the goals was very reassuring to see that the program is having a significant impact on the industry.

- The program has expended significant effort to identify proper progress and impact metrics, and to track them. Tracking the specific energy efficiency impact for energy simulation engine development is a difficult metric.

- One metric identifies the percentage of new construction projects with energy models as reported in the AIA database (as well as type of software used). This is a good source of data that identifies buildings that have been modeled, but doesn't necessarily show a true cross-section of commercial new construction in the U.S.

- Another potential source of this information that would provide a better cross-section might include local code from a cross-section of U.S. cities, including some in areas with 90.1-2007 code or equivalent requirements, some in areas with 90.1-200 or equivalent requirements, some with California Title-24 requirements, and some in areas with 90.1-2016 or equivalent requirements.

- The sub-program could also work with vendors to request optional sharing of data, such as number of licenses sold, number of simulations run (for an online license), etc.

- The sub-program is appropriately focusing on initiatives to better evaluate the savings realized by buildings with BEM versus buildings that don't use BEM. It would be helpful to focus on the stage BEM was used. It is expected that BEM used to inform the design process would impact savings, whereas BEM used only for the purposes of verifying project performance for local code, utility incentives, or LEED would not show significant savings versus buildings without BEM.
- I don't have sufficient information to evaluate this question.
- Does the sub-program have the proper progress and impact metrics as well methods of tracking them? – Yes, it does. In addition to data from the AIA 2030 Challenge, it is recommended that BTO try to partner with energy compliance certification agencies to gather data for compliance energy models submitted to determine the amount of energy saved using BEM for compliance. A similar exercise could also be undertaken with other organizations such as GBCI. It would also be beneficial to track software users. Would it be possible to conduct an industry-wide voluntary survey and publish these results?
- Does the sub-program perform well according to its chosen metrics? – It performs well on most metrics, but the industry would benefit vastly if BTO was able to achieve greater adoption for EnergyPlus. This would help improve overall quality, reduce tool fragmentation, and would also motivate developers to create solutions for a larger user base.
- Metrics:
    - Gross AIA 2030 Challenge square footage of buildings designed using EnergyPlus or EnergyPlus-based third-party tools
    - Number of BEMP professionals (proxy metric)
    - Number of EnergyPlus & OpenStudio downloads (proxy metric)
- If the goal is to reduce energy use through BEM use (most effective energy efficiency measure), then metrics could look at how the DOE is supporting industry initiatives beyond the software it provides and how that support allows new users of BEM to emerge:
    - Number of new BEM classes at universities
    - BEM becoming part of architecture/engineering programs
    - Gross AIA2030 challenge square footage of buildings designed using any (qualified; tool from suggested new list) BEM tool
    - Number of projects that comply with ASHRAE standard 209
    - Number of local authorities/utilities that reference the new 'qualified tools list' (suggested previously) as part of code compliance/incentive measures
- It's not clear whether success is measured in the context of all BEM software, or only E+ based tools in contributing to the reduction in energy use.
- The program performs well against its current metrics.
- There could be some improvement in the metrics used. I think one metric to be considered could be the actual cost of BEM per project (e.g., BEM cost per square foot or BEM cost per total project cost). I think this would do a better job at measuring the "effectiveness" of BEM, which is one of the critical things that this subprogram is directly addressing. Automating and standardizing more of the BEM process so that it doesn't act as a barrier to the ability to focus on energy efficiency solutions. As we look to bigger and deeper savings,

I think the benefits of BEM are undeniable. But the metrics get tricky depending on various political/scientific goals. For if BEM is to be successful, then it needs to be affordable and reliable.

- I am not sure what all of the impact metrics that are used by the sub-program are. Simply tracking the number of people downloading certain software doesn't necessarily capture the impact of the program. Also, not sure what the proper progress metrics and methods of tracking them would actually be. The sub-program director received some feedback on metrics that might be useful but obtaining these metrics would be difficult.
- The sub-program seems to perform fairly well according to its own relevant metrics.
- The program has metrics for measuring success, including the global metric of square floor footage being simulated with E+. The program might try to create a score card that has quantitative metrics for all six topics (or as many as the program intends to focus on). This would allow the program to identify areas for major improvements, because the current global metric is a too high-level performance criterion.
- As mentioned in my response to question 1, the portfolio's metrics seem to be focused on building square footage of projects using BEM tools, in particular in the new construction arena. This is a great, measurable start. My suggestion would be to consider additional types of metrics that are more broadly inclusive of a national constituency. Some metrics that come to mind include: number of design firms using BEM tools, average savings per square foot by using BEM, and RMSE and CV(RMSE) for assessing accuracy of energy models (to support efficiency persistence).

F. Additional Comments and Recommendations

1. Project Strengths

- The program is very well respected within the industry. Year after year, it delivers careful, high caliber work – so much so that I have come to trust the results before even seeing the validation data (and continue to be convinced after seeing the data).
- Empirical validation efforts are a key strength. Separating any potential BEM engine inaccuracies through carefully controlled empirical validation helps to separate issues with the actual engine from inaccuracies due to input error, and LBNL’s FLEXLAB and ORNL’s FRP are well-suited to perform this validation.
- The strength is in the performance of the BEM software, analytic capabilities, and level of coordination between efforts. The other strength is the vision for which the team has in the rapidly changing future and needs of the market. The move to Spawn will unlock an unprecedented and somewhat uncharted territory as GEBs become more prevalent and necessary. The co-dependence and the seamless integration between labs on EnergyPlus was a huge success. The deployment of OpenStudio is a tremendous success, and the future of the SDK and large-scale analysis will be much needed.
- The EnergyPlus/OpenStudio engine enables detailed calculations of interactive building energy systems, with highly accurate results. Other programs (such as Codes) rely heavily upon energy modeling from these tools to evaluate cost-effective improvements to incorporate into code requirements. For all areas where these codes are adopted, this facilitates improved energy consumption for all newly constructed buildings. The engine has also been used for the Asset Scoring Tool, which can be used for existing buildings to evaluate improvements to building performance.
- There are many useful initiatives that form the strength of the program, including:
    - Empirical validation testing
    - Advancing art and science of calibration

  - Advancing art and science of uncertainty analysis for BEM
  - Using good judgement to determine when to interoperate for new capability, and when to integrate capability into EnergyPlus
  - The "10x" project to increase EnergyPlus speed
  - Supporting design and BEM tool vendors for EnergyPlus adoption, including support for the use of the OpenStudio Software Development Kit (SDK)
  - Support of ASHRAE Standard 140 development
  - Support of ASHRAE Standard 205 development
  - Support of gbXML.org development of geometry transfer test suites
  - Development of BEM case studies to demonstrate best practices and cost effectiveness
  - Development of prototype building models
  - Advocacy for the use of ASHRAE Standard 209
  - Advocacy for the use of BEMP and BESA certifications to quantify modeler competency
  - Initiatives to promote BEM education at the university level and post-graduation thru conferences and organizations such as ASHRAE and IBPSA

- Powerful Tools Ecosystem: This sub-program provides an invaluable tools ecosystem for the industry. The continued maintenance of open source engines such as EnergyPlus and Radiance that are the foundation for many workflows for research, policymaking, and industry practice is vital. The OS platform with its measures, standards gems, BCL, PAT, etc. provide a full toolkit for advanced energy modelers and software vendors, thus fueling overall growth.

- Phenomenal Research Breadth: BTO's support of research areas such as the control of complex systems, grid analysis, urban scale modeling, and many related but different applications is critical to advancing the state-of-the-art.

- FLEXLAB and FRP: Some building performance models in the industry are viewed with healthy skepticism due to the large uncertainty ranges associated with model results. The emphasis on wanting to reduce uncertainty through investments in physical experiments could go a long way in improving overall credibility of model results. These initiatives also show BTO's willingness to put its own tools to the test in exposing potential flaws in calculation methods, bugs, reporting, etc. that could solve completely unknown issues for the end-user.

- Funding Private Innovation: BTO's deliberate utilization of all funding avenues available to it to promote research/innovation outside of the national labs is much welcomed. This fosters competition and provides vital support to novel ideas developed outside its orbit. Joint development, such as in the case of SimuWatt and others, helps with technology transfer as well.

- Supporting Professional Societies: BTO's association with professional societies such as IBPSA-USA and ASHRAE lends greater credibility and supports broader participation from the industry. This is key to inducting new entrants and facilitates the exchange of ideas between different interest groups. This greatly benefits the industry overall.

- Topic 1. Value (TableIII-1) Initiatives 1, 4, 5, 6. 8, 9 & 10 cover a good spectrum of initiatives to drive value.

- Sub-program advances state of the art by shifting focus to more granular, external tools in support of deeper analysis with Modelica.

- Adding an empirical test to ASHRAE 140-1 test cases is encouraging. Perhaps the next step is software/real building comparisons like the One New Change example provided.

- The BEM subprogram does a phenomenal job at advancing BEM technology and thinking ahead to where the software needs to be to deal with the next set of building energy hurdles, a constantly moving target. A good example is Spawn and the controls work looking towards building controls being a big target to manage both building energy and grid resources.

- The sub-program's strengths are: Deep integration with the building modeling community; new efforts leading toward greater degrees of automation and efficient workflows; and forward thinking leadership regarding changes coming to the buildings sector (both commercial and residential) and the energy sector as a whole.

- For the funding level available to the program, it is incredibly effective in both developing new energy modeling technologies and dissemination of knowledge to the industry that result in actual energy savings.

- The overall quantitative focus on the value proposition of BEM and the steadfast development on core simulation capabilities (EnergyPlus, OpenStudio, EnergyPlus 10X) are big program strengths. Also, Amir is a great ambassador for BEM and represents the BTO as a leader and visionary on the subject.

2. Project Weaknesses

- Explaining OpenStudio work and the transition away from the GUI continues to be confusing to most people that I talk to. For example, the project portfolio lists OpenStudio, OpenStudio Measures, OpenStudio Standards Gems, OpenStudio Server, OpenStudio 2.0, and OpenStudio Application. Discussion of SDK is mixed throughout the portfolio list and it is confusing to understand what encompasses what, and what new work will be backwards compatible with the existing interface if a different party was hosting.

- Perhaps not a weakness, but an opportunity may lie in expanding BEM via flagship projects like URBANopt to include more emphasis on not just GEBs, but on system planning. There is a major need to redesign aging and not-well-suited grid infrastructure in an evolving energy market. It seems like SETO is doing work here, but from the exposure to their work, it does not seem like they fully realize the importance, feasibility or reliability of BEM on their 'side of the house'.

- Several of the initiatives already identified for the sub-program are intended to focus on these weaknesses. However, after several years of development, the program has not addressed one of the biggest barriers in the energy modeling industry – the inability to use the integrative energy design process (such as referenced in ASHRAE 209) using a single modeling tool with limited duplication of effort, and then continue to leverage that model for building commissioning, and during ongoing building operations. This would require a time-effective method for iterative modeling in schematic design, and then the ability to port part of the model(s) for use in later phases of design, and continue to port the data from the model.

- Please see next question "Improvements".

- EnergyPlus Adoption: EnergyPlus continues to suffer from poor user adoption. Despite being "free-to-use," it continues to lag both free-to-use simulation engines as well as paid tools. Entry barriers for new users continues to be very high. Most modeling shops are small, so unless driven by longer-term strategic investments, it remains cost-prohibitive for companies to use it over DOE-2, especially for simpler buildings.

- OS Transition: The impending transition of the OpenStudio Application will greatly impede the industry's ability to generate native OpenStudio input files. The entire OS platform currently hinges on the osm file and it is also the foundation for most future development by this sub-program. The hamstrung ability of users to generate it would create a practical barrier to fully leveraging the entire platform. It may result in greater fragmentation of standardized tools and consequently have a detrimental impact on the overall credibility of model predictions. Moreover, it seems this move will subsidize the development of an SDK that will be used by third-party application vendors whose tools are not free-to-use for practitioners (as of this day). Its effect may be particularly detrimental on small modeling shops.

- SOEP: Apart from certain individuals/entities who have deep ties with professional societies or the national labs, most individuals are either unaware of SOEP, or know very little about it. Most major stakeholders have efforts underway to accelerate BEM automation to stay competitive and they are making significant strategic investments in their own workflows and modeling environments, while laying their faith entirely in EnergyPlus. This sub-program is encouraged to have transparent and inclusive conversations about its long-term plans for EnergyPlus, OS, and SOEP, thus allowing these entities to make informed timely choices for the selection of their tech stacks and platforms to safeguard their investments. This is particularly true for those who do not rely on OS for the generation of their models, either due to missing features, or due to its impending transition plan, or otherwise. Basing SOEP feature availability solely on the OS platform, assuming that EnergyPlus developers use the OS platform, may not be true. This team must be lauded for attempting to be innovative but may end up being negatively impacted by a rigid transition plan.

- As the DOE is focused on creating a leading simulation engine, relying on third parties to create usability. The DOE must support vendors who are making BEM easy to access whether that is through EnergyPlus directly or via interoperability. Perhaps the support could come in the form of a list of qualified tools (similar to the 179D list) but just for tools that pass certain standards (new ASHRAE 140-1) and maybe a subset of those tools that meet further requirements/certifications. This promotes BEM from the DOE directly. Having this list provided by any other organization, private or non-profit, would undermine the credibility of the list.

- Another barrier is a lack of local authority awareness of how to specify appropriate BEM tools and their ability to review the results. Perhaps, if a list like the one described above existed, then local authorities could look to reference that, or the subset of tools that meet the requirements/certifications for ASHRAE 90.1 Appendix G. section 2.2, for example, or certified 90.1 PRM automation tools. Also a standard form of results reporting (such as the EN1 form for NY) could be used to allow assessors to only review one type/format of report from all modelling software.

- One weakness would be adding more effort to share improvements that could apply to general practitioners. Specifically I am thinking of the lessons learned in the validation work that could lead to better performance curves or modeling practices regardless of the BEM platform being used.

- Another improvement could be helping the industry understand the intersection between data analytics and BEM. I think there is often confusion for the consumers of our analysis around where those practices are applicable and occasionally supplemental.

- The sub-program's weaknesses are: Lack of a clear plan for the OpenStudio interface and lack of clear communication about the role of their products and what they can actually do (e.g., OpenStudio as a whole); lack of easily accessible training materials and sample files for those learning energy modeling; and lack of a clear quantitative tie between the use of energy modeling and energy savings.

- Two major areas of improvement for the program could be (a) strategic layering of its topics with (b) quantitative metrics for each of the topics to be identified.

- I hope to see DOE's influence going even further by placing some priority on BEM accessibility, usability, and standards.

3. Recommendations

- As described in the "Roadmap": The variability between simulated and actual energy performance of buildings is due to both internal (tool) and external (user-input) error, but the relative contribution of each of these components is unclear. This distinction is significant from a public perception standpoint. Input error can be reduced via calibration, more intelligent defaults, better quality checking processes, and additional user training, but errors in the fundamental tools of the trade cast the entire enterprise into doubt and create skepticism among BEM professionals. The sense among BEM professionals is that inputs are a greater source of error—perhaps even far greater—than assumptions or bugs in the software.

- Increase educational outreach to users to encourage accurate inputs and flag which variables actually really matter vs. inputs that are within the margin of error.

- More outreach and education, more robustness of the BCL for MPCs, expansion into grid considerations, and a wider net of use cases from unusual suspects.

- Supporting initiatives that lead to integration of the OpenStudio engine into these two software packages may lead to significantly greater uptake of EnergyPlus, and could also significantly improve standardization, workflow, and other initiatives identified.

- Initiatives that focus on the following could significantly improve predictive accuracy:

  - Provide monitoring studies (or reference existing monitoring studies that have been done in utility incentive programs, etc.) to update the default ASHRAE 90.1 schedules and equipment loads (not updated since 1989) and expand the schedules to be specific per space function (not just building function). For receptacle loads in offices/schools, provide more than one option for defaults.

  - Data research study at a macro-level that links percent better than ASHRAE 90.1 or other energy standards, such as Title-24, Seattle Energy Code (using any metrics available – site EUI, source EUI, Cost, GHG emissions) versus benchmarked energy performance. The hypothesis for the study would be that relative savings predicted track with benchmarked performance.

  - Develop a tool that receives exported data from the energy model (using BEDES Data Dictionary terms), auto-processes the results, and helps the modeler perform QA on the model (note: this would also be a good way to provide standardized inputs in a trackable data format, which can be used for other uses as well)

    - Working with design authoring tool vendors to improve consistency, robustness, and analyzability of design model exports is a good focus. However, actually developing a data framework for these exports and automating the checks would further improve this effort.

    - Promoting certification for automated BEM tasks is an important initiative, and the role the Energy Modeling Portfolio takes in this will play a significant role in whether this succeeds. Note that certification should also be for modeling the most common baseline HVAC system types and controls.

- Opportunities:

  - Use of BEM in building operation for continuous commissioning – I didn't see initiatives designed to promote this use of BEM. But this probably has to come later after the current initiatives succeed at establishing the value proposition for energy modeling and the fidelity of BEM engines. Program should not lose sight of this as a future objective.

- There is a quote on page 32 of the "DRAFT Research and Opportunities..." report that "BEM engines such as "EnergyPLUS include rigorous and well-vetted modeling algorithms. Empirical validation is therefore unlikely to identify internal deficiencies whose mitigation will significantly improve BEM predictive accuracy." I think it is important to avoid being overly confident that significant improvements won't result from empirical testing. There are bugs in EnergyPlus and careful study and evaluation is steadily ferreting them out. For example, there was one rather subtle bug fixed in EnergyPlus 9.1 that was discovered almost by accident as a result of work on the KIVA interface. This bug fix will have a large effect on energy use estimates for common HVAC systems such as VAV/RH. Just by coincidence one of the FLEXLAB tests at nearly the same time discovered the importance of this aspect of room modeling for matching modeled vs. measured performance (this was the issue of natural vs. forced convection for internal surfaces at different supply airflow levels). My company's careful study of EnergyPlus over the last 5 years has surfaced many similarly significant defects in EnergyPlus. The EnergyPlus development team has been extremely supportive and responsive to this kind of collaboration to improve the engine. And as EnergyPlus gets wider use through commercial tools it will get closer and closer inspection of this kind. My hope is the team will continue to be responsive to this type of collaboration. We shouldn't lose sight of the value of empirical validation to discover opportunities for improvement like this. Empirical validation is valuable not only for testing and improving a BEM engine, but also for guiding application of BEM algorithms and compilation of input data to accurately model different building applications. An accurate BEM engine is of no use if the input data and choice of algorithms is not appropriate for an application. There are so many algorithms available for use in EnergyPlus it is sometimes difficult to choose the appropriate algorithm for an application and to construct appropriate inputs. Further, engineers are not in a position to choose the right algorithm or appropriate input values for such things as room surface convection or radiative properties. Guidance is needed from vendors to channel engineers into appropriate application of the models. The FLEXLAB and ORNL empirical validation work thus far is improving the understanding of how buildings behave – and that feeds a better understanding of how to apply algorithms appropriately to maximize accuracy.

- The DRAFT report rightly points out that one of the problems in our industry is the "silo-ing" of individual roles, such as the architect viewing his role not involving energy efficiency and the engineer's role being responsible for making the architects design energy efficient. If the program initiatives are successful in increasing the use of BEM, the energy efficiency gains may still be limited if roles remain silo-ed. Would there be value in initiatives to document and publicize the positive impact of Integrated Project Delivery (IPD) in elevating energy efficiency levels above that possible in traditional projects with silo-ed roles?

- Similar to the previous item, the DRAFT report also points out that in many situations building owners have no financial stake in energy efficiency of a building (such as speculative building or a building owner with leased tenants), and as a result only code-minimum energy efficiency is achieved. As a way of overcoming this barrier to energy efficiency, could there be value in documenting and publicizing the effect of building energy efficiency on building rental prices and building resale value? There is industry data suggesting that green or sustainable buildings command higher rental prices and resale value. Energy efficiency is one part of that story.

- This sub-program spans great breadth and depth and provides tremendous value to the industry. It is recommended that it continue to strive to overcome the barriers listed in the R&D opportunities document in the larger interest of the industry, and to ultimately reduce overall energy consumption for the US building stock.

- BEM is not immune to the technology disruptions underway in other industries. There has been an uptick in the adoption of web technologies, data-driven modeling techniques, simulation tool interoperability, BIM data exchange, etc. that are fundamentally different from the traditional physics-based models widely used today.

Innovative users and fervent believers in DOE's tools ecosystem have been creating novel workflows and need a stable and reliable modeling platform to build-off of. These are complex problems, so it recommended that DOE take cognizance of these efforts and minimize disruptions within its own tools ecosystem. Over the next couple of years, these teams (some with little resources) will have to contend with major disruptions: i) EnergyPlus files transition, ii) OS application transition, iii) SOEP transition, etc. Given the crucial dependencies, it is recommended that DOE have more frequent and intimate user group meetings to manage the day-to-day challenges experienced by these innovators so they can continue to leverage this sub-program's incredibly vital tools ecosystem. Open and frequent communication will significantly reduce development (code refactoring) costs for those at the bleeding edge in the years to come.

- DOE may even benefit from greater engagement with an advisory group consisting of non-lab industry stakeholders to avoid creating an echo chamber and equally represent interest areas such as academia, research, rating/compliance agencies, utilities, data collection agencies, practitioners, vendors, etc.
- Creation of a new qualified tools list on an EERE/DOE website page, listing all the software tools that have passed the ASHRAE 140-1 tests (and new empirical tests once they become available):
    - Tools must have results reviewed (in similar fashion to the 179D review process)
    - Tools must publish results online along with model files in an easy to access format (Excel/ standard compressed file formats like .zip)
    - Subset list of tools that are EnergyPlus based/interoperable with EnergyPlus (like Tas)
    - Subset of tools that meet the requirements of section G 2.2 from the ASHRAE 90.1 book
    - Subset of tools that meet further certifications, such as the proposed certification for 90.1 PRM (appendix G.) baseline model automation (NOT code minimum)
- Create a standard output report that all local authorities could expect from any BEM tool for code compliance/incentives. This could be like the EN1 form used in NY.
- At some level my recommendations are to keep doing what you are doing and advance the industry without them necessarily being aware of your role.
- Really, I think the improvements to the subprogram might be better performance metrics. Specifically, including metric relating the cost of BEM to the project (e.g., $/sf spent on BEM). I think one of the ultimate metrics for the BTO around BEM is to increase the adoption of BEM, but to also increase the cost effectiveness of BEM. Sure, from one perspective energy modeling as a payback on the order of a month, but it also has the potential to be mostly automated for a large percentage of buildings out there and that is what would truly drive further adoption.
- To improve the sub-program, I would recommend establishing the role of BEM through quantitative studies that help to clarify the role of energy modeling and its usefulness in different contexts (e.g., retrofit or new construction) and different stages of the design process, with verified and validated data to establish this quantitative tie, and doing the appropriate PR work to make this established place for BEM clear to stakeholders.
- I believe that coordination and partnership opportunities may exist at the local level as well (e.g., city or county governments with building efficiency targets) that the program has not yet tried to leverage.
- Please, identify strategic priorities among 6 strategic topics identified in R&D opportunities (this is an excellent document and a comprehensive outline of exciting opportunities). Further, please, if possible, provide quantitative metrics of progress for each topic. Finally, identify links to internal and external

stakeholders based on common/shared strategic goals. Also, the funding levels to universities could be higher as these strategic stakeholders could produce not only novel technologies, but also a workforce capable of carrying it into the marketplace.

- I hope to see DOE's influence going even further by placing some priority on BEM accessibility, usability, and standards. I have been doing energy modeling professionally for over fifteen years, in various capacities. I, like many of my colleagues, have probably spent more time trying to keep up with the latest BEM tool developments, than using BEM tools. It is an insanely complicated subject, but the intent is not complicated. People use BEM tools to help identify energy design solutions. They want to create better buildings. Yet the overall state of the BEM industry is one that is highly subject to entropy and needless increasing complexity. If we genuinely want to "Increase the effective use of BEM in all aspects of building energy efficiency", then I believe most earnestly, that visionary leaders should surface to help the masses navigate these boundless waters. I believe DOE has the potential to be one of these visionary leaders.

BTO Portfolio-Level Activities

Sensors & Controls, Grid-Interactive Controls

Portfolio Review: Sensors and Controls (Goals)

Presenter: Marina Sofos, U.S. Department of Energy

Brief Summary of Reviewer Comments

In general, reviewers agreed that the barriers are real, significant, and appropriate for DOE and the labs to work on. The barriers and technical challenges identified for adoption of optimized building operation strategies are widespread problems that only can be addressed with a large-scale effort initiated by the Federal government. Reviewers were generally in consensus that the major barriers and technical challenges have been adequately identified in the research agenda.

Multiple reviewers stressed the importance of technology-specific barriers, such as adoption of existing technology and evolving technology. Examples include use of programmable, learning thermostats in residential homes and building automation systems in small commercial buildings. One reviewer suggested a prioritization of which barrier(s) to address first in order to achieve BTO's targets to help to prioritize funding.

Most of the reviewers agreed that the sub-program advances the state of the art, particularly in controls and benchmarking, and has an opportunity to lead in the emerging area of comfort sensing. This program should be out in front in large part to encourage open-source, interoperable sensors and equipment. However, one reviewer did caution that there may be some challenges, particularly in meeting BTO's long-term energy saving goals, as more "smart" systems come on-line with buildings (both residential and commercial).

Reviewers generally agreed that the sub-program is supporting industry and contributing to BTO’s energy savings goals. Industry is involved in several projects through industrial advisory boards and the development of better sensors and controls, particularly related to building-grid interactions and grid harmonization, is critical to the achievement of BTO's energy goals as the grid evolves and as energy codes become more stringent. Reviewers suggested more engagement with building owners and managers who may see the most benefits both from energy savings and from user satisfaction point-of-view and more engagement with private sector partners in deployment, particularly of pilot projects.

Many reviewers described the sub-program as well-integrated, particularly within BTO, EERE, and DOE. It effectively leverages sub-program support and other sub-programs. In addition, BTO is clearly integrated within other sectors of DOE. For example, grid-to-building interoperability is part of the portfolio.

Reviewers agreed that the sub-program has good coordination with public organizations and private organizations (through industrial advisory boards), but reviewers did make suggestions for further coordination. It will be key to collaborate with ASHRAE, BACnet, Project Haystack, Brick, etc., as well as with private manufacturers interested in open communications protocols and interoperability to ensure that all technology developed by this program can be commercialized in a way that benefits all players in the market, as well as advances DOE's and BTO's efficiency goals. Also, coordination/collaboration with public and private organizations in sectors outside the energy sector, such as advanced manufacturing and entertainment sectors, would be beneficial.

As for communication and stakeholder engagement, reviewers agreed that this is a strength for the sub-program. The sub-program integrates inputs from national labs, industry, and academia, and the sub-program partners reach out to stakeholders, including building owners, managers, and users. Overall, reviewer consensus was that BTO Sensors and Controls is doing a great job of reaching out, engaging, and communicating with the proper stakeholders (public and private sectors).

Reviewers agreed that the sub-program had good external communication/publication of results and reviewers provided many examples of this. BTO does an excellent job of announcing funding opportunities and communicating project status and opportunities (e.g., publications, reports, announcements, etc.). Also, the BTO peer review and Better Buildings Accelerators are excellent ways to bring stakeholders together and communicate success.

Overall, reviewers agreed that the sub-program has the proper progress and impact metrics, as well as methods of tracking them. Furthermore, the sub-program is investing in benchmarking to help validate developed technology and its potential impact. The sub-program meets its energy savings goals and is the leader in defining occupant-centric measures.

However, reviewers made multiple suggestions for improving the sub-program's metrics. It should be considered to validate the cost and efficiency predictions of SCOPE and to include alternative technologies, as well as those outside the BTO scope, in order to ensure that the developed technologies are ultimately successful in the market. Also, a greater focus on accelerating technology adoption would be welcomed. The program could support this through education, outreach, and tools but also through technology development (e.g., simplification, self-configuration, self-commissioning).

Weighted Average: 3.57   # of Reviewers: 6
Scope: 3.33   Impact: 3.67   Collaboration, Coordination, and Integration: 3.83   Communication and Stakeholder Engagement: 3.50   Metrics: 3.50

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning.

A. Scope

This portfolio was rated **3.33** for the degree to which the scope identifies and targets key barriers and technical challenges that are appropriate for the Federal Government to address.

- Barriers and technical challenges identified for adoption of optimized building operation strategies are real, widespread problems that only can be addressed with a large-scale effort initiated by the federal government. In particular, introducing standardized ways to measure building operation inefficiencies and to measure performance gains is critical for moving this field forward toward targeted energy savings goals.
- The project portfolio addresses identified technical challenges, particularly interoperability issues and lack of affordable precision sensors and real-time controls.
- One significant barrier to adoption may be motivating stakeholders to engage in upgrades that would result in performance gains and energy savings. Perhaps it may be worthwhile to investigate potential incentives for building owners and managers that would encourage them to adopt and/or more effectively use existing BAS.
- I believe the major barriers and technical challenges have been adequately identified in your research agenda.
- First, note that some specific feedback comments I provided in this portfolio's other sub-program review (grid-integrated controls) may apply to this one too, so please review them both together.
- Yes, the barriers are real, significant, and appropriate for DOE and the labs to work on. For example, sensor development is a good venue for government research, especially when labs (and other government employees) team up with private sector entities to push major cost reductions in equipment (i.e., MOLEX/ORNL sensor).
- This project portfolio has significant focus on the sensors and equipment that will facilitate enhanced building/grid interaction. This is critical as one of the main blocks in building/grid interaction optimization is related to communications infrastructure, communications protocols, and signal processing from the grid to the building. The hardware components are key to this puzzle. Other key pieces include cybersecurity and interoperability. Other related projects are working on this. It will be very important for work in this portfolio to collaborate with projects in those areas being conducted by the labs and by other entities to be sure that interoperability of sensors is built in from the ground up.
- There are major real-world barriers to implementation of the technology being developed by this portfolio. Most of them are addressed, but this portfolio focuses mainly on the technological barriers (and economic/cost elements related to the technology). However, other categories of barriers include policy, regulatory, etc. A major barrier is related to utility rate structures: in much of the country there is just no economic reason for buildings to install sensors that can help them shift their loads based on time of use, not to mention responding to grid signals. I recommend that this team demo results from their work to the NASEO/NARUC grid harmonization working group and perhaps to individual PUCs and other regulators (after pilot projects have been completed to demonstrate results).
- All relevant barriers and technical challenges are identified. A prioritization of which barrier(s) to address first in order to achieve BTO's targets would help to prioritize funding.
- A mapping between the barriers/challenges and the project portfolio would help to understand how much funding is invested to overcome barriers/challenges. This could be complemented by an analysis of the influence of each barrier/challenge, i.e., how much additional energy savings could be achieved by removing this barrier. This analysis should be very practical, e.g., by interviewing building owners and building automation engineers.

- As an example, labor intensive and customized commissioning is one of the biggest cost drivers and therefore an important barrier for advanced sensing and control functions. Yet, this seems not to be reflected sufficiently in the project portfolio.

- The primary barrier is adoption of existing technology and the proper use of existing technology. Examples include use of programmable, learning thermostats in residential homes and building automation systems in small commercial buildings. BTO is providing tools and frameworks to address challenges. Interoperability is a big untapped opportunity.

- I believe the goals for the BTO Sensors and Controls Portfolio address many technical challenges/areas that impact the residential and commercial building sector. The four main technical areas (multi-function wireless sensor networks, adaptive and autonomous controls, advanced sub-metering/analysis, and occupant-centric controls) contain many technical challenges that need to be addressed. In addition, BTO has clearly identified several specific technical areas (MELs, interoperability, cybersecurity, and standardized test data sets) that also will be or are being included in its portfolio.

- On the other hand, it's not clear if BTO has taken into consideration just how disruptive data privacy and the Internet of Things (IoT) may (will?) have on the residential and commercial building sector.

- The news media is full of reports on data breaches and compromised consumer information due to vulnerabilities in current technology and policies. As building sensors and controls evolve and the use of crowd technologies and data sharing become more central to energy efficiency decision-making and actions, the need to address privacy, particularly as it becomes more regulated, will only increase, possibly impacting energy efficiency goals.

- In addition, as IoT, 5G, and other advanced communication/networking technologies become available, the list of smart, connected, and energy-using devices will greatly increase. It's not clear if current energy efficiency models adequately address this onslaught of devices and resulting complexity.

- Finally, more services and conveniences will be incorporated into both residential and commercial buildings. Although some of these new capabilities most likely fall under MELs and will be addressed there, the idea of buildings serving as service platforms, not just habitats, will impact everything from behavior/convenience modeling to fault detection. Energy efficiency will just be a service, along with energy supply, comfort, security, and many other services.

- Overall, I believe BTO is clearly on the right track. It's just going to be more complicated as technology evolves.

B. Impact

Assuming that the ***portfolio-specific goals*** are met, this portfolio was rated **3.67** for the degree to which the portfolio is ***expected to*** contribute to ***program and BTO goal(s)***.

- The program advances state of the art, particularly in controls and benchmarking, and has an opportunity to lead in the emerging area of comfort sensing.

- The industry includes many different stakeholders, including construction industry, real estate industry, building management companies, building managers, and building users. I believe that the sub-program effectively supports building management companies and end users.

- It may be beneficial to engage building owners and managers who may see the most benefits both from energy savings and from user satisfaction point of view. For many large entities that use older buildings, utility bill is simply a line item that is paid automatically, without consideration of possible improvements.

- Energy savings goals are well addressed.
- The sub-program advances the state of the art.
- The sub-program effectively supports the industry.
- I believe that you have effectively identified the major stakeholders and engaged them.
- The sub-program contributes to BTO's energy goals.
- This program is helping to advance the state of the art. I am sure other private R&D efforts are underway by some private entities/controls manufacturers, but this program should be out in front in large part to encourage open-source, interoperable sensors and equipment.
- This program is supporting the industry. More private sector partners in deployment, particularly of pilot projects, would be good.
- I am not aware of stakeholders that are not represented or supported.
- The development of better sensors and controls, particularly related to building-grid interactions and grid harmonization, is critical to the achievement of BTO's energy goals as the grid evolves and as energy codes become more stringent. Commissioning is a key piece of the puzzle too and it relies on good sensors. Additionally, AFDD is a critical element in ensuring that efficient buildings stay efficient as performance drift is pervasive and sucks an enormous amount of energy.
- Advancement of state of the art was only partially addressed in the presentation.
- Industry is involved in several projects through industrial advisory boards. Moreover, transfer of new sensor technologies into products shows effective support for industry. The transfer of the other technology fields (analytics, controls, occupant-centric) into products and solutions is not clear from the presentation.
- The contribution to BTO's energy savings goals is described by cost savings and energy savings goals. Yet, the SCOPE tool to derive these goals seems to be lacking practical proof-points and/or alternative technologies that are not considered within the tool, such as wireless sensor networks for residential buildings with $300 investment costs per residential building. Given limited actuation capabilities in residential buildings (lighting on/off, HVAC set-points for single zone), there are probably cheaper technologies to leverage these savings, such as home security systems/Google Nest/Amazon Alexa. It is similar for the data analytics field. Where do the energy savings come from?
- The sub-program includes a balance of state-of-the-art technology development (plug and play wireless sensing networks) and standardization of existing technology (OpenBuildingControl). Too much focus on standardizing traditional control sequences may stifle innovation and adoption of new approaches for self-learning, artificial intelligence-type control methods. Also, there are more opportunities to develop effective fault detection and diagnostics algorithms at a packaged equipment level than building level due to data availability and scale of standard equipment.
- In my opinion, the Sensors and Controls Portfolio is advancing the state of the art, has the support of industry, and is meeting BTO's energy saving goals.
- I believe there may be some challenges, particularly in meeting BTO's long-term energy saving goals, as more "smart" systems come on-line with buildings (both residential and commercial). As noted in question 1, the future appears to be moving buildings from being habitats that provide shelter and a place to work to a full-service platform with many capabilities, all-consuming power and all interconnected. These systems of systems architectures are going to be a challenge to manage, particularly from an energy efficiency

perspective. It might be prudent to reach out to some of these service providers (e.g., Amazon, Google, etc.) and collaborate to ensure energy usages are understood and the necessary technologies are developed to ensure future energy efficiencies are achieved.

- Overall, I do believe the current BTO Sensors and Controls Portfolio is well-positioned to take on that challenge.

C. Collaboration, Coordination, and Integration

This portfolio was rated **3.83** for the degree to which its activities demonstrate strategic collaboration or coordination with relevant programs and partners.

- The sub-program core mission and cross-cut strategies are well-integrated and support program goals.
- It is well-integrated within BTO, EERE, and DOE. For example, it leverages DOE labs and ARPA-E SENSORS program.
- The sub-program is well-positioned for technology transfer to stakeholders through channel partners, such as through licensing.
- Partnership with real-estate companies and building managers may help to raise awareness of potential performance gains and energy savings.
- The sub-program is well-integrated and internally cohesive. The sub-program is well-integrated within BTO, EERE, and DOE. It effectively leverages sub program support and other sub-programs.
- The sub-program does effectively utilize channel partners.
- I am unaware of any relevant research opportunities that you haven't already identified.
- The program is composed of several independent projects, of course, and the connections between them are, for the most part, well-thought out, but in some cases, they could use some more holistic thinking. I recommend a whole-building approach between projects. For instance, the AFDD project investigating common AHU-VAV faults may produce outputs that would be quite useful in the OpenBuildingControl project. Are all the AFDD outcomes going to be incorporated into the building control sequence and commissioning best practice recommendations? The same applies for the occupant-sensing controls project.
- It will be key to collaborate with ASHRAE, BACnet, Project Haystack, Brick, etc., as well as with private manufacturers interested in open communications protocols and interoperability to ensure that all technology developed by this program can be commercialized in a way that benefits all players in the market, as well as advances DOE's and BTO's efficiency goals.
- I recommend seeking to align projects more closely with the Continental Automated Buildings Association (CABA) and, particularly with those CABA members involved in sensors and controls (of which there are many). When it comes to devices, can NEMA be a helpful ally? I am truly asking. I am not sure if they would be or not.
- They have good connections to BEM within BTO, SETO, and other DOE departments, e.g., for cybersecurity as well as non-DOE organizations like ASHRAE.
- They have good coordination with public organizations and private organizations (through industrial advisory boards), yet industry impact could be stronger.
- Collaboration with industry is important in the sensing and controls area because of the fragmented value chain and "one off" nature of commercial buildings. BTO has done a good job convening industry

participants. The industry adoption of testing and evaluation platforms (e.g., BOPTEST) is less clear. Sophisticated manufacturers develop their own tools and less sophisticated manufacturers and installers would find these difficult to apply. The impact of these projects is questionable.

- The Sensors and Controls Portfolio is well-integrated internally. The various technology focus areas since 2014 address a broad spectrum of Sensors and Controls challenges. In addition, BTO is clearly integrated within other sectors of the DOE. For example, grid to building interoperability is part of the portfolio.
- Although BTO and its Sensors and Controls Portfolio are coordinating and working with other public and private sectors, this coordination/collaboration is predominately focused on organizations within the energy sector. As noted in responses to the previous questions, I believe coordination/collaboration with public and private organizations in sectors outside the energy sector, such as advanced manufacturing and entertainment sectors. For example, advances in interoperability and cyber-physical security developed in the advanced manufacturing sector could be leveraged by Sensors and Controls.
- Also, behavior tracking and other artificial intelligence/machine learning approaches from other sectors (besides energy) could be leveraged by reaching out to non-energy public and private sectors.
- Having said that, the current portfolio is broad and deep, so the above is simply a recommendation to consider.

D. Communication and Stakeholder Engagement

This portfolio was rated **3.50** for the degree to which it demonstrates integration of stakeholder input and effective communication of project information.

- The sub-program integrates inputs from national labs, industry, and academia. Indirectly through, the sub-program partners reach out to stakeholders, including building owners, managers, and users.
- The sub-program provides an opportunity to the public to respond to the proposed roadmap and contribute toward future areas of R&D.
- Peer-review is a great venue for the sub-program to timely communicate program goals and results.
- The sub-program integrates the input from the proper set of stakeholders. The sub-program provides sufficient and timely information about its projects, activities, and plans.
- The sub-program accomplishments and results have been communicated to the proper venues in a timely fashion.
- To my knowledge, which is somewhat limited, I believe the answers to these questions are yes. I have had somewhat limited interactions with the particular projects in this portfolio, so I am not sure in all cases whether all stakeholders have been informed and involved as needed. What I have seen has been positive.
- They have had good interactions at the project-level through industrial advisory boards. Interconnection at the sub-program level with building owners and building automation system vendors could be intensified to shape the project portfolio.
- They have had good external communication/publication of results.
- This is a strength for the sub-program. Using engagement models like challenges (e.g., advanced rooftop challenge) and Better Buildings Accelerators is an excellent way to bring stakeholders together and communicate success.

- BTO Sensors and Controls is doing a great job of reaching out, engaging, and communicating with the proper stakeholders (public and private sectors). BTO does an excellent job of announcing funding opportunities and communicating project status and opportunities (e.g., publications, reports, announcements, etc.). Events such as the BTO peer review and having members of the BTO team working with ARPA-E and other DOE agencies are great ways of engaging with other stakeholders. Also, in my experience, members of the BTO team have been very open to meeting with researchers to discuss current and future directions.

- I'm not sure I would change anything here.

E. Metrics

This portfolio was rated **3.50** for the degree to which it has identified appropriate metrics against which its performance will be measured.

- The sub-program has well-developed energy savings metrics that can be systematically tracked. Furthermore, the sub-program is investing in benchmarking to help validate developed technology and its potential impact.

- The sub-program meets its energy savings goals and is the leader in defining occupant-centric measures.

- Yes, the sub-program has the proper progress and impact metrics, as well as methods of tracking them.

- I don't know enough about the program's progress and impact metrics (and performance against those metrics) to answer this question. I did not see information at the Peer Review event, or in related documents/reports, that gives me the ability to answer this fully. Therefore, although my answer to the subsequent rating question is required, feel free to discount it as it's not based on much other than a general feeling that the program seems to be doing reasonably well.

- Metrics are well-defined (cost reduction, energy efficiency), yet the cost/efficiency values are highly dependent on the models used in SCOPE. Hence, it should be considered to validate the cost and efficiency predictions of SCOPE and to include alternative technologies, as well as those outside the BTO scope, in order to ensure that the developed technologies are eventually successful in the market.

- In general, the metrics are appropriate. More of a focus on accelerating technology adoption would be welcomed. The program could support this through education, outreach, and tools but also through technology development (e.g., simplification, self-configuration, self-commissioning).

- I believe BTO is using the proper metrics to track progress as we currently understand the environment. Having said that, I do believe the ability to forecast adoption rates of current and future technology and the role new technology will play on performance timelines may not be adequately addressed. On the other hand, I'm not sure how to capture this uncertainty other than by continuing to closely monitor the environment and adjust as needed. For example, as 5G and IoT penetrate the marketplace, what is the expected impact on power consumption, particularly in the residential market?

F. Additional Comments and Recommendations

1. Project Strength

- The sub-program strengths are listed below.

- The project team is able to engage government labs, industry, and academia in innovative research with a path toward technology transfer.

- The project is addressing very real and long-neglected problems of poor building control and management and end user dissatisfaction by developing cutting-edge sensors and controls strategies and including human-in-the-loop.

- The project is supporting innovation and benchmarking.
- They are clearly defining metrics for success.
- They are ultimately contributing toward significant energy savings.
- You are building upon a solid research foundation.
- The program seems to have good relationships with labs and some technology companies working on specific sensors and components.
- The program is working with several other initiatives (such as the ARPA-E SENSOR program).
- The program is working both at the sensor/component level and at the whole-building and beyond level (e.g., SCOUT).
- The program has substantial focus on interoperability and cybersecurity.
- Innovative R&D is complemented by simulation, benchmarking, and validation efforts to demonstrate benefits.
- They focus on price (low cost) to avoid development disconnected from market requirements.
- They have commercialization of innovative sensor technology through CRADA.
- The sub-program has done a nice job of driving technology development in the right areas, such as occupant-based sensing and controls and wireless plug and play sensing. In general, the research is focused one step ahead of where a large body of academic and industrial research is currently focused but not too far ahead as to be irrelevant. I think the sub-program has found an appropriate balance in this regard. One exciting area is the new infrared thermal comfort sensing project and one additional opportunity would be in using personal communication devices to provide occupant input and feedback on occupant comfort and preferences.
- The BTO Sensors and Controls Portfolio's strengths include a broad spectrum of technical challenges and the recognition of the importance of addressing MELs, interoperability, and cybersecurity. I also believe peer reviews greatly enhance BTO's program of ensuring the correct areas/sectors are addressed.
- In addition, the BTO is staffed with individuals with considerable experience and depth. Finally, the BTO is frequently engaging industry on a regular basis.

2. Project Weaknesses

- There are no significant weaknesses, beyond limited funding that seemed to have been focused on one program area per year. More funding would enable faster progress that would ultimately result in even more significant energy savings and more positive impact on the environment. A minor weakness is limited ability to reach out to real estate and building management stakeholders who ultimately make adoption decisions. This may be mitigated by providing some incentives to these stakeholders to be more actively engaged.
- There are no weaknesses that I am aware of. You have been very thorough.
- The program may not have enough focus on bringing component-level innovations in sensors and components up to the whole-building level.
- The impacts of various projects in this portfolio will be limited by several factors including regulatory (i.e., rate structures, energy code details, etc.), market (fragmented groups of service providers, equipment/building owners, manufacturers, the building owner/tenant split incentive problem, etc.), and more. Many of these

issues are beyond the scope of these projects (justly) but should be kept in mind when working on products and technology innovations to ensure that they can be rolled out in the real world to a reasonably successful degree.

- The transfer from traditional building automation (installed base) to innovative control (model-predictive control) and analytics (machine learning) should receive more attention. What is missing/needed to shift existing building automation/management systems toward these new technologies at scale?
- While there is a focus on system integration and interoperability, there could be more attention on developing strategies for data-integrated building systems which share data between system domains (HVAC, lighting, security, power, IEQ monitoring, etc.). This is an emerging area with a lot of opportunity to deliver incremental energy savings, as well as other occupant and building performance benefits.
- Overall, the BTO Sensors and Controls Portfolio is a strong program. If there is a weakness, it would be a lack of looking at other sectors (e.g., advanced manufacturing) to determine how these sectors are addressing overlapping/common problems (e.g., interoperability). Finally, I also recommend talking to the big data/service providers like Google, Amazon, and others to learn about their future technical directions (at least as much as possible given proprietary issues) that may impact energy efficiency goals.

3. Recommendations

- The sub-program has potential to make a significant impact on energy savings. However, with limited funding, focus areas are targeted sequentially. More funding would enable more integrative approaches to compete for funding, which could bring solutions to practice more rapidly.
- I have nothing to add to the research that you have already identified.
- I recommend that you review the CABA/NBI Controls in Zero Net-Energy Buildings research report. In particular, it may be useful for the OpenBuildingControl project.
- Leverage machine learning empowered controls to take advantage of data generated by research projects. Take the Nest approach and apply it to sensor improvement any time you have a pilot project where that's a helpful approach. Consider how data gathered from pilot projects can be leveraged to benefit other related but separate projects.
- Seek to quantify non-energy benefits of energy efficiency upgrades (related to sensors and controls of course) because the only way we will get to widespread adoption of deep efficiency gains will be to justify projects for multiple reasons at once.
- A prioritization of barriers to achieve BTO's goals might help to prioritize R&D funding.
- The market calculations with SCOPE are, in some cases, counter-intuitive and should be evaluated against alternative technologies.
- Focus less on developing simulation and emulation tools for system developers and more on developing the next generation of learning control systems that can address the significant installation, commissioning, operations, and maintenance challenges with existing sensing and control systems. Additional focus on system interoperability and integration is also warranted given DOE's significant role and influence in standards development.
- As previous noted, I believe the current BTO Sensors and Controls program is robust. I do recommend the following.

- Engage more with other sectors (e.g., advanced manufacturing) to learn how they are addressing overlapping challenges (e.g., cybersecurity, interoperability, etc.).
- Watch the data privacy regulatory climate as policies and regulations passed may have a disruptive impact on future Sensors and Controls technologies and BTO energy usage goals.
- Engage with big data/service providers such as Google, Amazon, and others to learn of future technical directions and potential impacts on BTO goals.
- Watch the rollout and evolution of 5G, IoT, and other advanced communication technologies as they will facilitate the growth of new services and devices that will most likely impact BTO energy goals.

Portfolio Review: Grid-Interactive Controls

Presenter: Erika Gupta, U.S. Department of Energy

Brief Summary of Reviewer Comments

In general, most of the reviewers agreed that the barriers and technical challenges identified are real and appropriate for the Federal Government to address. Many of the barriers have to do with challenges that span across states, across industries, and across various layers of the grid and the building, such as communications protocols to enable building systems and devices to accept (and act on) grid signals, making them unlikely to be addressed by the private sector. Also, transforming the existing building stock to accommodate and enable increased renewable energy is a substantial challenge that will have wide-ranging benefits to all of society, an appropriate challenge for the Federal Government.

Many reviewers expressed concerns about market adoption as a major barrier. While these topics are incredibly important, transactive controls are so new that it will take a comprehensive plan to penetrate the market at this point. An awareness and outreach campaign may not be premature to include even in the research phase of the sub-program. One reviewer warned to be careful not to counteract what the market wants to do naturally, while another reviewer suggested that important non-technical/market barriers should receive more attention.

Most reviewers agreed that the sub-program significantly advances the state-of-the-art (SOA). The 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 our electric grid. Also, grid-interactive efficient buildings (GEBs) are such a forward-leaning area of focus that most work in this space advances the SOA, and controls is an area of immense need.

Multiple reviewers were uncertain about the sub-program's support for industry. The extent to which the industry members were participating in R&D (versus providing equipment) was not clear. Despite reviewers' uncertainty about the relationships with industry partners through these projects, some reviewers commented that the sub-program does support the industry, not only in publicity for those who stepped up as key partners, but also in terms of providing solutions to other technology providers.

Several reviewers noted that the projects do not seem like they are part of a cohesive plan. Compared to other sub-programs, it did seem like each lab was pursuing common challenges, but it did not seem like there was common thread that made all the work inter-dependent. One reviewer suggested that there may need to be a concerted effort to bridge gaps between projects and to pull lessons learned and tools developed from one project to the next.

Many reviewers praised the sub-program for being well-positioned and well-coordinated with private sector organizations. This was clear from the demonstration projects and the partners incorporated. Some of the pilot projects did note private sector vendors, hardware suppliers, test sites, etc. as being part of the projects. With this being such a new area for BTO, multiple reviewers agreed that it seems like there is a lot of room to grow in this private sector collaboration and transfer to private sector should receive more attention.

With regards to communication and stakeholder engagement, many reviewers agreed that utilities should be more involved. The sub-program should conduct interviews with utilities about their needs and overall, the projects would benefit from much greater electric utility, DRMS provider, and demand aggregator (both residential and commercial) participation. One reviewer suggested that this sub-program should integrate more with utilities that are explicitly interested in activating grid-enabled controls and potentially even transactive energy in their territories.

Overall, reviewers agreed that sub-program accomplishments and results appear to be communicated in the proper venues and in a timely fashion. Multiple reviewers agreed that the information provided was very sufficient to give the reader a solid understanding of what is trying to be accomplished through its lab projects, and how they relate back to BTO-wide goals. One reviewer suggested that the results should be presented at more conferences and events as they are available.

Most reviewers were uncertain if there were any progress and impact metrics and tracking methods, since they were not covered in the presentation. Therefore, it was difficult for the reviewers to assess performance based on metrics based on the information provided. Metrics should be clearer, especially financial goals to bring this into the market.

However, reviewers pointed out that some individual projects did define metrics. For example, the PNNL projects do a reasonable job of listing goals and defining success and the sensors and controls (S&C) logic models also describe key outputs such as next-gen prototypes, predictive algorithms, adaptive controls, etc. Using the S&C key outputs as the basis of sub-program metrics, the sub-program does appear to be making progress toward several of the key outputs.

Weighted Average: 3.12 # of Reviewers: 11
Scope: 3.27 Impact: 3.36 Collaboration, Coordination, and Integration: 2.91 Communication and Stakeholder Engagement: 3.00 Metrics: 2.45

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning.

A. Scope

This portfolio was rated **3.27** for the degree to which the scope identifies and targets key barriers and technical challenges that are appropriate for the Federal Government to address.

- This is a new area that still needs to stake out the corners of the market. It is absolutely critical that the DOE address this challenge. It's nice to see the team interpret the challenge from the smallest scale of sub-system controls up to grid-scale controls in the context of transactive controls.

- It seems to address most of the challenges, but there seems to be a couple areas to further develop before being able to fully help the market. One is a further understanding of the supply side market, both wholesale rates and transactions, as well as grid infrastructure needs. Grid infrastructure needs are important in that maintaining the status quo existing conditions are not needed. What is needed is a redesign of the grid and approaches to solve this. The second area to focus on is the integration of BEM, especially in the advent of Modelica/Spawn for a true physics-based, bottom up understanding of the buildings, rather than a misplaced utilization on RC models.

- The barriers are many. The regulatory landscape is a moving target in terms of what is possible in front and behind the meter. Second is market adoption and deriving value from the research. While these topics are incredibly important, transactive controls are so new that it will take a comprehensive plan to penetrate the market at this point. An awareness and outreach campaign may not be premature to include even in the research phase of the sub-program.

- Generally, yes, care should be taken to pursue technology and support system development for needs that have unrealized value, not just for technical curiosity. This appears to be largely the case with efforts like VOLTRON and the overall effort to enable peer to peer transactions.

- Be careful not to counteract what the market wants to do naturally. The market has an incredible ability to draw out exactly what it wants and needs exactly when it needs it. Technology development that may have been stagnant for years can suddenly accelerate to accommodate a maturing value stream, seemingly out of nowhere, in the market. There should not be an obligation to see research results and developed tools as the ultimate adopted outcome, but rather, be satisfied if the development helped to foster and support whatever ultimate outcome happens.

- The scope for this area is complicated. In general, there are many challenges with getting standard building controls to be plug and play and interoperable, let alone the controls and systems for GEB and for buildings to have two-way communication with the grid. On the other hand, the transactive energy and work related to responding to price signals trends toward market, tariff, and rate design that is less about needing to test technical barriers and is rooted in energy business model and regulatory issues. I think for DOE to be most effective, they need to focus on controls and communication to work thru the technology challenges.

- Much of the work seems to focus on price. Price is great if externalities are properly internalized and people make perfect decisions. With many buying decisions people make, price is not the only factor, especially when externalities aren't included. Has DOE tested other metrics besides energy price to see how consumers may respond to signals such as resource mix, environmental (fish), local needs/constraints, severe weather, etc.?

- The team has done a nice job identifying both the HEMS and transactive signal system components to allow for DER load control for grid optimization in an open-source decision tool. The main component missing from this configuration is pricing. Knowing what tariff the building owner is on will help identify the actual economic benefits of load control to the customer.

- The barriers and technical challenges identified are real and appropriate for the Federal Government to address. To succeed in this program, a comprehensive paradigm shift is necessary. I am impressed at the accomplishments made thus far and laud your progress.
- Yes, I feel that the barriers were well identified and addressed in this presentation, for the most part.
- I feel that the government has a role to play in addressing each of these barriers, even if they're not all 100% within the government's wheelhouse to address. A good example is interoperability. The government can call for and require completely open control protocols and send a clear message to the industry that they need to innovate on this front.
- I do not think that all the barriers were sufficiently addressed. For instance, the communication and interoperability barriers say they'll be addressed using VOLTRON and GAP. Currently, I don't believe that VOLTRON has had much uptake in the private sector, so I wouldn't call this barrier "addressed" by simply listing VOLTRON and GAP. Cybersecurity and interoperability are the two largest and seemingly unsolvable barriers preventing the government from experimenting with GEB control, and these two need to be taken more seriously.
- I appreciate that almost all of the barriers had direct ties to DOE-funded lab work.
- Yes, I believe that the portfolio does a nice job of addressing the barriers and technical challenges, as well as it could. These are new and emerging challenges, and I'm sure the barriers will shift each year until we achieve success. So, for the time being, yes, the project portfolio does a nice job rounding out the barriers, with the exception of my comment above on interoperability and cybersecurity.
- See comment above about need to more deeply address interoperability and cybersecurity. Yes, I know I sound like a broken record!
- Yes, the barriers identified here and addressed here are real and should be addressed by DOE and national lab partners. Many of the barriers have to do with challenges that span across states, across industries, and across various layers of the grid and the building, such as communications protocols to enable building systems and devices to accept (and act on) grid signals. These are certainly important, but in today's fragmented market, they are unlikely to be addressed by the private sector in a way that leads to open-source, consistent, universal, and economically efficient outcomes. Knowing the scale of the opportunity (quantitatively) will be critical in achieving buy-in to roll out these technologies.
- The portfolio addresses the barriers it identifies, though of course there are acknowledged gaps (e.g., security, communications). There is somewhat minimal focus on real-world demo projects, Connected Homes notwithstanding.
- There are some barriers related to real-world implementation that aren't fully considered. For example, how do grid enabled sensors show up in utility programs, governmental policies, and energy codes? They need to have demonstrated impacts and cost effectiveness evaluations. This means careful evaluation of a range of specific ECM/strategy packages and their costs and benefits so that we can develop a set of options for implementation.
- Priority research needs are clearly identified and addressed by the projects in the program.
- What is the BTO/building-specific research need for cross-domain technologies like security and interoperability beyond "simple" transfer from other domains?
- Important non-technical/market barriers should receive more attention.

- What are market barriers, i.e., why are technologies that are demonstrated at TRL8-9 not being picked up by start-ups or major vendors?
- Under which constellation is the setup (amount of renewable integration, number of flexible loads) competitive to alternative solutions like renewable curtailment?
- What does the market look like, if 10% of all residential homes participate in transactive markets? What size of a flexibility market is required to sustain the investment in home energy management systems and who is paying for this flexibility (renewables, taxpayers, the other 90%)?
- The barriers and technical challenges identified and addressed by the sub-program are real, significant, and appropriate for the federal government to address. Transforming the existing building stock to accommodate and enable increased renewable energy is a substantial challenge that will have wide-ranging benefits to all of society. The sub-program has done a fairly thorough job of outlining specific challenges related to the primary objective. For example, characterizing building ability to participate in transactive markets and system scalability are two noted priority research needs.
- The project portfolio addresses the identified barriers and technical challenges in a number of ways. For example, the Oak Ridge Smart Neighborhood projects and the PNNL Texas Campus project are gathering valuable insight into real world challenges. Several projects are also aimed at characterizing flexible building loads.
- Although the program does a good job of identifying barriers and challenges at the building-grid interface, there may be other barriers that are more clearly identified from the utility/grid perspective.
- One reviewer noted submitting review comments in other related sessions.
- Overall, yes, this sub-program notes many key challenges and does not appear to have sufficient resources to address them all.

B. Impact

Assuming that the ***portfolio-specific goals*** are met, this portfolio was rated **3.36** for the degree to which the portfolio is ***expected to*** contribute to ***program and BTO goal(s)*.**

- There are some areas where it excels and some where it does not. Some of the TCC presentation was excellent, until the parts where they use RC models instead of physics models using EnergyPlus. And the use of linear algebra (MILP) rather than using modern analysis of AI/ML/DL would be expected of the labs to really be on the cutting edge of research. They are on the right track with VOLTRON and using multiple agents, but it could really be excellent if combined with spawn and other BEM sub-program techniques. The connected homes and PPPO work was enjoyable and seemed to be very well thought out.
- In general, the sub-program does effectively support the industry. There could be more up-front coordination (and it does seem like it's in the early stages of doing so) with IRP practitioners. The team has a unique opportunity to bridge an industry gap between system planners, DSOs, load balancing authorities, LSEs, and DSM admins.
- It seems like they are at varying stages of integrating all stakeholders, and there were no glaring gaps, but again, they are at varying stages of engagement.
- It was promising to see how cost effective this sub-program forecasts some of its work will be for the market. It opens up a whole new range of possibilities for energy savings that can fit under energy efficient programs and of course, be extended to all other IDSM/IDER programs.

- Generally, I say yes to all questions. I wrestle a bit with the need for open communications, a stated priority research need. A requirement for open standard can be an impediment to adoption because it can end up being a glove that fits no hand. Standardized communication often means open but not always. Also, the pursuit of standard and open methods can create enormous time delays to development, while manufacturers wait to do any core development until a standard is fully developed and vetted. Meanwhile, proprietary systems may develop and provide very high value. I have no wise guidance here.
- Voltron, CTA 2045, Open ADR, and interoperability projects continue to move forward with controls issues. They need to continue to test a different array of communication pathways.
- The transactive energy work has been tested for years with little adoption. They need to ensure they have a good handle on the barriers and understand the impact the work is having. Much work is going on overseas related to deregulated energy markets that could inform DOE's efforts.
- The value proposition presented by the team advances the technical state of the art, creating models of decision for load adjustments. I'd like to see the decision framework being developed here to be tested in one of the ORNL projects, such as those in Georgia or Alabama.
- The sub-program significantly advances the state of the art, and the sub-program effectively supports the sub-program objectives. This research is critical to shift to the solar economy.
- This sub-program advances the state of the art, without a doubt. GEB is such a forward-leaning area of focus that most work in this space advances the state of the art, and controls is an area of immense need.
- I also feel that the demonstration projects are an excellent first step in addressing GEB controls in real life, demonstrating the impact and uncovering the challenges. ORNL's Alabama and Georgia examples were the most meaningful toward showing that DOE is making progress toward its goals in a real-world application. The PNNL examples felt too far from real-world implementation and too focused on achieving results in a controlled setting. While I recognize the value of experimenting first in a controlled setting, I feel that we need to move the GEB concept faster, even if that means failing quickly in real-world applications. The largest risks are overvaluing the capability of demand-flexible technologies, and the risk of not delivering hot water, heating, cooling, etc. is quite low. The former relies more on real-world conditions and uncertainties than laboratory experimentation, and I'd hope that these projects could drive more toward real-world implementation.
- I believe the sub-program does effectively support the industry, based on the demonstration projects and the partners involved. It's not 100% clear what the relationships with industry partners are through these projects, but I believe that if these projects are carried out in the same transparent ways that most DOE-funded projects are, they will support the industry, not only in publicity for those who stepped up as key partners, but also in terms of providing solutions to other technology providers. I particularly appreciated the vast array of technology partners on the ORNL projects, which seemed more expansive than the PNNL projects.
- I feel that a larger portfolio of utilities could be supported because there are so many utility/regulatory arrangements in the United States, that this small cohort of represented utilities could be vastly expanded.
- I also don't see much engagement from the ISO/RTO community, who I believe to be an important stakeholder in the GEB conversation, particularly in valuing demand flexibility and other services.
- I would say that the sub-program contributes well to BTO's overarching goals and contributes to energy cost savings and, to a lesser extent, to energy savings themselves.
- GEB also contributes somewhat to energy savings, but GEBs do not need to save energy. The point is that they provide flexibility, which lowers grid costs and grid carbon emissions, while generating revenues or energy cost savings for the end user.

- This space is moving fast. That fact, coupled with the fragmented nature of the market for building systems and components (controls included), means that there's substantial risk of a whole lot of dead-end technologies (think laser disks and minidisk players) as new products and capabilities come to market. If DOE supports research that can lay the foundation for consistent, clear grid-integrated controls and equipment standards that manufacturers can agree on, that would make a big difference. Interoperability and security are critical pieces of this puzzle and this portfolio should be sure to align its work and outputs closely with other BTO work on those topics.
- I don't know enough about the key industry players beyond my slice of the pie to say if this effectively supports the industry, or whether key industry stakeholders are left out. The collaboration with ASHRAE, BACnet, Project Haystack, and Brick is encouraging.
- This contributes to BTO's energy savings goals, especially as the role of buildings and the grid changes. The focus on GEB is largely predicated on controls and communications between those controls and the grid. This is critical work.
- The sub-program advances the state of the art by taking advanced methods into field tests (high TRL).
- Utilities and vendors are included in field tests. Yet, significant impact can only be achieved if transactive control is transferred and scaled up in the private sector (start-ups, major vendors). Some of the corresponding barriers (market design/regulatory framework) should receive more attention.
- BTO's energy savings goals are supported, yet, transfer to market needs to be clarified.
- The sub-program does advance the state of the art by supporting novel control platforms that are seeking to change how the balance of supply and demand is achieved within our electric grid.
- Industry is somewhat supported in several of the projects through partnerships with residential water heater and HVAC manufacturers. The extent to which the industry members were participating in R&D (versus providing equipment) was not clear.
- Design engineers do not currently appear to be represented in the current portfolio. As flexible buildings begin to play an increasing role in ensuring reliable and efficient grid operation, designing buildings that incorporate increased levels of flexibility will require revising traditional design practices.
- Energy efficiency is included as an objective of the transactive and smart control architectures, so the sub-program does effectively contribute to BTO's energy savings goals.
- The program both advances and lags the state of the art.
- As an example of lagging state of the art, demand aggregators have been using home-specific thermal models to plan and provide optimal DR to utilities programs.

C. Collaboration, Coordination, and Integration

This portfolio was rated **2.91** for the degree to which its activities demonstrate strategic collaboration or coordination with relevant programs and partners.

- Compared to other sub-programs, it did seem like each lab was pursuing common challenges, but it did not seem like there was common thread that made all the work inter-dependent. In BEM and Data sub-programs, there were foundational building blocks such as EnergyPlus or BEDES/BuildingSync that every lab was either working on or dependent on. In the same manner, it would be nice to see if this sub-program could find that common thread so that all the labs were strategically co-dependent on each other to succeed.

- There was one element that did stick out to me which was the lack of integration of BEM advancements when it came to TCC, MPCs, etc. With both the residential and nonresidential advances in physics-based energy modeling with high sophistication, I was puzzled why some of the labs were not using that 'under the hood' of their work. It seemed to be a glaring opportunity for cross-program collaboration. Also, OE and SETO, and the counterparts at the labs working on those contracts, could be more involved to bridge the gaps between other office work products.
- Some of the pilot projects did note private sector vendors, hardware suppliers, test sites, etc. as being part of the projects. With this being such a new area for the BTO, it seems like there is a lot of room to grow in this private sector collaboration.
- It seems too early to have channel partners at this time, but planning ahead for it would be beneficial.
- As mentioned in the previous question, some of the big controls contractors/vendors are at the table. Just as the Data sub-program seemed to have created a standardized market of stakeholders, volunteers, and participants, this sub-program can likely do the same.
- This is a difficult question to answer, as I am not intimate with the sub-program and its primary practitioners. Nothing I've seen indicates that it is not well-integrated within DOE, but I really don't know.
- Regarding external organizations, the DOE should strive to be supportive and complimentary to the industry it serves. It must be careful of its size and stature and that it does not intentionally or unintentionally dominate the direction of the electric and buildings sectors. By its sheer size, it can change the direction of the industry and potentially expend massive amounts of money on unknown value. With this particular sub-program, I cannot point to anything that fits that category, but there is a sincere obligation on the DOE staff to make sure that it doesn't happen.
- This sub-program should be guided primarily by the U.S. utility industry and its experienced practitioners who know the dynamics of the electricity business. There is good connectivity with external stakeholders including electric utilities, manufacturers, universities, and other solution providers.
- With the ORNL smart neighborhood, there is great engagement with Southern Company, EPRI, and other industry partners, including testing of multiple control strategies (open ADR, CTA 2045, etc.).
- Cybersecurity is a huge issue and needs appropriate focus. Any flexibility loads could provide would be offset by potential cybersecurity concerns to the grid.
- There are efforts related to open field message bus for interoperability within distribution communications, DERMS advances, and other methods like block chain. They need to ensure DOE is keeping abreast of communication market changes.
- I'm not as knowledgeable about BTO, EERE, and DOE goals and programs, but this appears to leverage knowledge in other areas such as residential retrofits, demand response, and commercial retrofits for building optimization, in addition to AFDD. The team is utilizing VOLTRON for operational strategy, in addition to GAP. I recommend using a variety of communication protocols when testing these systems to see which might integrate best with commercially available control applications at the building level.
- The sub-program is well-integrated and internally cohesive. The sub-program is well-integrated within BTO, EERE, and DOE. The sub-program appears well-positioned and coordinated with the relevant public and private sector organizations.
- Is the sub-program well integrated and cohesive internally? It's difficult to answer this based on the materials provided.

- Is the sub-program well-integrated within BTO, EERE, and DOE? Does it effectively leverage other sub-programs and support other sub-programs? It's difficult to answer this based on the materials provided.
- Yes, it is clear from the demonstration projects and the partners incorporated that the sub-program is well-positioned and well-coordinated with private sector organizations. I would say that there aren't many examples of public sector organizations represented and that this could be improved.
- Does the sub-program effectively utilize channel partners? It's difficult to answer this based on the materials provided.
- I would say that the partnership opportunities included appear to be the right ones, and I am particularly pleased to see some dedicated utility partners who are invested in the work. See comment above about continuing to broaden the net of utility partners. I recognize that it's difficult to cast a wide net with a finite amount of funding, but I want to note this as a potential area for continued growth (to get a greater diversity of utility/regulatory structures represented).
- Also, see comment above on including ISO/RTO players.
- Aggregators could also play an important role in these projects.
- This sub-program feels a bit more like several related projects (which to be fair, all sub-programs are), but I think there may need to be a concerted effort to bridge gaps between projects and to pull lessons learned and tools developed from one project to the next. In particular, leverage the work presented by Di Wu to quantify potential impacts, and scale that work to go beyond just preheating and precooling, to make an effort to define the scale of opportunities in the specific focus areas of other projects. That will help all these projects go beyond the conceptual stage.
- Be sure to leverage work of the previously mentioned partners: ASHRAE, BACnet, Brick, and Haystack. Surely there are other key partners beyond these.
- The sub-program should be careful to avoid "picking a winner" in terms of technology and manufacturers and should avoid endorsing proprietary systems, but I do recommend working closely with controls manufacturers to deploy equipment and evaluate project impacts. It would be better if these demo projects avoided proprietary communications protocols that can lead to "vendor lock," but in the real world, that's not always the prime concern, so maybe it's forgivable.
- The sub-program has good interconnection within BTO and within DOE (GMLC, SETO, VTO).
- There are several industry partners in the field tests. However, transfer to private sector (Nest, Johnson Controls, UTC, start-ups) should receive more attention.
- One reviewer provided their comments in other related sessions.
- The projects within core research groups (e.g., national labs) appear to be cohesive. It is difficult to evaluate the cohesive nature of projects across the entire portfolio. As expected, there are some similarities. However, unique contributions appear to be present among all presented projects.
- The sub-program does appear to be well-integrated with BTO. Many of the sensors and controls projects would support, inform, or feed into other sub-programs, such as HVAC and CBI. The program topics also appear well-integrated with other interests across EERE, such as SETO Systems Integration. The program also appears well-aligned with broader Beyond Batteries and GMI initiatives. There could be more collaboration across offices within DOE. For example, collaboration with OE could be beneficial.

- Channeling partner utilization for commercialization of advanced sensors and controls topics was not immediately apparent in the presented material.
- The program currently leverages several utility partnerships and mixed stakeholder technical advisory groups.
- The projects do not seem like they are part of a cohesive plan. I think this reflects how GMLC funding was allocated well before the current program manager came on board. Hopefully, this will change with a sub-program manager on board.
- Overall, the projects would benefit from much greater electric utility, DRMS provider, and demand aggregator (both residential and commercial) participation, as well as a greater focus on field testing and demonstration to see how effectively solutions developed really work and hit real-world implementation challenges. The ORNL projects with Southern Company are notable exceptions.
- I think the sub-program could be integrated more closely with DOE-SETO's work, particularly its SHINES demonstration projects, many of which include significant buildings load management components integrated with renewable generation and storage.

D. Communications and Stakeholder Engagement

This portfolio was rated **3.00** for the degree to which it demonstrates integration of stakeholder input and effective communication of project information.

- Aside from the major players in the market, it does not seem like the pool of stakeholders to engage is that large at this point. In addition to finding the rare early adopters, it is promising that the program is looking at test environments for such projects.
- The information about its projects, activities, and plans appear to be timely. Not having followed this track as closely over the last year as other programs, it is difficult to say how effective they are. But from what was shared, it sounds reasonable.
- Are sub-program accomplishments and results communicated in the proper venues and in a timely fashion? This is the same as the previous answer.
- Yes, sub-program accomplishments and results appear to be communicated in the proper venues and in a timely fashion.
- ORNL seems to have a good set of stakeholders engaged. LBNL seems to have a good set of California stakeholders engaged. PNNL could broaden their transactive energy campus stakeholders. For the measurement and verification work, it seems that it could reach beyond the SEE action network to organizations like EVO in the DSM community and NAESB in the wholesale market community.
- I really like the use cases as a means of identifying who should be involved in this project and the communication approaches should be vetted.
- The sub-program integrates input for the proper stakeholders. The sub-program provides relevant and timely information with the relevant stakeholders. The sub-program accomplishments are widely communicated to the stakeholders.
- Does the sub-program integrate input from the proper set of stakeholders? It's difficult to answer this question based on the information provided.
- Yes, I believe that the sub-program does provide sufficient and timely information about its projects, activities, and plans, though the main way for a reviewer to understand this is based on the data point of this

one presentation at the BTO peer review. Based on this one instance, I would say that yes, the information provided was very sufficient to give the reader a solid understanding of what is trying to be accomplished through its lab projects, and how they relate back to BTO-wide goals. I cannot comment on the timeliness.

- Again, yes, sub-program accomplishments and results are communicated in the proper venues and in a timely fashion, based on this one data point, but it's difficult to answer for the sub-program as a whole without being involved long-term.
- I feel that this sub-program should integrate more with utilities that are explicitly interested in activating grid-enabled controls and potentially even transactive energy in their territories.
- Information provided is pretty good, but I think it'd be helpful to set up a website with regularly updated information about the progress of various projects. This space is fast-moving, and these projects are multi-year efforts. If they don't keep others appraised of their progress, they risk becoming obsolete by the time they're done.
- Yes, this program has sought input from a reasonable set of stakeholders. The results should be presented at more conferences and events as they are available.
- They have good publication of projects and results.
- Input from non-DOE sources is not clear. Which stakeholders are included beyond literature reviews, e.g., interviews with utilities about their needs?
- One reviewer provided comments in other related sessions.
- Many of the programs involve multi-stakeholder technical advisory groups and utility partners.
- I do not have enough information to evaluate.
- Accomplishments appear to be communicated in proper venues.
- Overall, the projects would benefit from much greater electric utility, DRMS provider, and demand aggregator (both residential and commercial) participation.
- I have many open questions about several of the projects covered in this session, i.e., the session touched on many projects, making it challenging to understand most of them in much depth.

E. Metrics

This portfolio was rated **2.45** for the degree to which it has identified appropriate metrics against which its performance will be measured**.**

- In the overview and in each of the panels, the evaluation criteria and specific metrics were not as embedded throughout the presentations and work products as others. It was assumed that they are still charting out the metrics, as is expected, and not much criticism can be given to that approach at this point in the sub-program.
- Yes, it appears that the sub-program has identified appropriate metrics against which its performance will be measured.
- The metrics weren’t clear to me reviewing.
- I didn’t see anything in the presentation about metrics.

- The sub-program has the proper progress and impact metrics and methods of tracking them. The sub-program performs well according to the chosen metrics.
- It's difficult to assess metrics based on the information provided. The sub-program did not report metrics, tracking methods, etc.
- The PNNL projects do a reasonable job of listing goals and defining success. The ORNL projects either don't do this or make it difficult to discern from their presentations.
- It's difficult to assess performance based on metrics based on the information provided.
- I will rate the group lower on these criteria, only because little information was provided.
- These metrics are quite difficult. I am not sure that I have enough information about the KPIs for this sub-program to measure them well. From what I learned at the Peer Review and what I've read since, I think the program is performing well, but take that with a grain of salt.
- Metrics should be clearer, especially financial goals to bring this into the market.
- The primary focus is not energy efficiency on a building level but on a regional scale. What are the required investments and the potential savings?
- One reviewer provided comments in other related sessions.
- I do not recall specific mention of sub-program progress, impact metrics, and tracking. Individual projects undoubtedly have their own performance targets and goals that are being tracked. The S&C logic models also describe key outputs such as next-gen prototypes, predictive algorithms, adaptive controls, etc.
- Using the S&C key outputs as the basis of sub-program metrics, the sub-program does appear to be making progress toward several of the key outputs.
- I did not see overall metrics defined or presented for this sub-program. Overall, the "Priority Research Needs" presented are more akin to "guiding principles" and "goals for the program.”
- The "know our building needs" need is not fully clear (vis-a-vis BEG). I think it should mean "the building operating constraints that building load management cannot compromise or the cost-compromise benefit for those constraints.”
- For the "system is scalable" need, I would emphasize that solutions should be very easy to implement, requiring negligible site-specific configuration, and highly reliable.
- Some individual projects did define metrics.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength is in the research area itself and the diverse set of teams that are addressing the challenges. I was impressed with the AFDD, TCC, Connected Homes, and Pliable Buildings presentations. It seems like products such as Voltron have tremendous potential. The team's openness to feedback and to succeed was apparent. The approach of the connected homes program can hopefully be extended to other programs in the sense that they are approaching the problem from the customer's perspective. Energy is not always the focus or may not even be on one's radar as they go about their daily life. Program approaches that have the customer and a value proposition in mind benefit the overall sub-program such as this one project.

- Project strengths are technical ability and wide reach to many stakeholders.
- The project has experienced teams and knowledge experts working across the set of lab projects.
- I like that the team identified experts to help with specific elements of the project such as weather forecasting and grid services.
- For this paradigm shift to a solar economy, we need a comprehensive set of tools including rate structures, controls, storage, and integration of systems. This program has been carefully crafted.
- The sub-program has excellent engagement with the industry and a variety of private sector partners who can really move the needle in valuing and adopting GEB strategies.
- The presentation of key barriers was clear, concise, and useful to generate discussion.
- The focus on real-world projects, and emphasis of those projects over focusing on program goals the entire time, was very valuable and very promising.
- This program is the first thing to give me faith that we are working toward some of the greatest challenges to achieving GEB control. This is largely based on the program's establishment of the right barriers upfront and attempt to solve these through its lab projects.
- The focus on demo projects is good and helps identify real-world problems.
- The focus on demonstrating the potential of flexible loads is good but limited to a few technologies. Expand this approach if it works in this setting.
- The project takes advanced technology into field tests/high TRL.
- The project addresses a broad scope of technical challenges.
- The PNNL and ORNL projects, which started with modeling and then large-scale field tests, are a great approach. While the scope and approach were slightly different, they were both compelling in their impact and learnings. The communication requirements in the Alabama and integration software implications were eye-opening and provide unique value to this area of study.
- The program's strengths are (1) the important challenges that are being addressed and the diversity of the portfolio of projects investigating related issues, (2) several strong demonstration projects such as ORNL Smart Neighborhood, NREL AI Smart Communities, and PNNL Tx Campus, and (3) good leveraging of past developments, e.g., VOLTRON, FNCS/HELICS, etc.
- The overall needs outlined for the sub-program make sense and should be further prioritized to ensure that DOE-BTO makes significant progress in the high-priority areas where industry is less active.
- The two ORNL field demonstration projects with Southern Company are exemplary.

2. Project Weaknesses

- Some of the weaknesses pointed out are the missing binding agent that ties all the sub-programs together. While this may not be easy to just identify instantly, it seems that once it does bubble to the surface, the programs will reach more cohesion. Also, there is a big challenge in the existing industry to bridge the gap between supply and demand side 'usual suspects.' Perhaps this sub-program can fill that gap and have a large impact on the market. But at this point, it did seem like some of the labs were missing that balance between demand side awareness (in BEM specifically) with the system operation. There seemed to be a wide range of familiarity with each side but not specifically with a rooted expertise in both aspects of the market or technical research. Also, I hope RC models are not used any more since BEM is readily available and applicable to this research.

- Don't get complacent by continuing to pursue subjects just because they have been pursued in the past or because they've not been seen to their end. Let the current situation determine if research is valuable.
- It seems like there could be a better understanding of the controls and communications landscape, including how the different options work together (or don't).
- With communications, the telemetry and communications latency are important. They need to understand the time response (full path from command issued to response) of buildings as different grid services have different requirements both in time and duration.
- I would have liked to have seen more prioritization of the research needs, especially when it comes to the use of transactive signals for DER optimization. Scaling will come later, but for now, the value proposition to the customer and understanding how to value the load reduction as a monetary asset is very important.
- My biggest concern is the role of the utilities and potential of gaming of the rate structures. I lived through the dark days of Enron. Providing tools to compare rate structures would help.
- The program does not clearly address cybersecurity and interoperability. There was some explanation given at the presentation, but I wish there was more exploration of this in the presentation materials and by the groups performing field work. If the group is doing work in this field, it should spend more time talking (bragging!) about its work here.
- The presentations of PNNL and ORNL's work was very dense and not parallel. The groups should have coordinated their presentations to (1) be clearer and more succinct, with deep detail saved for appendices, (2) focus on the metrics and other aspects reviewers would need to answer to, and (3) more clearly highlight successes and lessons learned thus far.
- More time should have been given to focus on the PNNL and ORNL field work.
- Include a deeper focus on commercial. Most of the projects that I saw were residential-focused.
- There was a lack of focus on security and communications protocols.
- A fast-moving market means that developments risk becoming obsolete quickly.
- Fragmented market means that it is very difficult to produce uniform and universal communications and connectivity standards.
- Non-technical barriers for transfer into market at scale should receive more attention.
- I think there is an opportunity through working with the DOE Office of Electricity to address the challenges and opportunities of using rate-design as an important tool to support grid-connected controls and GEB functionality. Similarly, while cybersecurity is not necessarily a specific area of focus for BTO, it is a critical issue for implementation and adoption.
- The sub-program has an admitted weakness in the area of cybersecurity.
- The demonstration projects are considered an overall strength. However, most of them appear to be limited to new development. Developing and/or demonstrating applicability and relevance to the existing building stock appears to be a potential weakness.
- Many of the developments also appear to be focused on the residential building domain.

- This sub-program has very large and important ambitions relative to the projects presented (are there more?). Thus, it should prioritize 2-3 needs/goals and focus on those, carefully considering ongoing industry efforts to identify where DOE work has the greatest value.

- I think that this program would benefit from a much greater focus on learning from real-world testing of it. This will surface very concrete problems for DOE to address in close collaboration with ultimate deployment entities, such as electric utilities, leading-edge facility operators, and DERMS providers (conspicuously absent from most projects). Some of the ORNL projects, particularly those with Southern Company, are excellent in this regard.

- For example, the LBNL project "Risk-based framework for dynamic assessment and prioritization of flexible building loads" only will develop models for two baseline models. This should be tested in several (ideally dozens) of different real-world applications, i.e., buildings.

- I would like to understand the type and extent of the field testing incorporated into the PNNL "Quantification of Flexible Load Potential" project. Field testing should be a major component that occurs in many residential buildings at different times of year. Unfortunately, the project focuses on residential, and industry has already implemented models for both DWH and communicating thermostats for DR program optimization (e.g., Tendril, Whisker Labs, Nest).

- "Understanding if buildings can provide reactive power" is listed as a gap. It probably makes more sense for PV inverters and energy storage systems to provide reactive power (along with utility infrastructure). Buildings tend to provide slower services, so this is not a good fit, whereas inverters and ESS controllers can provide faster response.

- PNNL's "Scaling of Building Transactive Controls..." project uses agents at the device level for control. It is based on the real-world communication volumes noted by ORNL when they integrated their systems with Southern Company's control infrastructure. Is the approach outlined viable? Would an aggregator consider this approach?

- PNNL's Connected Homes project has pretty modest ambitions, i.e., utility programs are already achieving >10% reductions in demand from communicating thermostat programs (and have proven electric WH as a resource as well). In addition, the well-intentioned comfort-performance trade-off queries ask a lot of occupants, i.e., the interfaces conceived will almost certainly be too complex for most people. This needs to be really simple. Also, the project appears to actuate based on a fixed price level, i.e., if the price for the next fifteen minutes exceeds the threshold, the system curtails. If that is the case, it is not clear how it will optimize demand because it doesn't consider future loads and utility prices beyond that time horizon. Finally, testing in five homes is underwhelming, considering existing utility DR programs.

- I have a challenging time envisioning a building owner listing "all the assets and data sources associated with their power consumption and controls." Most won't take the time or really know all those things. Instead, I think DOE should focus on self-learning and configuration approaches. I am also very skeptical about people providing the inputs to develop a "value function" that represents their balance between gains and losses. As with the other project, this kind of input should be very simple to have a chance to be used.

3. Recommendations

- Take the teams and travel out of the US to understand how the rest of the world is operating connected buildings, whether its district energy systems or places with lax regulatory constraints. Take on a Rockefeller Foundation project to advise on an international project in a developing country where you have a blank canvas and no energy infrastructure. Get more real projects any way you can and don't let regulatory challenges get in the way of technical potential. Lastly, find ways to create value to stakeholders to the point where voluntary adoption of technologies in this sub-program are so beneficial, they don't need to be incentivized. Transactive energy seems to have a large potential in this area.

- In line with an earlier comment, be careful that the sub-program is always doing benefit to the greater industry and not accidently pulling the industry in a less than optimal direction. The DOE is in a unique position, by the nature of its size and country-wide domain, to have very large influence on the smaller players in the industry.
- It seems important to relay the role of building commissioning to GEB and controls. We've long known the importance to commission controls and buildings, but GEB adds to this importance. A well-commissioned building should have better control and known flexibility. At minimum, add language to relay the impact to and importance of commissioning. It may require research to prove the importance.
- Most of this work is based on price. I suggest looking at the buildings ability to respond to other signals such as resource mix, environmental (fish friendly), local grid constraints, emergency/non-routine operations, and occupant comfort.
- The work assumes occupant comfort is a static variable and constraint. I do agree occupant needs should be met, but in general, we poorly understand their needs and whether they are being met (a single thermostat is a poor indicator of whether an occupant's needs are met), but I think we need to test occupant needs as an input variable, especially for providing flexibility in emergency situations. We need to distinguish much better between flexibility for daily operations versus emergency and flexibility provided for reliability versus resiliency. I think better understanding the buildings response and controls actions for specific reliability products and for reliability versus resiliency responses is important.
- I didn't see metrics or a timeline included in the slides. Both would have been good to understand what elements of the projects will be available when.
- See previous question.
- Include a deeper focus on commercial. Most of the projects that I saw were residential-focused. There is greater need and greater opportunity for GEB in commercial buildings. It's assumed that commercial energy management is well-understood and well-addressed, and that all we need are functional control algorithms. The interoperability issue is major here and prevents most building systems from talking to one another (let alone letting them talk to the grid and respond to price or carbon signals).
- Not sure if this is an appropriate place to talk about the modeling sensors and controls report, but that report was very high level and scattered. They could use greater coordination with this group, mention of these excellent pilot projects, and a lot of clarification, editing, and re-organizing.
- Overall, enhance transactive energy valuation framework to value resiliency. An example is a building that could pay a premium for higher reliability (priority in blackouts, etc.) or that could be compensated (lower rates) for accepting lower grid priority in events because they are more resilient and are better positioned to handle loss of grid power. How can we lay the groundwork for sensors or equipment that can activate this market approach?
- For Priority Research Need, I'm not sure which project can do this, but I recommend that DOE examine rate alignment and fund the creation of coordinated datasets of TOU/real-time rates, so that the time-related needs of the transmission system, distribution, and consumer can be aligned in terms of rates, at least in theory (as a first step). At a minimum, create synthetic TOU rates across the nation even if the actual rates aren't there yet (for research purposes).

- For the Quantification of Flexible Load Potential Project, can these tools be used to define the bounds of potential impacts in various asset classes, to define thresholds by equipment, system type, region, building type, etc.?
- For the Oak Ridge Smart Neighborhoods Project, they need enhanced focus on automation and training for the occupant/end user. For instance, how do you simplify the controls so that a homeowner could select "saving" mode or "override" mode. In the next phase (the commercialization phase), this will be critical.
- Investigate technology to market transfer barriers and how to remove them.
- I wouldn't rely solely on the VOLTRON platform in grid-connected control projects. The PNNL and ORNL projects are very impressive, but hardware isn't really the limitation at this point and system providers are unlikely to adopt the platform for commercial use. After successful field testing, collaboration with system providers using commercial technology should be the priority. Also, agent-based transactive methods are very interesting, but other approaches should be considered to balance computational, communications, and market considerations.
- The PNNL recommendation of combining functions such as GEB, AFDD, and model-based commissioning to increase the energy savings and value to the home/building owner is an excellent idea which should be pursued.
- Thank you for the opportunity to review this sub-program. In general, the organization and achievements of the sub-program are noteworthy. The following ideas may be considered for potentially improving the sub-program in the future: (1) expand project portfolio to include more complex commercial building systems and urban environments, (2) collaborate/coordinate more closely with other programs, e.g., SETO, GMI, VTO, and Office of Electricity to ensure alignment of desired outcomes and joint development of project thrusts, and (3) begin shifting the energy efficiency conversation to a more holistic/community-level perspective. As buildings become more efficient at the site-level, investing in technologies that improve grid efficiency (e.g., through reducing PV curtailment with flexible loads) may have a greater overall impact. This shift in perspective may also alleviate real and/or perceived tension between energy efficiency goals and provision of grid services from flexible loads.
- This project has very large ambitions relative to the projects presented (are there more?). Thus, it should prioritize 2-3 goals and focus on those and also, coordinate efforts more closely with other DOE entities, as well as utility stakeholders.
- Overall, this area would benefit from much greater integration with and participation of electric utilities, particularly to implement field demonstration projects to surface and address major implementation challenges. The two large ORNL projects with the Southern Company are exemplary in this regard. Furthermore, projects should be implemented in grid locations where the key problems to be addressed already exist. This will put solutions to the test and provide greater insight into the design of future solutions.
- DOE-BTO should work on cybersecurity through existing industry associations.

BTO Partnership Activities

Commercial Buildings Integration

Partnerships Review: Commercial Buildings Integration (CBI)

Presenter: Amy Jiron, U.S. Department of Energy

Brief Summary of Reviewer Comments

Overall, reviewers greatly approved of the Commercial Buildings Integration (CBI) Partnership portfolio, which included presentations about Advanced Energy Design Guides, DOE Campaigns, and the Better Buildings Initiative. The majority of reviewers indicated that the barriers and technical challenges that CBI identified were pressing and appropriate for the federal government to address. CBI's work with zero energy buildings, involvement in early stage research and development (R&D), and work as a coordinating organization and clearinghouse were highlighted as great examples of the portfolio's effort to overcome technical and market barriers. One reviewer explained that CBI's involvement in R&D enables new technical solutions to become available sooner and with those advancements, the benefits are also realized earlier. A reviewer summed up their comments by stating, "DOE is a trusted brand and an appropriate source of unbiased information on energy efficiency."

In terms of how well CBI addresses the aforementioned challenges, reviewers agreed that the portfolio was extremely effective and has resulted in significant benefit across the commercial building sector. Several reviewers brought attention to the comprehensiveness of the portfolio's approach and mentioned the different outreach types in coordination with its impact. However, two reviewers expressed concern that CBI was not explicitly differentiating between the various segments such as Better Buildings Challenge (BBC), Better Buildings Alliance (BBA), Accelerators, Technology Challenges, and Campaigns. These reviewers were uncertain whether new partners would understand the differences without further communication.

While reviewers offered suggestions on additional challenges CBI could work to overcome, the consensus was that the team was not ignoring any significant barriers. Giving the team's resources, many reviewers applauded the scope of the portfolio and noted how few gaps existed. Some of the recommendations included a focus on workforce barriers, a renewed effort to increase energy efficiency in existing buildings, and further partnership with utilities. Another gap that a reviewer identified was the Building Technologies Office's (BTO's) support for legislators and continued by suggesting a communication method between stakeholders.

In general, reviewers commended the team for their innovative approaches and provided examples of which aspects of the portfolio were particularly inventive. Specifically, reviewers remarked on DOE's industry challenges, the Green Lease Leaders Program, and CBI's work with communities and districts. While one reviewer commented that CBI had numerous innovative projects, they also noted that not all approaches need to be cutting-edge and that validating and promoting energy efficiency is an important contribution that BTO makes for the industry.

With regards to the impact of CBI's Partnership portfolio, reviewers were complimentary and demonstrated great support for the team's efforts. The majority of reviewers agreed that the portfolio advances the state of the market and noted that it brings early adopters into a position to demonstrate success. One reviewer mentioned that BTO has an even greater influence in areas of the country that do not prioritize energy efficiency policy. Some of the programs referenced in conjunction with market advancement were industry challenges, Campaigns, and the Green Lease Leaders program.

Reviewer comments on CBI's support for industry and other key stakeholders were positive and most reviewers recognized that there were few gaps in engagement. A reviewer acknowledged that DOE listens to industry when establishing priorities, which they viewed as an important aspect of stakeholder engagement. Some of the reviewers reiterated that workforce development was an area that CBI could further support. The reviewers continued by mentioning that CBI is likely trying to work the relevant stakeholders, but the groups are often difficult to reach and influence. It was also recommended that, to the extent that resources allow, BTO coordinate more directly with state and local governments.

Many reviewers commented that the portfolio contributed significantly to BTO's energy efficiency goals both directly and indirectly. By supporting the partnership work, one reviewer explained that CBI "ensures that the path to meeting those goals is commercially feasible and aligned with industry's needs." Examples of indirect impact were the testimonials from participants that utilized the recognition and data from DOE to motivate their organization to focus more on building energy efficiency.

Overall, reviewers lauded the CBI Partnerships portfolio for providing support and influence that would otherwise not be achieved without BTO investment. The impact on the industry was described as "unique, significant, and critical" in that only through a program like the CBI Partnerships portfolio would an organization be able to collaborate with the relevant stakeholders to achieve common goals. Another reviewer mentioned that there were very few other groups that operate in this space and little overlap exists between them and BTO. The reviewer concluded that the work would probably not be completed without BTO's support.

Furthermore, reviewers approved of the portfolio's collaboration, coordination, and integration with the relevant programs and stakeholders. Many of the reviewer comments described CBI's Partnerships as well integrated with other commercial energy efficiency efforts such as industrial partnerships, utilities, and building owners. In addition, reviewers mostly agreed that the program was effective in supporting related efforts and projects. Once more, reviewers expressed similar concerns and suggestions for organizations and focus areas for additional coordination with CBI's team.

CBI's Partnerships portfolio was said to be well positioned and well-coordinated with public and private sector organizations. Reviewers highlighted how well the team effectively leveraged channel partners and other relevant stakeholders in order to reach more people and increase CBI's impact nationwide. The peer recognition portion of the portfolio was mentioned multiple times as an excellent method to maintain influence, reward participants, and recruit new industry partners.

Weighted Average: 3.45   # of Reviewers: 10
Scope: 3.40   Impact: 3.60   Collaboration, Coordination, and Integration: 3.30

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning.

A. Scope

This portfolio was rated **3.40** for the degree to which the partnerships identify and target key barriers and technical challenges that are appropriate for the Federal Government to address.

- Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
- Yes, the most significant is to engage the trades to make sure that the skill sets are properly transferred to the workforce that will be implementing the programs.
- Does the project/portfolio address these challenges effectively?
- Yes, for the most part. The suggestion is for the Better Buildings (BB) team to initiate a full strategic plan for the workforce development portion and identify partners that can provide the resources that the BB team does not have. By staying at the "30,000" foot level, the BB team can better utilize their time in developing guidance and training standards which are then implemented by partners under an education/training MOU.
- Does the project/portfolio ignore any significant barriers?
- No, not really. However, there is a perception that the team does not have all of the resources they need to expand workforce training.
- Does this project/portfolio apply any innovative approaches? Please specify if possible.
- Yes, rather than continuing to focus on the macro scale and spreading themselves thin, the BB team has identified that sub-districts and neighborhoods can achieve the same economies of scale – this includes the concept of accelerator districts. This approach also recognizes that on-site generation is yet another conservation method as long-distance transmission results in considerable energy waste. Providing guidance documents is also key in the success of this innovative approach.
- One would have to agree that the program is outstanding and has high aspirations but also recognizes the limitations of the BB team. By continuing to pursue appropriate partnerships to fill in "resource holes", it is anticipated the program will continue to meet the Building Technologies Office (BTO) goals.
- Barriers & challenges: I believe that DOE takes the right approach in identifying barriers and challenges. They ask private sector practitioners what factors inhibit broader adoption of energy efficiency. This insures that the community is solving for issues that will have an impact in the real world. Given the diversity of the U.S. building stock that requires engagement with many types of companies, DOE has done an excellent job with that outreach. The program is very appropriate for federal government involvement for two reasons. First, government involvement in early stage research will result in earlier availability of new solutions. Second, DOE involvement as a coordinating entity and clearing house means that important information will be maximally deployed to decision makers throughout the U.S. real estate industry.
- Effectiveness: In short, the results in terms of the energy/water savings to date speak for themselves. DOE's efforts are clearly having an impact. The Lighting Energy Efficiency in Parking (LEEP) Campaign recognition was important in a client's decision to proceed with a major parking lot lighting project.
- No significant barriers were identified that are being ignored.
- Innovation: The industry challenge programs (high efficiency rooftop unit (RTU), low cost sub-meter) are both innovative and effective.

- The net-zero resources (goals for net-zero ready buildings and Advanced Energy Design Guides (AEDGs)) are spot on. Influence on building codes is enormous and has increasing potential for future. REScheck and COMcheck use is widespread. LEEP project is impressive.
- DOE's resources for architects and owners are well-utilized and have real impact. Developing more resources for contractors and trades seems like a gap to be addressed in future.
    - The portfolio does a pretty good job of addressing a number of barriers to greater efficiency in commercial buildings
    - Many of the projects are excellent; some are good; there are a couple that could be better, but overall they are doing well. The one global observation is that a number of the projects had stated objectives that were overly ambitious for the scope of the project – for example, having market adoption/penetration as an objective when the scope of work was focused on technology development/proof of concept and didn't have a specific task/budget for market assessment and implementation support.
    - Some of the projects (e.g., 22244) did an excellent job of being conscious of the human factor in designing the technology or the program (i.e., consider who would be expected to 'adopt' and make sure to develop an empirical understanding of the adoption process and the people who ultimately use the tech); others (e.g., 22240) didn't.
    - The projects 22244 and 22292 were cutting edge.
- BTO’s Commercial Buildings Integration (CBI) program appears to provide a comprehensive array of programs to address barriers and technical challenges by supporting and collaborating on early stage research (Technology and Market Solution Teams, High Impact Technologies, and Identifying and Recognizing Market Leaders to Validate and Verity Solutions), consolidating and disseminating best practices (Better Buildings Initiative, Building Energy Codes Program, Better Buildings Accelerator), and supporting implementation efforts with utility and industry partners (Better Buildings Alliance/Challenge, Advancing the Zero Energy Ready Building Workforce, Transforming American Communities, and recognition programs). Furthermore, CBI is working aggressively to engage stakeholders to inform programming at every step of the way (Stakeholder Roundtables, etc.), and CBI does appear to have a clear understanding of market hurdles at this time. These are critical for the federal government to address.
- The portfolio does appear to address these challenges effectively. It is important to note that the Codes work done by BTO remains critical and effective even if it is not something that is seen to be as innovative as other efforts.
- Some areas where CBI and BTO could expand or tailor offerings is provided below:
    - While buildings are being looked at comprehensively, why is there not as much focus on electrification of heating? This is an area where there will be significant growth in the coming years and decades and conducting the research and developing/sharing the best practices around this is critical to avoid technical pitfalls and facilitate widespread deployment. There is a need for developing industry best practices, providing guidance to utility efficiency programs, and identifying opportunities for bundling heat pumps with weatherization and/or solar in existing buildings. The Better Buildings Initiative and Advancing the Zero Energy Ready Building Workforce programs seem like good avenues for research on electrification of commercial buildings.
    - It was mentioned that there is interest in increasing focus on existing buildings. This area has been underrepresented historically and is an area that needs critical attention. There are clear aggressive pathways to low-energy/low-carbon new construction (such as zero-energy buildings), but retrofits have

historically fallen into a category of building upgrades that target only modest utility cost-effectiveness (like 30% reductions). There needs to be a pathway to get retrofits to significantly lower carbon operations, probably through a combination of traditional efficiency, low-carbon heating, and on-site generation. Retrofit efforts might fit under the Better Building Initiative, but this area still needs significant attention.

    - Much of the discussion focused on energy reductions, but the conversation really needs to shift to carbon reductions. There is not much of a shortage of energy, but there is a shortage of bandwidth in our atmosphere to accept more carbon. When evaluating programs and goals on a carbon basis, it seems like it would not only more directly target our bigger problems but also more clearly identify the optimal and most cost-effective pathways for DOE to reduce carbon.
    - On a similar note, DOE's goal of 30% energy use intensity (EUI) reduction in 2030 vs. 2010 seems somewhat modest relative the scale of energy reductions needed to achieve greenhouse gas (GHG) reduction needs. It would be great if DOE could align its energy reduction goals with the more aggressive greenhouse gas reductions that are necessary in the coming decades.
    - Workforce is a crucial issue in the HVAC trades. The focus on Advancing the Zero Energy Ready Building Workforce is appreciated. This should be kept high on the priority list.
- The following programs were particularly innovative:
    - Green Lease Leaders Recognition Program: this program addressed a challenge in the market and uses federally branded recognition as a carrot for multifamily buildings to do this work. With that, it also advertises the value of the high-efficiency building to occupants. It addresses an important issue for relatively low cost.
    - The High Impact Technology program's LEEP lighting initiative identified an opportunity to make significant steps forward in energy reduction in a short amount of time.
    - Communities research and development (R&D) partnerships: by working with communities and sub-communities to pilot R&D of energy technology, BTO is able to get real-world implementation data while providing energy benefits to consumers. And by integrating with local partners, BTO is able to expand its reach of influence.
    - Zero Energy Districts Accelerator: This is a complicated, high impact concept. It seems like an appropriate place for DOE to be involved given its complexity.
- In general, the priorities of the program are reasonable for the federal government and they have a good understanding of the barriers. This reviewer particularly likes what they are doing on zero-energy schools and encourage them to expand to other building types, such as multifamily, and to also do more to explore approaches to more challenging building types such as retail, groceries, and hospitals. The Better Building Challenge has been good at motivating some owners to achieve 20% energy savings, but would encourage establishing a higher tier for deep retrofits in appropriate buildings, perhaps with a 40% savings target. More generally, the program should think more about goals for ~2030 and focus efforts on achieving these long-term goals. For example, zero-energy codes might be such a goal, and to achieve that goal more work is needed on both common buildings such as schools, offices, multifamily and retail, but also some more challenging building types. Another goal should be retrofit efforts that achieve at least 20% savings in many buildings (more than at present) and deep retrofits in some (primarily those undergoing renovation). As for equipment, continued work on RTUs make sense, but it is also suggested to look into amorphous core transformers.

- This is the first time this reviewer has seen all of the DOE research/partnership types presented in a comprehensive manner. This reviewer never understood the difference between campaigns, challenges, and technology demonstrations. This seems like a powerful and comprehensive approach. The identified barriers and technical challenges are certainly real, significant, and appropriate for the federal government to address.
- The portfolio absolutely addresses these challenges effectively, including the following: using technology demonstrations to prove the technology, using campaigns to address awareness, trust, and comfort with new technology, and using challenges to push the manufacturing industry is a comprehensive and impressive approach.
- One concern, however, is that this reviewer has been reading DOE research for years, and just figured out the difference between these outreach types now. Perhaps the comprehensive approach that DOE is taking isn't being communicated to the public well enough.
- There's also an opportunity for DOE to partner more deeply with utilities. This isn't for lack of trying (on DOE's part). Coming from the utility side of the equation, utilities could have much better internal engagement/"buy in" to DOE partnerships.
- Finally, the last piece of the puzzle that should be addressed – which isn't being addressed well enough – is contractor and facility operator training. One of the biggest barriers to technology adoption is getting contractors and facility operators familiar and competent enough with new equipment. Adding those two outlets to the approach would add significant value.
- The identified barriers and technical challenges are real, significant, and appropriate for the federal government to address, but they are not comprehensive. As is evidenced by a growing body of research, economic or market demand forces are not sufficient to compel enough wide-scale deployment of new building technologies needed to materially curb carbon emissions. To use an odd analogy, as a society, we are not firing on all pistons to fight climate change. BTO needs to foster coordination and information sharing between labs, academia, industry, and policymakers. One of the largest gaps is in support for legislators. Lawmakers are being directed by state and local policies to create laws and incentive programs, but they need tools to create the programs. BTO cannot promote specific laws or regulations, but they can provide useful resources like a library of legislative language and supporting information for lawmakers to draw from. BTO can also provide an equivalent library for makers of codes and standards to support new technologies. BTO would benefit from having a standard set of collateral required from each project working on a new technology or method in need of large-scale adoption (most projects). This collateral would include form policy language and supporting data, code/standards language, RFP language, training material and/or college curricula, and in the case of technologies requiring IT integration, guidelines for ensuring IT security is maintained. The collateral would populate a new, free and easily navigated online library. There are many innovative approaches in the portfolio (e.g., new method of billing for heating, pre-fab modular apartments, guide for incorporating new technologies into the real estate cycle), but there are also some less innovative approaches that are still valuable as proof points (e.g., implementing EMIS, DC power delivery, integrated systems). It is okay that not all approaches are innovative. Validating and promoting building technologies is as much about methodically ascending the tall mountains of getting the word out and convincing the populous about known solutions as it is about developing new, innovative solutions the likes of which the world has never seen.
- DOE is a trusted brand and an appropriate source of unbiased information on energy efficiency. While it is generally appropriate for the federal government to serve in a collaborative/coordinating role, given its position in the market, it doesn't mean that BTO/CBI should fill all gaps. It should look for those which provide the most leverage in the market. The totality of the CBI work is broad and attempting to fill all gaps. It is hard to sort the highest priorities, what is effective, and what is missing.

- The most effective, innovative approaches seem to be those which create an umbrella of tools and interventions that are relevant to the market to be served. Better Communities is an example of this. Such an umbrella provides a navigable path to success for participants. For example, in the presentations, it took some time to sort out the differences and nuances between an Initiative, an Alliance, a Partnership, a Campaign, a Subprogram, an Accelerator, and a Challenge. New partners may need some handholding to find the right entry point as there are many options.
- Yes, they are extremely real.
- The project portfolio defines the challenges more effectively rather than address them. The most significant barrier to any organization is the inability for energy managers to convince their line leaders to invest in energy savings technology. The buy-in from several building operators is also a significant barrier since they are trained to run the building a certain way, they detest the implementation of new technologies or are scared to learn new programs or software. Lastly, finance mechanisms is a major barrier for implementation of energy efficiency measures.

B. Impact

Assuming that the ***portfolio-specific goals*** are met, these partnerships were rated **3.60** for the degree to which they are ***expected to*** contribute to ***program and BTO goal(s).***

- Does the project/portfolio advance the state of the market or lag behind it?
- The portfolio appears to continue to advance the state of the market. The BB team also recognizes that there are some market shifts within the code sector such as with performance modeling in lieu of REScheck or COMcheck for permit applications. Whether or not this presents the case for diminished support of the above products remains to be seen.
- Does the project/portfolio effectively support industry or other key stakeholders?
- For the most part, yes. There are perhaps additional opportunities available in the construction industry with organizations such as the Association of Subcontractors & Affiliates. Also, the concept of workforce continuing education can be expanded to the construction contractor typology as continuing education is required to maintain licensure in many jurisdictions.
- Are there industry stakeholders that are not supported, but should be by the project/portfolio?
- Yes, the workforce endeavor could really use additional resources and support.
- Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
- Yes, it absolutely contributes directly via the implementation of strategies but also indirectly via policy influence.
- Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
- Yes, the entire Better Buildings Solution Center (BBSC) website is a testament not only to the success of the program but it is also a rich resource that provides guidance for those who may be hesitant to adopt the full BBC path.
- The methodologies and strategies outlined in the portfolio are all valid. There is no question that the impact is enormous even though the percentages of adoption to date are small. This reviewer is looking forward to when the portfolio conservation results are reported in Quads.

- The program is advancing the market. Two particular examples would be the industry challenges (spurs the creation of new products) and the Green Lease Leaders program which supports an underserved impact area (leasing).
- The program does a great job both reaching out to, and supporting, all key stakeholders. The most important point is that DOE listens to stakeholder input when establishing priorities.
- No key stakeholders have been ignored.
- The partnership program is critical to meeting BTO's goals because it ensures that the path to meeting those goals is commercially feasible and aligned with industry's needs.
- Only by reaching out with this type of program will BTO be able to work collaboratively with industry to achieve its objectives. Bottom line, without industry participation and collaboration, the goals will not be met.
- Partnerships have demonstrated that owners are motivated to have broad sustainability goals (not just energy, but water, waste, carbon, and renewables as well).
- They have great testimonials from property owners/managers on using energy achievements and data from competitors to motivate their organizations to do more.
- In terms of portfolio advancing the market, Power over Ethernet (PoE) LED lighting is a nice example.
- "Effectively support" is hard to measure, but it is a positive sign that there is a great deal of meaningful stakeholder involvement – particularly from industry – in most of the projects.
- This reviewer can't think of unsupported stakeholders.
- There are a few others who invest in this type of research – the California Energy Commission, some utilities, NYSERDA, etc. There is very little overlap between the BTO program and the Energy Commission EPIC R&D program, which is to say that the work would be unlikely to have been done without BTO support.
- The portfolio largely does advance the state of the market, especially for the large areas of the country where energy efficiency policy is not a high priority. However, there are a few areas as mentioned in question one where DOE could integrate concepts of electrification and carbon throughout their program to address what will be happening in 5, 10, and 15 years. By continuing to get ahead of the curve, DOE will continue to have great relevance in this space.
- BTO has done a good job at getting their messages and programs across to industry and utility stakeholders. There is always room for more outreach and engagement with those audiences and broader audiences. As a director at a state clean energy office, this reviewer has rarely engaged on BTO webinars and initiatives and much could be gained by increasing involvement. That is a message that needs to be relayed to others in the same space. There are bandwidth limitations at BTO, but the work is very valuable and the DOE seal of approval holds a lot of water.
- Through the Better Buildings Challenge, Advancing the Zero Energy Ready Building Workforce, and Green Lease Leaders Recognition Program, DOE is providing valuable recognition to important partners and is validating what they did by having it come from DOE.
- To the greatest extent possible, it is valuable when DOE publishes best practices, guidelines, case studies, etc. The DOE seal of approval is important, and BTO should continue to do this and keep information up-to-date so that partners can further utilize it. One example of where this is effective is the Advanced Energy Design Guides for zero-energy buildings.

- Even in the state with the most aggressive energy efficiency policies in the country, there are still significant gaps in commercial energy efficiency practices. While residential energy efficiency practices remain somewhat lacking, commercial implementation has been even further behind. CBI should evaluate if there are any practices from the Residential Buildings Integration (RBI) program on utility energy efficiency program engagement that could be replicated on the commercial side. This might already be being done. Engagement would be even more valuable for smaller utilities or those with tighter budgets than Massachusetts.

- As general feedback, BTO should continue to integrate the idea of "how to scale up" into programming. While the current impact of programs is impressive, the community needs to target an even larger portion of existing building upgrades and new construction, and to have aggressive carbon reduction goals (e.g., 30, 50, or 80%) in those efforts. Because buildings only replace HVAC systems every 15 to 20 years and building renovations are probably even less frequent, it is critical that targets be set to effect large carbon reductions through a bundling of measures at the next point of building upgrades. Small incremental approaches will not be sufficient to meet critical GHG reduction needs.

- BTO makes a unique, significant, and critical impact on the industry, and much of the progress in this field would not happen or would be much more stubborn to achieve without BTO's great contributions.

- The portfolio does advance the state of the market and works effectively with many key stakeholders. There are significant impacts that would not be achieved without BTO investment. Good examples are the Rooftop Challenge, the work on wireless sensors, and work on zero-energy schools.

- It seems like DOE has a huge impact on the industry. From challenges to demonstrations to campaigns, they seemed to segment the barriers appropriately and address them with meaningful research tactics. The portfolio absolutely advances the state of the market, and provides impact that would not be achieved without BTO investment.

- There may be a couple industry stakeholders that are not supported. Contractors and facility operators could, perhaps, be addressed more comprehensively. That being said, DOE is trying to address these stakeholders, they are just two very difficult stakeholders to influence.

- The projects/portfolio is advancing the state of the market. It does not seem to lag behind it. It is supporting many stakeholders, but one of the largest gaps is in support for legislators and BTO should coordinate more directly with industry associations representing whole hosts of stakeholders (e.g., state and local governments, procurement specialists, building operators and developers, educators, etc.). Creating a public library of material/tools that is useful for stakeholders would be very effective. It seems clear the BTO work is having a direct, significant impact on new building and retrofits in the U.S. that would probably not otherwise be achieved in the near-term. This is evidenced by the fact that many new, energy-efficient building technologies have been adopted and are becoming required across the U.S. (e.g., LEDs). There is much more work to be done, but as mentioned by Dr. Paul Matthew from Lawrence Berkeley National Laboratory (LBNL), in 2017, over 41% of commercial office space in the top 30 U.S. markets was certified as "green" or "efficient" showing significant, growth from 5% in 2005. One very specific improvement that BTO should do concerns the Financing Navigator. The tool should be enhanced to connect state and city employees and elected officials with financial organizations that can create bonds to be used for large-scale incentive programs. State and municipal bonds are a common way to support incentive programs and banks are eager to provide bond-related services, but surprisingly few state, county, and city staff know how to go about initiating the creation and sale of a bond.

- In many areas, the portfolio advances the state of the market as it provides tools, benchmarks, and technical assistance to bring early adopters (like Portland, Oregon) into a position to demonstrate success.

- Each project or initiative should be clear about the target market. The goals should not be to cover all bases, but to define the target audience that provides the greatest leverage in that market (schools example).

- The program does advance the state of the market by supporting the implementers with case studies of proven technologies and bringing together multiple implementers under one forum to share their best practices. These measures significantly contribute BTO's energy savings.

C. Collaboration, Coordination, and Integration

This portfolio was rated **3.30** for the degree to which its partnership activities demonstrate strategic collaboration or coordination within BTO/EERE and with relevant external stakeholders.

- Is the project/portfolio well integrated with other relevant efforts?
- Yes, the project is well integrated for the most part. It also appears that policy templates may afford additional opportunities to integrate BTO goals at the local level.
- Does it effectively leverage and/or support other projects?
- Yes, the continued support and integration into the Building Codes Program is highly recommended. However, if "reducing compliance burden" is one of the goals, it is recommended to continually evaluate REScheck and COMcheck support as energy modeling specialists providing full modeling continue to emerge. It also appears that the accelerator district concept is one of the strongest opportunities for BTO engagement besides workforce development.
- Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
- Yes, it is well positioned for the most part. The technology screening/validation/verification process appears quite robust especially as a gateway to preventing overextension of the BB team.
- Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?
- Absolutely. The peer recognition portion appears to be an excellent method to garner continued support from partners and relevant stakeholders. There may be additional partners and relevant stakeholders that could be pursued to carry forth strategic initiatives for which the BB team does not have internal resources (construction contractor membership organizations, continuing education for contractor licensure, etc.).
- One would have to agree that most every aspect of the framework that has been constructed for this portfolio/program is outstanding. One would hope that continued strong BTO support as well as resource provision would assist this portfolio/program to be extremely successful in furthering BTO goals.
- In closing, it is recommended to continue to be pro-efficiency and fuel agnostic. Neutrality is a very powerful negotiating tool.
- The breadth of the program's outreach to industry is outstanding. The efforts are well coordinated/integrated and span all of the required industries.
- The Better Buildings program does a good job at engaging all types of building types and owners. The results of the program are impressive.
- Recognition is the best way to reward owners and recruit more members.
- DOE "brand" is strong and well-respected. DOE needs to do outreach to more owners to encourage them to set a sustainability goal. The business community would have a positive response to that.

- Smart Building Roundtable sounds like an effective way to facilitate peer-to-peer best practices/lessons learned sharing.
- There is an opportunity to partner with 2030 Districts to recruit more members that are already committed to sustainability goals.
- Campaign partnerships are great. The results are really strong.
- The participation at the workshop demonstrated that there is broad participation across industry and other public sector organizations. Their presence is also seen in the stakeholder groups working with the various awardees.
- The portfolio does seem to be well integrated with other efforts, especially on industry partnerships, building codes, and with utility efficiency programs.
- The outreach done via continuing education credits and outreach is very valuable for engaging with current or potential workforce.
- On the state energy office/clean energy agency engagement side, it would be valuable to have a “liaison” and annual or biannual check-ins to identify collaboration opportunities or shared lessons.
- BTO has done a great job working with channel partners, but there remains significant opportunity to expand outreach to these partners and to a broader set of partners.
- The portfolio appears to be well integrated with related efforts such as those by ASHRAE and U.S. Environmental Protection Agency (EPA). It does leverage those partners.
- DOE is doing a great job. They are covering the vast majority of the industry with different outlets of support and research.
- That being said, there could be better collaboration and integration with the utility industry, with facility operators, and with contractors.
- The BTO program would benefit from a more direct and broad engagement with utilities, policymakers, state and local employees and officials, trade organizations that provide training, and universities. BTO should not only support these organizations efforts to decarbonize through useful information and tools, BTO should help connect them. The U.S. is so vast and fractured, the only way BTO could do this is through engagement of trade groups. BTO could benefit by hiring a staff member whose full-time job is to form relationships with these organizations and ensure they receive and distribute partnership opportunities, and most importantly, the latest BTO work-products via communications like periodic email announcements, conference presentations, and ideally, a link to libraries of useful tools (e.g., legislative language and supporting data, RFP templates, code/standard language, training curricula, etc.). Organizations may include, but are not limited to EPRI (utilities), ICMA (International City/County Management Association), National League of Cities, National Association of Counties, National Association of Local Councils, Council of State Governments, BOMA (Building Owners and Managers Association), NAA (National Apartment Association), NMHC (National Multifamily Housing Council) and others. It would be good to promote BTO finding and ideally a new BTO library of tools for policymakers to those organization's membership lists on a regular basis. Similarly, BTO could promote form RFP language through organizations like NASPO (National Association of State Procurement Officials), NIGP (National Institute of Government Procurement), the American Purchasing Society, etc. In addition, BTO could provide form training curricular to organizations like the AIA, the National Association of Trade and Technical Schools, and the Association of American Universities.
- CBI may be well integrated (within DOE) but it is not clear that all links are made. This is likely a huge challenge. Perhaps a map of linkages would be helpful (not just to reviewers) but to partners and DOE staff.

- CBI could be more coordinated with REEOs as they have a coordinated set of stakeholders that DOE could leverage. It is suggested that BTO coordinates with the National League of Cities as a supplement to NASEO.
- No comments.

BTO Partnership Activities

Residential Buildings Integration

Partnerships Review: Residential Buildings Integration (RBI)

Presenter: Joan Glickman, U.S. Department of Energy

Brief Summary of Reviewer Comments

In general, reviewers approved of the Residential Buildings Integration (RBI) Partnerships portfolio, which included presentations on Home Performance with ENERGY STAR, Better Buildings Residential Network, Home Energy Information Accelerator, Zero Energy Ready Homes, and Solar Decathlon. The majority of reviewers agreed that the challenges identified by RBI were significant and appropriate for the federal government to address. One challenge that was repeatedly identified was the difficulty of getting information to the relevant groups and organizations. Several reviewers stated that the RBI programs excelled at disseminating information through the various networks and that U.S. Department of Energy (DOE) is best positioned to host national peer exchanges and serve as a resource clearinghouse. One reviewer mentioned this in relation to the Better Buildings Residential Network since DOE's position and reputation enables the team to share lessons learned and keep stakeholders across the country well-informed.

While reviewer comments on the scope and effectiveness of the portfolio were predominantly positive, some reviewers shared recommendations for improvement for the different programs. A handful of reviewers noted that RBI's decision to increase focus and future resources on existing buildings was well-founded and necessary. Workforce development was also specified as a particular challenge for the industry that should be addressed more directly through the Building Technologies Office's (BTO's) program offerings. However, some reviewers applauded Solar Decathlon for its innovative approach that trains the future workforce in energy-efficient design and construction practices as well as increases public awareness of the benefits. One reviewer suggested expanding Solar Decathlon for local competitions and further utilizing the Solar Decathlon brand and platform to garner more media attention.

Multiple reviewers agreed that RBI's Partnership portfolio does not ignore any significant barriers, but reviewers stressed that the programs need adequate funding commensurate with both the challenges and the program objectives. Several reviewers commented that the overall effectiveness of some programs was limited due, in part, to the level of resources allocated. Despite the limitations, reviewers complimented the team's efforts to develop a comprehensive portfolio of programs.

Reviewers found that many of the programs within RBI's Partnership portfolio were impacting the industry and advancing the state of the market. Some of the programs that were repeatedly referenced in this regard were Zero Energy Ready Homes, Solar Decathlon, and the Home Energy Information Accelerator. The different strategies for the programs were highlighted in terms of how quickly each program could accelerate the market and provide a lasting impact. For example, one reviewer described the Zero Energy Ready Home program as "pursuing an incremental rather than a disruptive strategy." The same reviewer continued by explaining that this approach has a better chance of success.

In terms of impact, reviewers were generally in consensus about the team's support for industry and their stakeholder engagement efforts. The majority of reviewers described RBI's portfolio as effective in its partnership with the wider community. Comments varied by specific program in terms of each reviewer's approval of the team's coordination with industry and whether there were gaps in support. One reviewer recommended strengthening BTO's ties with the financial sector and potentially leveraging the expertise in the technology sector. Furthermore, some reviewers mentioned that the RBI Partnership's portfolio could improve its support of residential building owners. However, reviewers also noted that this stakeholder group would be very difficult to engage and influence towards energy-efficient choices and behaviors.

Reviewers were slightly split regarding how effectively the RBI Partnership portfolio contributes to BTO's wider goals. Most reviewer comments indicated that the portfolio successfully achieved energy savings with some programs contributing directly to the goals and others indirectly. However, some of the reviewers stated that they were uncertain to the extent to which the portfolio contributes to BTO's goals because the presentation lacked key information and data. Nevertheless, reviewers agreed that much of the portfolio's impact would not be achieved without BTO investment. A reviewer reiterated this point by stating, “the market would do little if it were left to its own pressures.”

The team’s collaboration, coordination, and integration of the RBI Partnership portfolio was predominantly well-received. Reviewers generally found the portfolio to be integrated as well as coordinated with other relevant efforts in the energy efficiency community. One reviewer stated, “the lines of communication seem to be very open at DOE and this collaborative tone ultimately serves to benefit all of our work.” Regional engagement was identified as a potential area of improvement given that each climate zone has unique characteristics and challenges to consider. It was also suggested that better visualization of the interconnections between programs, initiatives, and stakeholder groups can help communities better understand the dynamics of the portfolio.

While the majority of comments on collaboration were encouraging, two reviewers reiterated that there was insufficient data presented on the specific stakeholders involved in each program. The reviewers noted that this absence of information made it difficult to draw conclusions about the level and extent of engagement. Other reviewers highlighted the current portfolio partners and remarked that there may be additional opportunities to effectively leverage new channel partners. It was also recommended to further connect with state and local organizations working in the same space in order to collaborate and share lessons learned.

Weighted Average: 3.29   # of Reviewers: 9
Scope: 3.22   Impact: 3.22   Collaboration, Coordination, and Integration: 3.44

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers of these portfolio activities to inform future portfolio planning.

A. Scope

This portfolio was rated **3.22** for the degree to which the partnerships identify and target key barriers and technical challenges that are appropriate for the Federal Government to address.

- Additional comments will be provided directly to Joan Glickman.
- This review references the following projects referred to collectively as the Residential Buildings Portfolio:
    - Home Performance with Energy Star
    - Better Buildings Residential Network
    - Home Energy Information Accelerator*
    - Zero Energy Ready Home
    - Solar Decathlon
- Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
    - Yes. Catalyzing deep energy retrofits at scale for U.S. residential homes is a real and significant challenge that can best be addressed with support and coordination from the federal government.
- Does the project/portfolio address these challenges effectively?
    - Some of the portfolio's projects to address this challenge have been very effective (e.g., the Home Energy Information Accelerator overcame what had seemed intractable obstacles to getting energy efficiency information effectively and consistently imported into multiple listing services). Other projects have strong foundations to build on but are extensively under resourced, which is hampering their ability to meet their mission objectives. Examples of these are the Zero Energy Home program, which has made good progress pushing in recruiting innovative companies and advertising their success as the first step in a market transformation model. The next stage however of generating significant numbers of early adopters and market presence broadly in the U.S. throughout all 50 states and thousands of cities and towns will take 10x or more funding than is currently allocated.
    - The Solar Decathlon has a strong brand and platform which should be much more intensively leveraged to garner earned media. The addition of local contests and builds is a great start and should be expanded, which again will require a significant budget increase.
    - Home Performance with Energy Star's program model is not working, reaching under 100,000 homes per year. It is not even growing linearly year on year, when what is needed is exponential growth. A model that relies of inconsistent insufficient utility incentives to motivate action cannot achieve deep savings at scale. It is possible that an entirely new model is needed that embeds the Home Energy Score as a central component and grants an EnergyStar label to homes achieving above a certain score.
    - Home Energy Score has been steadily improving but needs broad inclusion in MLS as a populated field in order to have influence during real estate transactions. It also needs rating certification to become a standard part of national HVAC training and certification and be embedded in standard practice. The best route to that would seem to be getting the leading states or cities to require it as a benchmarking tool in the same way that they have done for Energy Star Portfolio manager.
- Does the project/portfolio ignore any significant barriers?

- Adequate program funding commensurate with the program objectives is needed.
- Invisibility of energy efficiency (out of sight out of mind; observability is the second largest factor determining the rate of diffusion of an innovation after comparative advantage) keeps public awareness low.
- Other barriers include the low relative cost of energy and the value of savings for high and moderate income households, and the lack of low to no-risk financing resources for low-income households even with high energy burdens

- Does this project/portfolio apply any innovative approaches? Please specify if possible.
  - Innovation is overrated. Most innovations fail. Instead, DOE is recommended to look for bright spots and top performers in its own past and current program portfolio
  - DOE should instead look to emulating past and current successful program such as DOE Solid State Lighting (SSL) program and its components, the Home Energy Information Accelerator, EPA's Operation ChangeOut, DOE Municipal SSL Streetlighting Consortium, and DOE and NEEA collaboration on Energy Star Windows launch.
- The majority of the barriers and technical challenges discussed are real and significant. DOE presented these issues in an accurate and thorough fashion, showing good depth and breadth of knowledge. Most of these issues are both significant and appropriate for the federal government to address. Examples include the age of the housing stock, costs of technology, the induced problems with moisture and indoor air quality, and the fragmented nature of the energy efficiency field. Also, real and significant is the lack of data and knowledge on the part of key stakeholders such as realtors, appraisers, and local governments. However, it's uncertain whether the lack of data is really the problem with mortgage lenders and underwriters. There are some very sophisticated entities in this industry, with a lot of data. The problem is more their willingness to share or use the data in a way that would effectively target energy efficiency.
- The project is generally well designed to target the challenges it identifies. It is good that it includes programs like Home Performance with Energy Star that target the existing housing stock, in addition to programs that mostly target new construction. However, effectiveness is somewhat limited due to the level of funding.
- One barrier that is becoming increasingly significant but that the program doesn't address is the way local governments are implementing design standards that conflict with, or otherwise make it difficult to accommodate, energy conserving measures. Examples include requiring more windows, or exterior materials with a high level of embodied energy, or architectural detail that limits the possibilities for solar panels. Many of these local standards clearly serve no purpose beyond aesthetics and can increase design and construction costs substantially, making it more difficult to find financial resources for additional energy efficiency measures.
- One approach that the project applies that seems innovative, and likely to have an impact, is the way the Zero Energy Ready Home program uses actual builders who can credibly explain how their zero-energy ready(ZER) projects have been profitable.
- Zero Energy Ready Homes (ZERH)
  - Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
    - Absolutely. The program is preventing known risks/problems in high-performance homes and trying to prevent the downsides of increasing energy codes/construction.

        - There is no research and development (R&D) in construction.
    - Does the project/portfolio address these challenges effectively?
        - The solution is good. Energy Star issues is a headwind.
    - Does the project/portfolio ignore any significant barriers?
        - Energy Star issue. It is not really addressing most homes or incentives, many of which are driven by energy savings only (ERI). The team should consider if it's possible to take lessons learned and apply them (i.e., pieces of the program) to stretch codes and utility incentives.
    - Does this project/portfolio apply any innovative approaches? Please specify if possible.
        - ZERH builds off of the success of the Energy Star model; it is next generation.
- Solar Decathlon:
    - Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
        - Yes – it is training the future workforce on ZERB design and construction. It increases public awareness of efficient buildings
    - Does the project/portfolio address these challenges effectively?
        - Yes – it is actively engaging students in projects, connecting with building professionals, and "celebrating" on National mall in the folk life fest.
    - Does the project/portfolio ignore any significant barriers?
        - It is a limited scope project, which is nice.
    - Does this project/portfolio apply any innovative approaches? Please specify if possible.
        - It includes outreach to colleges – networking and career events and international outreach.
- Home Performance with Energy Star
    - Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
        - The barriers and challenges are extremely real and significant; they require the federal government's intervention.
    - Does the project/portfolio address these challenges effectively?
        - Not really. Trying to create a new workforce is naïve (it is better to focus on contractors doing their jobs better). The installation and workforce standards are good – perhaps the team should focus on that.
    - Does the project/portfolio ignore any significant barriers?
        - Market barrier. The team is primarily relying on utility sponsors.
    - Does this project/portfolio apply any innovative approaches? Please specify if possible.

        - Maybe remote quality assurance.

- Better Buildings Residential Network (BBRN):
    - Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
        - DOE is best positioned to host a national peer exchange and serve as a resource clearinghouse.
    - Does the project/portfolio address these challenges effectively?
        - Yes, the team tries to share lessons learned and make energy efficiency stakeholders more informed.
- Better Buildings Home Energy Information Accelerator
    - Are the identified barriers and technical challenges real, significant, and appropriate for the federal government to address?
        - DOE is best positioned to host a national peer exchange and serve as a resource clearinghouse.
    - Does the project/portfolio address these challenges effectively?
        - Yes, the team tries to share lessons learned and make energy efficiency stakeholders more informed.
- Absolutely, there are real and significant barriers and technical challenges that are critical for the federal government to address in order to accelerate the use of high-performing (and grid-interactive) energy efficiency systems across the U.S. residential sector.
- The portfolio of RBI's projects (R&D, tools) and partnerships (HPwES, HES, ZERH, BBRN, SD) is effectively addressing these challenges in large part. There may be ways to improve and/or expand partnerships to bring DOE's solutions into the hands of more stakeholders, particularly consumers, through more creative channels. To date, it seems the technical solutions that have been developed have largely remained within the technical field (a few advanced builders and utilities, NGOs, certain government actors, passionate students, etc.). DOE could leverage its position and reputation as a trusted source of information to get more of these solutions into the mainstream to really accelerate market transformation.
- The portfolio doesn't necessarily ignore but it could do more to address barriers related to consumer information gaps. How many consumers are aware of the cost-effectiveness and benefits of heat pump water heaters, for example? DOE could cultivate partnerships with certain groups (in media, entertainment, or others) to come up with creative, simplified messaging to start getting the right information to significantly more homeowners. Millions of consumers are watching renovation shows on HGTV on a regular basis where such messaging could be seamlessly integrated, to everyone's benefit, as energy issues (and zero-energy solutions) become more mainstream – starting in California next year.
- Yes, the portfolio does apply some innovative approaches. For example, the Solar Decathlon (SD) has been an innovative approach to build awareness of ZE buildings and benefits and train the next generation workforce – SD is such a successful and replicable model that it seems there could and should be more plans to expand internationally beyond the five international partnerships mentioned (even if in a light-touch advisory role for DOE). The ZERH program has also been innovative and successful in working with leading builders (e.g., Thrive, Mandalay) to scale best practices – there may be ways to amplify the voice and successes of these builders to other builders and to consumers as well.

- Because energy is so cheap in America, the market creates little incentive for creating low energy buildings. However, because climate change makes it imperative that buildings use as little energy as possible, the government needs to do all it can to promote both new and existing buildings to minimize their energy usage. Since most of the necessary knowledge is relevant to all 50 states, and since reinventing the wheel 50 times makes no sense, it is appropriate for the federal government to be very active. The challenge is not so much in the lack of technical knowledge, but rather in getting that knowledge to the players in the building field (e.g., owners, architects, builders, planners, bankers, and realtors). The various programs that were presented do a good job of disseminating the vital information that exists but is underutilized. For example, the Better Building Home Energy Information Accelerator is working with the real estate market; the Better Building Residential Network is a national clearing house; the Home Performance with Energy Star is focusing on existing buildings; the Zero Energy Ready Home is properly focusing on those issues that need to be addressed during construction because they are very difficult and expensive to add later (e.g., insulation), while the expensive photovoltaics (PV) can be easily added later if the buildings was prepared for it. The ZERH is most important because it promotes the axiom, "pick the low hanging fruit first." PV is a high hanging fruit, while efficiency and some solar responsive design ideas such as orientation, color, shading, and passive solar need to be implemented initially.

- Because a big challenge is to get the information to those who need it, the programs should also connect with community colleges to reach future builders, and science museums and K-12 schools to reach parents through their children. Maybe, a version of the competitions such as the "Design Challenge" could be established for high school students. Instead of "science fairs," there could be "energy fairs" part of which would include ideas for homes. The "fact sheets" are a great idea and should be made available in big box stores. The team should make a fact sheet that presents all the main ideas (one of the slides was of a house with notes on the different parts that should be addressed). Besides a short description, each strategy should have a web address that provides more detail. There could be a different fact sheet for consumers and for builders each with appropriate web links.

- RBI appears to provide a comprehensive array of programs to address barriers and technical challenges by supporting early stage research (ZERH), consolidating best practices (HIE), and supporting local implementation efforts (e.g., utilities) (Better Building Residential Network, Energy Star). These are critical for the federal government to address.

- The portfolio does appear to address these challenges effectively, though feedback on some areas where RBI and BTO could expand or tailor offerings is provided below:

- While buildings are being looked at comprehensively, why is there not as much focus on electrification of heating? This is an area where there will be significant growth in the coming years and decades and conducting the research and developing/sharing the best practices around this is critical if we want to avoid technical pitfalls and facilitate widespread deployment. There is a need for developing industry best practices, providing guidance to utility efficiency programs, and identifying opportunities for bundling heat pumps with weatherization and/or solar. The ZERH program seems like a good avenue for research on electrification of homes, and the research on indoor air quality, moisture, etc. is critical for success in this area.

- It was mentioned that there is interest in increasing focus on existing buildings, this area has been underrepresented historically and is an area that needs critical attention. There are clear aggressive pathways to low-energy/low-carbon new construction (Energy Star, Zero Energy Ready Homes), but retrofits fall under a category of building upgrades that falls under modest utility cost-effectiveness initiatives that could lead to 30% reductions. There needs to be a pathway to get retrofits to significantly lower carbon operations, probably through a combination of traditional efficiency, low-carbon heating, and on-site generation.

- Much of the discussion focused on energy reductions, but the conversation really needs to shift to carbon reductions. There is not much of a shortage of energy, but there is a shortage of bandwidth in our atmosphere to accept more carbon. When evaluating programs and goals on a carbon basis, it seems like it would not only more directly target our bigger problems but also more clearly identify the optimal and most cost-effective pathways for DOE to reduce carbon.

- Workforce is a crucial issue in the HVAC trades. While workforce was not discussed much, there are other workforce initiatives that are ongoing. This should be kept high on the priority list. In the example of Massachusetts, there is market demand for high efficiency solutions and heat pumps, but there is a shortage of contractors to deliver the work, leading to lower competition, higher costs, and potentially lower quality work.

- The HIE factsheets have a high-impact and relatively low-cost. These should be expanded to face a residential audience. People are interested in maximizing efficiency, and so much planning occurs prior to involvement of a contractor or utility program. Having good resources for a customer audience would set home improvements in the right direction from the earliest state of planning.

- For the Solar Decathlon, are any of the design components that are conceived valuable to the industry? Can they be documented or brought into design practices or business accelerators?

- Residential Buildings Integration/Better Building Residential Network: This program is very important. It seems like this could potentially be a program that could utilize a fee for service? Just a thought.

- The Better Buildings Home Energy Information Accelerator appears innovative as it taps into an existing financial transaction point for buildings and identifies opportunities to utilize it for home energy information. It coincides with the ideal period for home energy improvements, so it seems very valuable.

- The Solar Decathlon is innovative as it utilizes an education contest to drive interest for future green building professionals and catalyzes academic institutions to increase focus on these areas. It delivers a lot of valuable learning and career direction at a critical time in many students' decision about what to do for work and does it through something fun. Ingenious!

- In general, the program targets the right barriers and challenges, particularly advancing the state of new construction (through Zero Energy Ready) and retrofits (through Home Performance and related efforts such as the Network and Accelerator). These are major challenges and the resources deployed are not really up to the task. This reviewer would encourage doubling or tripling the budget for Zero Energy Ready and Home Performance, recognizing that this will require support from both DOE leadership and also Congress. The Solar Decathlon is another excellent program but seems to be adequately resourced. The Home Improvement Expert looks promising.

- Yes, the barriers and challenges are real and appropriate for BTO to address. The challenge is not to try to address every challenge but to support challenges that provide the most leverage in the market.

- The program has successfully identified barriers and technical challenges. The acknowledged focus on new home construction needs to be shifted toward existing home retrofit. A shift toward an existing home focus was identified for future work. Innovative approaches to defining incentives for consumers and other stakeholders need to be expanded, possibly looking at combined benefits of energy efficiency retrofits with resiliency benefits, for example.

B. Impact

Assuming that the ***portfolio-specific goals*** are met, these partnerships were rated **3.22** for the degree to which they are ***expected to*** contribute to ***program and BTO goal(s).***

- Does the project/portfolio advance the state of the market or lag behind it?
    - Home Performance with Energy Star lags the market, and the market itself is highly undeveloped and weak.

- Better Buildings Residential Network helps advance the state of the market. The extent of impact is unclear from the data provided. Is it reaching a significant portion of relevant decision makers? It probably is not yet.
- Home Energy Information Accelerator advanced the state of the market. Continued support at a lower level rather than an abrupt spinoff might be a better strategy so DOE can stay involved and lend its strengths where needed.
- Zero Energy Ready Home generally advances the state of the market. The team is pursuing an incremental rather than a disruptive strategy. That has a better chance of success. Others have set a higher performance standard so in that sense it is lagging (e.g., passive house).
- Solar Decathlon is advancing the state of the market in some respects, less so in its brand forward "solar" arena. It has the potential to powerfully drive advances with an expanded cope of building categories that include cost, speed of manufacture, speed of assembly, factory-built parts, multifamily, tiny home/tiny apartment, community redevelopment, etc.

- Does the project/portfolio effectively support industry or other key stakeholders?
  - It is very hard to say as very few industry stakeholders were present at the Peer Review. Data from stakeholder populations would be needed, which was not presented or available.
- Are there industry stakeholders that are not supported, but should be by the project/portfolio?
  - There is very limited data on which to base a response. There are probably many given the limited number of stakeholders present at the peer review or even the volume and mix of attendees to the Better Buildings Summit when juxtaposed with the number of attendees to low-income housing, public respiratory health, mainstream building, renovation, and HVAC and other trade association conferences.
- Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
  - Yes. The new programs direct contribution will necessarily be small since they are focused at the early stage of market transformation. Major impacts take many years to develop and mature with only a few programs ultimately contributing the majority of savings. For BTO, the current impacts of past efforts on Low-E glass/windows, voluntary standards, and establishment of rating and certification organizations, appliance standards and building codes, LED R&D and support for market introduction likely dwarf the impacts of the current programs.
- Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
  - Home Performance with Energy Star: No.
  - Better Buildings Residential Network: Yes, the scale is unknown.
  - Home Energy Information Accelerator: Yes.
  - Zero Energy Ready Home: Yes.
  - Solar Decathlon: Yes, with design education institutions. Otherwise, it is unclear.
- There can't be any doubt that the project advances the state of the market at least to some extent.
- The project certainly supports a number of key stakeholders. The Zero Energy Ready Home program, for example, provides some support to the private new residential construction industry. Similarly, Home

Performance with Energy Star supports the private remodeling industry, and the Solar Decathlon, supports some key parts of the energy efficiency research community. It doesn't provide much support to owners of residential properties, however.

- The project clearly contributes to BRO's energy efficiency goals, and has impacts that would not otherwise be achieved. However, the impact is somewhat muted because the project only impacts owners of existing residential properties in the most indirect sense. The programs listed as targeting homeowners really target industry professionals, the homeowners only participate if they own homes that the professionals work on, and these numbers as a percentage of the entire housing stock are relatively small. Nothing in the programs subsidizes or educates the typical owner in a way likely to seriously impact his or her behavior,
- ZERH:
  - Does the project/portfolio advance the state of the market or lag behind it?
    - Advances.
  - Does the project/portfolio effectively support industry or other key stakeholders?
    - Yes, it is an efficient use of industry stakeholders.
  - Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
    - Yes, directly.
  - Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
    - Yes, there is no R&D in the homebuilding industry.
- Solar Decathlon
  - Does the project/portfolio advance the state of the market or lag behind it?
    - Advances.
  - Does the project/portfolio effectively support industry or other key stakeholders?
    - Yes – it focuses on students. It's great that there is a design challenge now.
  - Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
    - Indirectly, it is a long-term play of education and awareness.
  - Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
    - Yes, these is limited education on building science
- Home Performance with Energy Star
  - Does the project/portfolio advance the state of the market or lag behind it?
    - Slowly advances.
  - Does the project/portfolio effectively support industry or other key stakeholders?

        - It is supporting industry but needs to refocus on training and industry engagement.
    - Are there industry stakeholders that are not supported, but should be by the project/portfolio?
        - HVAC training industry (is there one?).
    - Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
        - Directly, yes.
    - Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
        - Yes, but it's unclear what they are actually achieving.
- Better Buildings Home Energy Information Accelerator
    - Does the project/portfolio advance the state of the market or lag behind it?
        - Advances.
    - Does the project/portfolio effectively support industry or other key stakeholders?
        - It plays a key role. Additional funding and support is encouraged.
    - Does the project/portfolio effectively contribute to BTO's energy savings goals? Directly? Indirectly?
        - Indirectly – and yes. It has massive potential.
    - Does the project/portfolio provide impact that otherwise would not be achieved without BTO investment?
        - Yes, DOE is the only entity capable of playing this role.
- The portfolio certainly advances the state of the market and is doing a lot of work on the leading edge of technical solutions (e.g., GEBs) that are carrying the industry forward.
- The portfolio does effectively support industry and other key stakeholders, with the exception of more limited direct support or motivation for consumers / homeowners (which is no doubt a difficult stakeholder group to influence but arguably the most critical as well).
- There are no clear industry stakeholders that are not supported by RBI's range of projects and partnerships, although ties to/links with the financing sector in particular could be strengthened, and there may be ways to get the technology sector more involved in this space as well (leveraging AI, AR/VR, more automation, etc.).
- Yes, the portfolio contributes both directly and indirectly to BTO's energy savings goals. It contributes directly through HPwES and ZERH, and indirectly through BBRN, HEIA, and SD.
- Yes, there are examples of ways the portfolio provides impact that otherwise would not be achieved without BTO investment: Solar Decathlon fills a gap in technical education and practical training around zero energy buildings for students; ZERH program engages with builders in ways that few other platforms or organizations could. There may be ways to stimulate further innovation like through an engineering competition and prize – identifying specific areas that could benefit from innovation/where it's been lacking (e.g., public housing) and borrowing lessons learned from Solar Decathlon.

- The market would do little if it were left to its own pressures. The market responds to demand that is being generated in large part by the activities of BTO. The Solar Decathlon and Design Challenge are admirable, but that program only influences some schools and even in those that participate, only a small fraction of faculty and students get involved. Another approach would be to certify architecture schools that make low-energy design a priority in their education. There is an effort to create such a certification program (see www.beenow.org). The team should also integrate ZERH into the Solar Decathlon because it is a great idea not only for financial reasons, but also for educational reasons. Because of the popularity of PV systems, they distract from all the other solar responsive design strategies that need to be implemented first. As a start, at least one building in the next Decathlon should be a ZERH. That would send an important message to all who come visit the Solar Decathlon exhibit.

- Another idea for getting more architecture students involved is to have schools compete on the basis of what percent of the students are doing low-energy design projects. Thus, the winning school is the one where the largest percent of students are working on low-energy projects.

- The portfolio largely does advance the state of the market, especially for the large areas of the country where energy efficiency policy is not a high priority. However, there are a few areas where DOE could integrate concepts of electrification and carbon throughout their program to address what will be happening in 5, 10, and 15 years. By continuing to get ahead of the curve, DOE will continue to have great relevance in this space.

- BTO has done a good job at getting their messages and programs across to industry and utility stakeholders. There is not always room for more outreach and engagement with those audiences and broader audiences. This reviewer has rarely engaged on BTO webinars and initiatives. State energy officials would gain a lot by increasing their involvement. And, that is a message that needs to be relayed to their colleagues. There are bandwidth limitations at BTO, but the work is very valuable and the DOE seal of approval holds a lot of water.

- Through the ZERH program, Better Buildings Residential Network, HIE fact sheets, and Energy Star, DOE is providing valuable information to important partners and is validating that information by having it come from DOE. This is valuable, and BTO should continue to do this and keep information up-to-date so that partners can further utilize it.

- Even in the state with the most aggressive energy efficiency policies in the country, there are still significant gaps in energy efficiency practices. The Better Buildings Residential Network is critical to help guide energy efficiency programs in the right direction. It is even more valuable for smaller utilities or those with tighter budgets than Massachusetts.

- As general feedback, BTO should continue to integrate the idea of "how to scale up" into programming. While tens of thousands of projects per year is great, we need to be targeting millions of homes per year making aggressive energy upgrades that reduce carbon by 30, 50, or 80%. Because residential buildings only replace heating systems every 15 to 20 years and home renovations are probably even less frequent, it is critical that targets be set to effect large carbon reductions through a bundling of measures at the next point of home upgrades. Small incremental approaches will not be sufficient to meet critical greenhouse gas reduction needs.

- BTO makes a unique, significant, and critical impact on the industry, and much of the progress in this field would not happen or would be much more stubborn to achieve without BTO's great contributions.

- The program does advance the state of the art, working with many key stakeholders. It looks like the programs have had substantial impact, although Zero Energy Ready and Home Performance could have more impact if budgets could be increased, even if that means reallocating from other parts of the BTO program.

- Looking back to the role of DOE Regional offices (now closed), stakeholders had good ties and relationships that supported broad, sustained engagement (based on experiences in the Midwest). The Chicago office staff understood Midwest needs including climate zones, regulatory direction, and political situations.
- This is all to make the point that sometimes a one-size-fits-all (or most) tools are not well received in every region. To the extent that some tools and approaches are flexible, this should be called out to diminish the perceived gap by some stakeholders (this is true in the NW region).
- RBI, in the course of this work, is collecting a huge amount of data. This data may be held in discrete silos depending on the program. It would be helpful to know how RBI is creating market intelligence from this data that can inform future direction of the market so that RBI can avoid lagging behind. Perhaps this is already being done by the labs but it would be good to take a look at the "intelligence" gleaned from the data collected and show how this is influencing future direction.
- The program clearly contributes to the BTO's energy savings goals and has many impacts which would not be achieved without BTO investment. Notable for industry wide contributions is Zero Energy Ready Home, which is engaging trend-leader builders. It is concerning that on the existing home retrofit area, the key pressure point in the value chain may not have been identified or targeted. It would be good to see the learnings from the Home Energy Information Accelerator rolled into a more comprehensive (rather than pilot) program to provide leadership to the real estate and appraisal industry.

C. Collaboration, Coordination, and Integration

This portfolio was rated **3.44** for the degree to which its partnership activities demonstrate strategic collaboration or coordination within BTO/EERE and with relevant external stakeholders.

- There is insufficient data to make most of these determinations. The following should be treated as modestly supported opinion.
- Home Performance with Energy Star:
  - Is the project/portfolio well integrated with other relevant efforts?
    - Unclear.
  - Does it effectively leverage and/or support other projects?
    - Not obviously.
  - Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
    - No, it is poorly positioned relative to building trades that service vast majority of homes.
  - Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?
    - There is very modest leveraging of utilities. As currently evaluated, the cost per kWh of HPwES is high relative to other measures.
- Better Buildings Residential Network: No data.
- Home Energy Information Accelerator: Yes, key market actors are all involved.
- Zero Energy Ready Home:

- Is the project/portfolio well integrated with other relevant efforts?
  - Yes, to some degree. It is one of several competing high performance residential homes standards. Builder preference is to stick to one.
- Does it effectively leverage and/or support other projects?
  - Yes, it leverages Building America research. There are some synergies with Solar Decathlon. Integration with HES is unknown.
- Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
  - Probably, yes. Anecdotal experience suggests good brand recognition in high volume new homes industry.
- Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?
  - Yes, it has attracted innovative builders to champion that have demonstrated value and competitive advantage to the rest of the industry.

- Solar Decathlon
  - Is the project/portfolio well integrated with other relevant efforts?
    - No data was provided.
  - Does it effectively leverage and/or support other projects?
    - No data was provided.
  - Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
    - It has a strong potential position. It is not fully realized. Major solar and other relevant industry associations are not engaged.
  - Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?
    - Some. No data was presented on extent relative to potential unknown.
- The project is certainly integrated with a number of other relevant efforts, but there was not much evidence that indicated it is integrated with green certification programs offered by an entity other than the federal government. To the extent any of them are mentioned at all the presentation, Green Globes, Indoor AirPLUS, LEED for Homes, Living Building Challenge, the National Green Building Standard, and Passive House Institute U.S. appeared only on the slide of outreach activities for Zero Energy Ready Homes. They seem to be ignored entirely in the Better Buildings Residential Network, where one might particularly expect to find them, given that program's stated goal of serving as a national residential energy efficiency hub and honest broker.
- Zero Energy Ready Homes is also the only one of the programs that seems coordinated at all with relevant trade associations in the construction industry that are in position to disseminate energy efficiency products

and processes to their members. No evidence was presented regarding whether Home Performance with Energy Star has collaborated with trade associations that serve the for-profit remodeling sector.

- ZERH
  - Is the project/portfolio well integrated with other relevant efforts?
    - Yes, efficient use of industry stakeholders.
  - Does it effectively leverage and/or support other projects?
    - Yes, efficient use of industry stakeholders. It builds off Energy Star and IAP.
  - Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
    - Yes.
  - Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?
    - Yes, grid-integrated and resiliency should be shown more. Prescriptive/specific examples of how ZERH homes are built should be presented on more.
- Solar Decathlon:
  - Is the project/portfolio well integrated with other relevant efforts?
    - Not much else is relevant, other than education. The team should integrate with SETO for Solar Districts.
  - Does it effectively leverage and/or support other projects?
    - It is unclear how they interact with Building America (solutions center).
  - Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
    - Yes, NREL, Folklife Fest.
- Home Performance with Energy Star
  - Is the project/portfolio well integrated with other relevant efforts?
    - There should be a better focus on workforce standards and providing resources to installation contractors.
- Home Energy Score
  - Is the project/portfolio well positioned in relation to and well-coordinated with relevant public and private sector organizations?
    - Yes.
  - Does the project/portfolio effectively leverage channel partners and other relevant stakeholders (i.e., entities that contribute to overall impact/dissemination of EE products, processes, etc.)?

- The team should refocus on training and resources for contractors and QA for utility energy efficiency sponsors. The program won't go anywhere until there is a market case.
- Assuming that there is a market case for energy efficiency, what does the community need in this situation? QA of installations? Best practices for e-e improvements?

- Better Buildings Home Energy Information Accelerator
  - Is the project/portfolio well integrated with other relevant efforts?
    - Yes – data exchange is key, and they are doing it well with the right partners.
  - Does it effectively leverage and/or support other projects?
    - Yes.

Emerging Technologies

HVAC, Water Heating, and Appliances

Advanced HVAC Technologies

Project #31251: Advanced Adsorption Technology for New High-Efficiency Natural Gas Furnace at Low Cost

Presenter: Zhiming Gao, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

The project's approach of developing an integrated adsorption technology in residential gas furnaces to reduce oxidation from sulfur content garnered mixed reactions from reviewers. While some reviewers found this approach to be interesting, sound, and addressing a real need, others noted that this was a temporary patch to a solution, and the long-term performance may need further examination. The majority of the reviewers commented that, if successful, the impacts on efficiency and cost effectiveness could be significant. One reviewer, however, cautioned that the conservative HVAC industry would be reluctant to use this type of technology, and it could face market adoption trouble.

Almost all of the reviewers agreed that, given the early stage of the project, it is on-target and making good progress. One reviewer noted that the absorbent remains to be scaled up in the right form factor, and a viable approach for its regeneration should be developed. Overall, there was unanimous consent that the project team had collaborated with appropriate stakeholders, including Rheem and Corning, though one reviewer commented the industry involvement should go beyond furnace providers.

Two reviewers recommended developing a regeneration strategy in the remaining project work, with a clear analysis of the consequences that could result from the failure of the acidic gas trapping (AGT) component. But overall reviewers were pleased with the clearly outlined remaining work.

Reviewers applauded the project team's diverse expertise, as well as their interest in exploring the important problem of reducing corrosion in boilers to enhance performance and longevity. On the other hand, reviewers did express concern regarding the project's cost effectiveness, the undefined regeneration process, and the long-term performance of the nano-array-based monolith.

Weighted Average: 2.88 # of Reviewers: 5
Approach: 2.60 Impact: 3.00 Progress: 3.00 Collaboration/Coordination: 3.00 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- AGT approach as a core technology seems interesting to be applied for the natural gas fired furnaces
- The project aims to develop an integrated adsorption technology in residential and gas furnaces to reduce oxidation from sulfur content, resulting in a significantly increase efficiency for non-condensing furnaces. The adsorption coasting is based on a Ba based nano-structure that is intended to be integrated in the combustion chamber. The concept of reducing sulfur content in the combustion process at low costs has indeed merits and could have large impacts if properly implemented.
- This is a new project. The approach to develop a high efficiency furnace to overcome two existing issues 90%+ AFUE furnaces is sound. The steps outlined are fairly reasonable as are the steps outlined to tackle some of the technical issues. More attention to the adsorbing substrate and its long-term performance might be appropriate.
- This research is addressing a real need and adsorption approach could be a solution.
- This project appears to me to be a temporary patch rather than a solution to a problem. While it can be argued that the AGT will permit the use of cheaper heat exchangers in gas furnaces, there are still risks to using this technology. If the AGT becomes somewhat less effective, for whatever reason, then the carbon steel heat exchanger will rust, and the manufacturer will have to replace it under warranty. It won't take many such warranty replacements for the manufacturer to quit using the AGT approach.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the impact may be substantial. However, performance efficiency and cost-effectiveness must be more justified.
- The project could have large impacts by increasing the efficiency of lower costs furnaces with a low cost/efficient coating.
- If the system with the characteristics outlined is fully developed, and the compelling price target specified is met, implementation is very likely.
- The project can have an impact if the proposed adsorbent can be fabricated at low cost with a reasonable strategy for its regeneration.
- I fear that the conservative HVAC industry will be reluctant to use this type of technology as a way to use cheaper heat exchangers. I would be surprised if it would be widely adopted even if it met all its project targets.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Significant progress has been reported given the starting date – October 2018.

- The project is at very early stages and difficult to assess overall progress towards achieving final goals. The team, however, has made very good progress in demonstrating the synthesis of the nano-based ZnO/BaO synthesis. This is the enabling technology.

- The project is new and the early steps taken are on the mark.

- Progress on development of the absorbent has been made. But it remains to be scaled up in the right form factor, and a viable approach for its regeneration should be developed.

- Since this project is only about 6 months along, it has largely met its objectives to date, primarily consisting of scoping assessments.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The stakeholder team seems very capable to move the technology forward to the marketplace within the shortest critical path.

- The team appears to be in good communication and coordination with key and relevant stakeholders, mostly manufacturers of gas-fired furnaces.

- Ongoing dialog with and involvement of the collaborators including industrial concerns early on would be very helpful. Rheem is listed as “furnace provider" something that Sears could do too. I hope that industry involvement goes well beyond a furnace provider for the success of the project.

- Project has a good team.

- There is a good project team assembled for this effort. I am especially glad to see Rheem and Corning involved in the project since I think they will keep appropriate emphasis on system reliability which is important to HVAC manufacturers.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Given the fact of early stage of the project the stated remaining work for 2019-2020 is critical for the overall project success. Especially the component design (2019) and retrofit (2020).

- As indicated before, the project is at early stages, and progress so far has been satisfactory, however, minimum. Overall performance would need to wait at least one more year.

- Future steps on the new project are clearly outlined. I think the team might need more time and resources to evaluate and perfect the nano-array-based monolithic AGT adsorber. It appears that this technology is in development.

- A regeneration strategy should be determined first.

- The project has an appropriate schedule and tasks laid out for the remainder of the project. I was somewhat concerned that the AGT regeneration issue appears to have been given little attention so far since that seems to be a key aspect of the ultimate success of the concept. The regeneration control will be key to the successful operation since if allowed to operate too long between regeneration cycles, the AGT effectiveness may become unacceptable

F. Additional Comments and Recommendations

1. Project Strengths

- Selected monolithic AGT adsorber for AFUE enhancement is the strength of the reviewed project.
- The strength of the project is the problem is trying to solve. This is a very important problem, reduction of corrosion in boilers as it impacts both performance and longevity. The team has excellent diverse expertise, and this is an additional strength.
- The project team is very good; the first two external collaborators are essential in the early developments. Successful development of the system at a price point that is significantly below the current comparable units is a huge plus. The nano-array-based monolithic AGT adsorber might find applications beyond furnaces.
- The use of an adsorbent is a good strategy in this application.
- This project uses a concept similar to automotive catalytic converters to address an issue which results in difficult design challenges that require expensive materials to address in a gas furnace.

2. Project Weaknesses

- Cost-effectiveness of the claimed benefits should be better justified (i.e., cost of HX materials, design for potential humidification, etc.). High temperature required for the AGT regeneration may affect the cost of the system components.
- The major weakness of this project is the undefined regeneration process. The PIs need to make a solid case about how this challenge will be addressed. The Q/A at the BTO review did not help to make this case, and reviewers were left with this key question. Whether the coating can be self-regenerated, or will need to be replaced needs urgent answer. The final cost of the matrix is an additional unknown that could potentially limit the technology if successful. Finally, strategies to address the retrofit market are not defined, and this sector will need to be targeted to reach high levels of impact.
- I do wonder about the nano-array monolith and its performance, long term performance. But this is a concern. There does not seem to be any obvious weakness otherwise in the project outlined.
- It is not clear how the adsorbent will be regenerated.
- The automotive catalytic converter comparison is not exactly the same since as this AGT system. If the catalytic converter effectiveness degrades, the car does not fail or stop working. If the AGT system loses its effectiveness, the heat exchanger may rust and the furnace then fails (or could cause hazardous leaks of CO into the house). I think this risk will be foremost in manufacturer's minds when they would consider using this AGT concept.

3. Recommendations

- No comments at this early stage.
- This reviewer recommends that DOE request to the PIs a specific plan to address the issue of regeneration of the system.
- A plan B in case the monolith does not meet the requirements would be great to have.
  It would be helpful to list and compare component by component an existing 98% unit with the proposed unit and show where the huge cost saving (\$1500 vs. \$950) comes from. This was not made clear in the presentation.

- I recommend a design of the adsorbent bed can benefit from theoretical transport modeling.
- Special emphasis will need to be placed on the AGT regeneration process, with a clear analysis of consequences that could result from the failure of the AGT.

Project #32226u: Drop-in, Retrofit Furnace with Maximum Efficiency – Self Powered System

Presenter: Kyle Gluesenkamp, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Most reviewers found the approach to the self-powered gas furnace to be sound and reasonable. One reviewer commented on the notable market potential for this technology, though one reviewer added that, while it may add marginal thermal performance by reducing parasitic costs, it will add significant resiliency to the systems under non-electricity scenarios like those during extreme weather events. More critically, one reviewer comments that although the approach is attractive, it is not new.

Generally, the reviewers noted that the projects could have strong potential to both maximize efficiency and provide autonomy and resilience during extreme events if successful. However, almost all reviewers not that this is only possible if the technology is cost effective. One reviewer cautioned that "the prospects for this to [be adapted into existing systems] appear to be low given the high risk of the concept." Reviewers expressed confusion and disappointment that this project was considered "early-stage," as it had been started in October 2017, and only general concept analysis had been completed after 18 months.

Four of the five reviewers noted that the project team should coordinate or collaborate with a furnace OEM, as such a partner could help identify practical design directions before a prototype is designed and developed. One reviewer recommends partnering with an OEM soon, as this may help with the remaining work. Looking at the other remaining milestones and project work, reviewers were surprised to see the amount of work left ahead, particularly the actual fabrication and testing of the unit. As the project continues, the reviewers noted a few weaknesses for the project team to focus on, including the NOx increase, the cost and scale of TE being too high, and comments on the slow progress to date.

More positively, reviewers applauded the project team for focusing on a real problem with a reasonable strategy to address the challenge. Moving forward, the reviewers recommend consulting similar work done at MIT and for tankless water heaters.

Weighted Average: 2.61   # of Reviewers: 5
Approach: 2.80   Impact: 3.00   Progress: 2.20   Collaboration/Coordination: 2.40   Remaining Work: 2.40

Program Response

The Building Technologies Office leverages the peer review as an effective program management tool and will use the feedback provided by reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **2.80** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach of SPF is attractive but not new. Using TE or TPV versus municipal grid or local DG systems is quite expensive. Preliminary potential in cost-effectiveness should be justified.
- The project aims to develop a self-powered component for gas fire furnaces, which makes use of TPV (thermal photo-voltaic) technology, which works similarly to solar PV systems, however, with high temperature IR source, typical of combustion processes. The overall idea of developing self-powered furnaces is in general very good, while it may add marginal thermal performance by reducing parasitic costs, it will add significant resiliency to the systems under non-electricity scenarios such as those frequent in weather hazards.
- The project provides for a small, power generating unit (fuel (chemical) to thermal to electrical power) to make a furnace generate its own power to start and run, and not depend on the grid. It is an excellent idea.
- The approach adapted is very reasonable: to use the best technology for fuel to electricity conversion to start and run a furnace. Any waste heat from the electric generation is also utilized enhancing overall efficiency.
- An important issue is being studied.
- There are many potential market opportunities for a self-powered gas furnace. Even houses in the suburbs may opt for this unit due to the simplification of the trades needed to install the unit.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Self-powered appliances (including SPF) have a strong potential for the market impact if they are cost competitive. Beyond the improved energy efficiency there are some benefits of autonomy and resiliency of operation, lower maintenance cost, etc. High temperature to maximize the TPV efficiency may also lead to elevation of hazardous combustion emissions.
- The project could have large impacts if the proposed solution results into a reliable and cost effective one that can be adapted to existing systems, as well as new ones. However, the prospects for this to happen appear to be low given the high risk of the concept, and the many unknowns as revealed in the BTO review.
- Reliable and reasonably-priced power generating modules that can be easily retrofitted to regular furnaces could have a significant impact (good probability of early market adaption and market penetration.)
- Making the furnace self-supporting and independent of the grid, rather than the modest energy gain (as the expense the additional cost of the module) is the key.
- An estimate of the damage / loss due to losing furnace heat occasioned by electric interruption would further accentuate the importance of this project.
- If this is delivered at an acceptable cost, it removes an important barrier to market.
- This unit could be popular if first cost and reliability can be managed.

C. Progress

Based on current project efforts, the project was rated **2.20** for the degree to which the project has met ***project-specific goals***.

- Presented project start date is October 2017, so the effort cannot be considered as "early-stage" as reported. The up-to-date progress mostly related to the application potential and energy efficiency assessment.
- The team has been making good progress for these early stages of the project completing a survey of potential TPV generators, that may be of use in the proposed system. I found this survey an excellent value by itself. A system level analysis has also been completed.
- Apparently, the project started in Oct 2017, some 18 months ago, and has spent over 50% of the budget. What is reported in the presentation consists of numerical calculations and a comparison of technologies for making the module. Are there other significant works that have not been reported in the presentation?
- On page 15 of the presentation, it is stated that "the project is currently at early stage." With more than 50% of the budget spent, it is difficult to characterize the project as 'early stage."
- Not much progress has been made at this point. A TE power generator should be fabricated and tested.
- I am somewhat disappointed that only general concept analysis has been completed 18 months after project initiation. From what I can see, there has been no lab experimentation or detailed system design to date.

D. Collaboration and Coordination

This project was rated **2.40** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- A furnace OEM must be a key stakeholder for such an effort. Stated "ongoing discussions" with OEM illustrates indirectly a lack of OEM interest unless the specific details of such a collaboration are in confidential field.
- The team is interacting as needed and fluently with the corresponding stakeholders mostly TPV generators manufacturers. These interactions should also include furnace OEMS.
- Negotiations with MTPV to acquire their TPV system is evidently underway. I do not know about MTPV and did not find any specific information on their website. Coordination and collaboration with several furnace manufacturing would be prudent.
- TE partner is the most important collaborator.
- It is unfortunate that no furnace manufacturer is involved at this early stage. Such a partner could greatly help identify practical design directions before a prototype is designed and developed.

E. Remaining Project Work

This project was rated **2.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The list of remaining work is extensive. Partnering with furnace OEM is planned for 2020 that is quite risky for the overall project success. Given the integrated prototype design in 2019 the OEM should be committed and brought onboard as early as possible.

- There remains significant work ahead, and barriers to break, mostly associated to the final selection of the TPV unit, and testing of its performance under similar conditions as commercial furnaces.
- Based on what is reported in the presentation, several years of work remains. I do not know why?
- Does the industry partner have off the shelf TPV modules to sell? Or does it have to do R&D to provide the module? If the former, can a unit be purchased and run along with a conventional furnace as the first prototype? What is the issue? What are the challenges?
- The actual fabrication and testing of the unit remain to be done.
- The schedule seems to be quite drawn out. It is not clear what has really been achieved since the project initiation on Oct 2017 other than just simple concept development and back-of-the-envelope calculations.

F. Additional Comments and Recommendations

1. Project Strengths

- Self-powered appliance is a promising approach.
- The project strength is the problem is trying to address; self-powered gas fired furnaces is an important development the industry will benefit. The energy efficiency gains maybe marginal. However, the reliability and resiliency of the systems could increase significantly. The proposed use of TPV materials adds significant novelty to the project.
- The promise of this project is simple and attractive. The team is well qualified and can carry out the work. Most importantly, for the right price, the design may readily be adapted by the industry.
- The project is focused on a real problem and a reasonable strategy is being implemented to address the challenge.
- The basic concept should be a valid one for eventual commercialization if costs and reliability targets can be met.

2. Project Weaknesses

- The higher temperature the higher TPV efficiency - NOx emission increase is a weakness.
- The project has a few weaknesses that PIs should consider addressing:
- There are other proposed self-powered furnace solutions, such as TEG, and the team should benchmark against these solutions as well;
- The team should add electrical storage capabilities to the solution, and consider these into the cost equation. The unknown options for the final TPV add significant risk to the project.
- The presentation does not provide any information on any technical challenges ahead. As such, it appears that the main task ahead would be system integration and building a first prototype. If all true, the weakness of the project is in its slow execution.
- The scale of TE and its cost might be too high.
- Very slow progress to date. There are still lots of questions about the interface between the TPV unit and the fan and battery. There is no industry collaborator yet to provide guidance on early system design.

3. Recommendations

- Cost-effectiveness needs to be preliminary estimated and justified. A furnace OEM should be committed prior to any design work.
- This reviewer recommends that the team focusses on developing the enabling technology; TPV; final selections, optimization; control testing. This may result in larger benefits beyond gas furnaces.
- Expedite the project and move on with purchase of a module, testing it, and implementing it on an off-the-shelf furnace.
- Please check this work from MIT that seems to offer high efficiency TPV units:
  - https://tlo.mit.edu/technologies/high-efficiency-micro-thermophotovoltaic-generator-system
- There is similar work done by other entities essentially trying to do the same thing for tankless water heaters and cars. This project could be benefit from the existing past work.
- The project needs a manufacturer involved and needs someone with electrical system experience involved for the interface between the TPV and the battery and fan motor. The electrical components will not be trivial.

Project #32292: Residential Gas-fired Cost-effective Triple-state Sorption Heat Pump

Presenter: Kyle Gluesenkamp, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers generally found the SaltX project approach to develop a heat operated heat pump system that uses ammonia-based fluid encapsulated in a desorption matrix to be sound. Two reviewers, however, commented that practical efficiency limitations may prevent the team from reaching the eventual project targets. Responses from reviewers varied significantly for the project's impact. While some reviewers noted that the poor performance to this point does not bode well for meeting project targets, other reviewers found the project addressed BTO goals and would be impactful if successful and cost-effective.

Again, reviewers did not agree on how well the project was progressing, partially due to the project's difficulty meeting performance targets. One reviewer noted that the project is at an early stage and good progress has been made according to the working plan.

Although the project is partnered with Rheem, two reviewers did not understand the scope of this relationship, and wanted more details of the "active collaboration." Another reviewer recommended collaborating with experts in heat exchangers design in the future. Reviewers did not rate the remaining project work well, finding it had been delayed and unlikely to achieve its initial performance targets. The prototyping laid out in the remaining work may present challenges and obstacles that the team did not properly plan to mitigate, another reviewer noted.

Almost all reviewers agreed the project strength is its innovation and clear path forward. However, the low engagement of the OEM, the early stage, and the fundamental limitations are some of the project's weaknesses, reviewers commented. To address these challenges, reviewers recommended more OEMs be brought onto the team, testing the sorption solution under lab conditions, and conducting a detailed theoretical analysis to identify sources of inefficiencies.

Weighted Average: 2.69   # of Reviewers: 5
Approach: 3.20   Impact: 2.40   Progress: 2.60   Collaboration/Coordination: 2.80   Remaining Work: 2.00

Program Response

The Building Technologies Office acknowledges the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- SaltX is a very promising approach to achieve the DOE-set energy savings goals. The ancillary technologies for energy efficiency improvement have to be developed or identified (i.e., advanced insulation, heat recovery, etc.).
- The aim of this project is to develop a heat operated heat pump systems that uses an ammonia based working fluid encapsulated into a desorption matrix, referred as SaltX. The resulting unit cycles between desorption (gas) and absorption (ambient heat) to deliver heating to the building space. I found this concept innovative, and with a good approach to develop new heat driven heat pumps with minimum mechanical parts.
- The project is in its last year of its 4-year period. The approach is reasonable. I am not familiar with the early phases of this work, but it seems to be on track in meeting its objectives. Some information about the how the goal of 1.4 COP was established (including the conditions under which it is to be achieved) would have been helpful.
- The technology has fundamental efficiency limitations, which should have been realized during the review of the proposal, based on the existing knowledge in this field.
- This project has a good concept to eliminate the pump, but practical limitations may prevent reaching their eventual project targets. The concept of using the matrix material will be a good test of its practicality in this application.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.40** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project will likely contribute significantly to the achievement of the set goals if cost-effective design will be derived from this challenging collaborative effort between industry and academia. The component level (low-NOx burner, heat exchangers, etc.) developer or OEM should be identified and preliminary committed.
- The impact of the proposed system in contributing to DOE/BTO goals for energy efficiency by 2030 could be large in the gas fire heating systems markets. The proposed unit could be attractive to the markets due to the minimum parts required.
- Although the progress reported in several areas (such as in the salt matrix development) are valuable on their own, the true impact of this work, assuming complete technical success, is largely dependent on commercialization and market acceptance and penetration. Since Rheem is involved in this work, it would have been helpful to provide some detailed cost information (besides the summary payback plots). Initial and maintenance costs are keys, as is the likelihood that a manufacturer can provide long-term warranty given all the outlined positive attributes. A serious discussion of these aspects is essential to ascertain potential energy impact.
- The outcome of this project won't have impacts.
- The poor performance to date suggests that this concept may have more challenges than were anticipated. That does not bode well for successfully meeting project targets, and hence being successfully adopted for commercialization.

C. Progress

Based on current project efforts, the project was rated **2.60** for the degree to which the project has met ***project-specific goals***.

- The significant progress has been reported mostly on the component level while the integrated system design and prototype performance evaluation – still pending. The details on active Rheem engagement was not adequately reported.
- The project is at an early stage. However, the team appears to have made good progress according to the working plan. The team has completed system feasibility analysis projecting COPs as promised (of close to 1.4). Challenges appear to show in the prototyping phases, and this is concerning moving forwards.
- To the extent the overall project objectives are provided in the presentation, the project seems to have progressed as planned, and the team is addressing the remaining technical issues.
- The performance data fall way short of the promised metrics.
- The project has had difficulty meeting performance targets. Also, the limited range of effective heat pump practicality will limit how it will fit into cold weather climates and how much potential energy savings it can achieve.

D. Collaboration and Coordination

This project was rated **2.80** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The reported collaboration is mostly related to joint publications. Statement (slide 16) "Active engagement with Rheem" sounds too vague. More details of such "active collaboration" would be helpful for adequate peer-review assessment.
- The team is very engaged with the corresponding stakeholders to include R&D team, SaltX solution manufacturers, and HVAC system manufacturers. For R&D levels, this is adequate.
- I do not know the precise role of Rheem in this project because in the presentation, its name is mentioned in passing stating its role to "ensure market relevance, provide prototype materials."
- For the success of this project, active and continued participation of the manufacturer is essential. For example, was any aspects of the development changed because of Rheem's input, for example, regarding manufacturability, price, reliability, etc.?
- This project could have benefited from collaboration with experts in heat exchangers design.
- There is generally a good team for this project, and they seem to have their specific tasks and contributions well defined.

E. Remaining Project Work

This project was rated **2.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Based on presented materials the project is late, so extensive list of the remaining steps (especially addressing the low prototype efficiency and packaged prototype design) may result in further delay.

- The approaching prototyping and system integration phases may present challenges and obstacles, and the team did not present proper mitigation plans for addressing these lab scale challenges.
- The remaining work (project ending Sept 2019) is clearly outlined consisting of engineering work to optimize performance and fabrication of a working prototype. Evaluation of the prototype, however, is deferred to FY2020, after this project ends. Was this part of the project to be completed during this funding period? How much is Rheem involved in the development of the prototype ad its evaluation?
- It is not clear how performance will be improved.
- It is not clear that the project can achieve initial performance targets given the current levels of measured performance. It is not clear that practical solutions to the poor performance have yet been identified.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strength is in its innovative approach of using SaltX technology and bringing the leading OEM (Rheem) on board.
- The strength of the project is its innovation.
- The project strengths are its potential to contribute to BTO's objectives, its good team, its viable objectives, it’s clear path forward, and its reasonable progress to-date.
- None.
- The concept is quite novel and eliminates the prime mover. If performance levels can be achieved, this system might be competitive with conventional systems.

2. Project Weaknesses

- Weakness of the reviewed project is in low engagement level of the OEM at this point of project performance.
- The project appears to be very early stages, to a point of conceptual, thus expectations for high levels of TRLs maybe not realistic. This is the major weakness of this project. The team seem to be rushing to lab-scale R&D when questions remain at the fundamental level of the optimum sorption solution.
- These are not weaknesses but some reflections on the presentation:
    - Cost of the components of proposed system are not discussed (or considered?) to determine if such as system is economically viable.
    - Involvement of the industry in general and the industrial partner (Rheem) in particular are not adequately described and emphasized.
    - Some of the engineering issues with known solutions are outlined but what are the "technical challenges" that have to be overcome?
    - IP involved and how it is addressed between partners needs clarification.
- The technology has fundamental limitation.
- The system cannot provide significant heating from the heat pump components during much of the more severe part of the heating season, so overall energy savings would be limited. This may also limit the parts of

the country where this system could be used. Given that the project is scheduled to conclude in about five months, successful achievement of performance targets does not look promising.

3. Recommendations

- More OEMs (gas burner, heat exchanger, etc.) should be brought to the team for developing of the integrated prototype design to ensure its potential manufacturability and cost-effectiveness. The UL engineering team may likely be invited for the initial design review to avoid further issues with the market adoption.
- This reviewer recommends that the team focuses on addressing the selection of the optimum sorption solution, and test a reduce selection of them under control lab conditions. From there to proceed to proof of concept of the cycling and thermal performance. Attempting to commercialize this concept is the next two years seems unrealistic. The team should also be expanded to include materials sciences personnel.
- As alluded to earlier, to get the maximum benefit from the technical developments reported, and to contribute to BTO's objectives, SERIOUS partnership with industry is important at every stage of the project including its final year. Is any of the manufacturers ready to take this project on after 2020 and develop it to commercialization? Are there any reservations? If so, what?
- What is the life of the salt matrix? Has it been tested? What are the results? This is worth checking.
- I recommend the team conducts a detailed theoretical analysis to clearly identify the sources of inefficiencies. Also, they should prepare a realistic assessment of potential efficiency improvements and impacts.
- The concept does not appear to be a prime candidate for commercialization based on its current performance. Before the project concludes, the project team should try to quantify the exact nature of the system shortcomings to see if the concept can ever be expected to achieve the original performance targets.

Project #322101: Pre-Commercial Scale-Up of a Gas-Fired Absorption Heat Pump

Presenter: Michael Garrabrant, Stone Mountain
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

In general, reviewers approved of this approach to develop and commercialize a simple absorption system for residential markets. One reviewer commented that the approach is typical and appropriate. Another reviewer praised the principal investigator for making steady progress over many years to bring this technology to market.

Reviewers generally agreed that the product will be successful if it can be accepted by the market. If ammonia is accepted by industry, this technology would be a viable gas-fired heat pump for cold climates. One reviewer cautioned that if the costs can be managed, this system could prove to be quite acceptable in some cities, but there are a lot of non-technical factors that will determine if this system becomes commercially successful.

All reviewers agreed that the project has made good progress. The project seems to have met all the targets that were identified in advance. One reviewer praised the team for being able to secure commercial certifications for commercial-scale units, complete two units, complete design for manufacturing, and identify the two locations for cold climate field testing.

Most reviewers approved of the project's good collaboration and coordination. The team is heavily engaged with the corresponding stakeholders, including manufacturers, installers, utilities, and professional organizations. However, one reviewer questioned exactly which manufacturer is interested to jump in, design, manufacture, and market this product.

Reviewers agreed that the project is on-track to accomplish the remaining project goals of demonstrating commercial scale units of the proposed gas-fired absorption heat pump with the expected performance metrics. The remaining work is clearly defined. One reviewer suggested the team should have further engagement of the manufacturers.

Weighted Average: 3.01   # of Reviewers: 4
Approach: 2.75   Impact: 3.00   Progress: 3.25   Collaboration/Coordination: 3.25   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will leverage the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.75** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project aims to complete/develop a commercial scale gas driven heat pump system for residential markets. The core technology appears to be 2X-effect absorption system (likely ammonia as working fluid). The project is an evolution of lead group, SMTI, from previous early stage GAHP systems. The specific goal now is commercial field testing and commercialization.
- The approach is typical and appropriate.
- This is a sound technology and PI has made steady progress over many years to bring this technology to market.
- If an absorption system is going to be successful, it will be something like this one that is as simple as an absorption unit can get. Simplifying the basic cycle rather than trying to expand performance by complicating the system will likely have a higher chance of success.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact of the technology could be limit due to several factors. Market acceptability of ammonia-based systems from both users and installers, high costs, and the fact that a large portion of the market is moving towards electrification of the heating systems in buildings.
- With a payback period of 3-5 years, the impact would be outstanding provided the product reaches the market.
- Given the industrial participants in this majority tax-payer funded project, it would be great to strive to revise the "End Goal: Advance Development to Commercial Readiness" to "End Goal: Advance Development to Commercialization." If not, what are the obstacles? Could they be addressed in the course of this project? What are the manufacturers' plans regarding this product?
- The answer to these will establish impact.
- If ammonia is accepted by industry, this technology would be a viable gas-fired heat pump for cold climates.
- The adequate performance of this system should be acceptable if the first cost can be managed. While this system won't be used in Atlanta or maybe even St. Louis, it may prove to be quite acceptable for Chicago and New York. Lots of non-technical factors will go into whether or not this system becomes commercially successful.

C. Progress

Based on current project efforts, the project was rated **3.25** for the degree to which the project has met ***project-specific goals***.

- The project is making very good progress towards the agreeable goals with DOE/BTO. The team has been able to secure most commercial certifications for commercial scale units, has completed two units, has completed design for manufacturing, and has identified the two locations for cold climate for field testing. This is good progress in a little more than one year.

- The tasks have been executed largely according to the plan and progress has been good. The presentation does not show any significant issues.
- Good progress has been made.
- The project seems to have met all the targets that were identified in advance.

D. Collaboration and Coordination

This project was rated **3.25** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team is heavily engaged with the corresponding stakeholders that includes manufacturer, installers, utilities, and professional organizations. Feedback seems to be integrated into the development process.
- There is (appropriately) a long list of collaborators and stakeholders, but exactly which manufacturer(s) is (are) interested to jump in, design, manufacture, and market this product, perhaps to the markets that have the shortest payback period? What are the prospects for this?
- PI has a good team working with him for years.
- The project team seems to have clearly identified the contributions of each team member and are making good use of the strengths of each partner group.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- I consider that the team is on track to accomplish the goals for demonstrating commercial scale units of the proposed GAHP with the expected performance metrics.
- The four tasks (7-10) outlined are reasonable and appropriate. Further engagement of the manufacturers (maybe high-end manufacturers) would be helpful.
- The remaining work is clearly defined.
- The project appears to be in a good position to satisfy the remaining project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength of the project is the fact that is building from a proven technology and track record of development by the team and leadership of SMTI.
- The project moves the device from the R&D to the commercial-ready stage addressing testing, performance enhancement, market analysis, cost, etc. These are the standard and essential steps that are taken by the team.
- A viable technology with a good efficiency.
- Keeping the concept simple, it is just trying to optimize the performance of a fundamental absorption system while keeping a close eye on first costs.

2. **Project Weaknesses**

- The major risk this technology presents is market acceptability due to risks of deployment of ammonia, elevated initial costs, and a shrinking market for gas-based heating processes.
- I do not see any obvious weakness.
- It remains to been seen how ammonia systems will be accepted.
- It is not clear who the commercialization partner is, or their manufacturing capabilities. It was stated that Stone Mountain wants to manufacture the basic absorption unit, but Stone Mountain is not a manufacturer, so I presume they are in communication with someone other than Trane for building these systems. Given the stage of the product, they need to have a manufacturer ready to go and plans in the works for manufacturing facilities, etc.

3. **Recommendations**

- This reviewer recommends that SMTI develops a technology road map where this learning experience is used to develop zero-carbon HVAC technologies, perhaps using solar thermal processes at different kinds (i.e., concentrated and low temperature), coupled to thermal storage systems.
- I would suggest that the team establish communication and collaboration with high-end overseas manufacturers, in Europe and particularly Japan because the natural gas prices there is 2x in the US. Payback period would be significantly shortened, thus a better market for this product.
- No specific recommendation.
- The residential HVAC contractor industry knows very little about the installation and servicing of absorption systems so Stone Mountain will need to develop and manage a tech training program. This training effort needs to occur well before the units are being built. Such a training effort is not trivial and local gas utilities cannot be relied on to run or coordinate an effective training program.

Project #32295: High-efficiency Low Global-Warming Potential (GWP) Packaged Rooftop System

Presenter: Ahmad Mahmoud, UTRC
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Most of the reviewers approved of the approach to use a low-pressure low global-warming potential (GWP) refrigerant. Although one reviewer found this project approach difficult to assess, most reviewers agreed that the approach is excellent and the project looks to be well developed, they understand the root challenges, and they were addressing them head on. One reviewer praised the project because it is clear that UTRC plans to develop this product into a commercially sold product line and they have a very clear set of objectives and targets to reach that commercial objective.

In general, the reviewers agreed that this project will lead to energy savings and contribute to overall DOE goals for energy efficiency and low GWP refrigerants. Significant improvements in performance have been achieved relative to the baseline and this is valuable. One reviewer highlighted that rooftop units account for a high percentage of commercial A/C systems, so improving their performance will have an impact on the overall commercial market.

Most reviewers agreed that the project is showing good progress. The project appears to be on-schedule and the targets set for the work are largely met. One reviewer expressed concerns if the first prototype completion continues to slip.

Reviewers agreed that the project's collaboration and coordination is exclusively carried out by UTRC and their manufacturing arm, Carrier. Reviewers suggested additional collaboration efforts with someone with greater knowledge of heat transfer and pressure drop in two-phase flow and end users, at the appropriate time, to ensure that units have good remote fault diagnostics. Another reviewer highlighted that it is difficult to assess collaboration when so many aspects of the project cannot be revealed, so it is difficult to gauge how deeply involved everyone may be.

Overall, reviewers agreed that the remaining project work includes making the prototypes, optimization of various components, lab-level testing, cost analysis, and commercialization. From what was shown, the project looks to be well-planned and well-run. The project appears to be on-schedule and the team is marching toward its ultimate goal of commercialization, with very clear targets and timelines for the rest of the project.

Weighted Average: 3.12   # of Reviewers: 5
Approach: 3.20   Impact: 3.00   Progress: 3.20   Collaboration/Coordination: 3.00   Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project aims to develop a high-performance V/C unit, using a low GW potential refrigerant for residential markets which currently uses R410. The approach is to optimize every thermo-mechanical component to use a low-pressure low GW potential refrigerant. I found this project difficult to assess due to the very limited information provided by the PI during the review. From wat was presented, it was not evident what was new about this project.
- This project has a mature approach, with step by step optimization. Excellent.
- The system components are modified to accommodate a low GWP refrigerant. Fundamentally, this is the correct approach.
- It is clear that UTRC plans to develop this product into a commercially sold product line. They have a very clear set of objectives and targets to reach that commercial objective.
- The project looked to be well developed, looked to understand the root challenge, and was addressing them head on. I liked that the project is balancing end user ROI goals with technical challenges.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact of such proposed concept could be large contributing to overall DOE goals for energy efficiency and low GW refrigerants. However, it is not possible to assess the impacts of this particular project.
- The system meets (or possibly exceeds) DOE target. Because of its short payback period, adaption and market acceptance could be swift and thus impactful.
- Significant improvements in performance have been achieved relative to the baseline and this is valuable.
- Rooftop units account for a high percentage of commercial A/C systems, so improving their performance will have an impact on the overall commercial market. If Carrier comes out with a highly successful unit, it will drive the rest of the industry to develop something very similar.
- The project impact is increasing the COP/SEER should drive significant energy savings, over the next 10yrs. Even if new refrigerant’s do not work out, general improvements to the unit should drive energy savings.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The project seems to be on target to accomplish the prescribed goals of performance (and maybe cost). Very good advances in the compressor side reaching efficiencies above 80%. The system level analysis show potential to reach the SEER levels of above 21.0. This is all good progress.
- The targets set for the work are largely met.

- Good progress has been made. There seems to be some deficiencies associated with the evaporator coil due to different flow boiling characteristics relative with the previous refrigerant. This can be solved through in-depth research.
- The project appears to be on schedule and has largely satisfied all performance targets.
- While still early the project looks to be reasonable on track and budget is being managed well. However, if the first prototype completion continues to slip, this would be a concern.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This is a UTRC driven project, and therefore, very little expectation for interacting with other stakeholders other than their manufacturing arm, Carrier.
- Carrier is the sole commercialization partner of UTRC, and it seems to be onboard to manufacture and market the product.
- This entity and its affiliate have sufficient capabilities to conduct this project. The team could benefit from someone with greater knowledge of heat transfer and pressure drop in two-phase flow.
- This project is somewhat unique in that it is managed almost exclusively from a private company. It is difficult to assess collaboration when so many aspects of the project cannot be revealed, so it is difficult to gauge how deeply involved everyone may be.
- The project looks to have good collaboration. I would like to see a bit more collaboration with end users at the appropriate time, to ensure that unit have good remote fault diagnostics.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The prospects for the team to complete the goals of the projects with the proper milestones are good. The team is now evolving into system level and corresponding lab level testing, which is on track with the proposed timeline to DOE/BTO.
- The remaining work is clearly outlined, consisting of making the prototypes and optimization of various components followed by cost analysis and commercial plan.
- The remaining work includes further optimization and testing, which is logical give the nature of this technology.
- The project appears to be on schedule and the team is marching toward its ultimate goal of commercialization. They have very clear targets and timelines for the rest of the project.
- From what was shown, the project looks to be well planned and well run. It was the only project that honestly called out any slip in the project.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strength is what is intending to accomplish; a competitive cost residential HVAC unit that operates at higher levels of performance according to DOE goals, using a low GW refrigerant.

- The project's strength is UTRC's expertise and experience and its close collaboration with Carrier with clear objectives.

- The project approach is a strength; and the need for redesigning the system components to accommodate alternative refrigerants.

- There is a very high probability that this work will result in a commercial product and will have a significant impact on the rooftop unit marketplace. I was also impressed that they are putting everything on the table in terms of improving its energy efficiency. I liked the idea that they even modified the fan system to achieve improved fan system efficiency.

- The project strengths are listed below:

  - If enough energy savings can be achieved and cost kept in line for a two-year payback, there is a strong potential for large scale adoption, driving material global energy use reduction.

  - Units will weigh less and fit on existing curbs, making the decision to switch easy.

2. Project Weaknesses

- There are two major issues with this project;

  - Lack of details of the enabling element, the low GW refrigerant, and the corresponding associated operational details (such as pressure, temperature) to assess possible risks and benefits; and

  - Limited exposure to larger pool of stakeholders.

- There does not seem to be any weakness. Is Carrier committed to manufacture and market this product? Any schedule for that?

- Some of the details are not being disclosed. So, it is difficult to determine deficiencies is design and execution.

- The project manager cannot divulge a lot of details since they are considered proprietary. However, this aspect may be a good tradeoff so that a private company will get involved in such a major system re-design.

- The two-year payback maybe too long for people justifying before end of life replacements based on energy savings.

3. Recommendations

- This reviewer recommends that DOE requests the PIs provide a detailed, confidential report and for DOE to evaluate internally the technical and commercial potential of this project to achieve the goals of delivering a unit that is; higher performance, operates with a low GW refrigerant, and at competitive costs. Further, PIs should engage a larger set of stakeholders, while protecting competitive market (and IP); particularly HVAC engineers for constructive critique, as well as other prospect stakeholders in the supply chain such as installers, government agencies, etc. to test market acceptance.

- New developments and optimization of a range of components are carried out and reported in the presentation. To the extent possible, results should be published as soon as IP is secured.
- I recommend the team works with an expert in two phase flow, if they don't have one already in their team.
- Quite frankly, it is difficult to come up with suggestions for project improvements. They are doing a good job and seem to be headed toward their ultimate goals.
- I would like to see more focus on onboard fault detection diagnostics, refrigerant charge, OA %, economizer activity, proper airflow, etc. Also, I would like to understand the impact of new refrigerants. If you used current refrigerants, with all the efficiency enhancements in the unit, would the COP/SEER be even better? We need to make sure that the net lifetime effect of the new refrigerant over 15 years with average loss, is really a net GWP reduction.

Project #32296: Mechanical Dehumidification Using High-Frequency Ultrasonic Vibration

Presenter: Ayyoub Momen, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

While all three reviewers expressed confidence in the project's approach to overcome technical barriers and risks, two reviewers suggested the project team could benefit from focusing subsequent research on the system's size, which they ultimately intend to reduce by 30%. The currently proposed system, one reviewer acknowledged, does increase the regeneration efficiency, but the whole process is still limited by the dehumidification step. The team's approach could be improved, this reviewer said, first by determining the dehumidification process's RMC range, then by examining the ultrasonic regeneration energy needed at different RMC ranges, and finally be evaluating the durability of the moisture-absorbing materials. Nevertheless, all three reviewers were convinced that a successful prototype could considerably reduce the energy required to dry clothes – if the aforementioned challenges are effectively overcome in subsequent research.

Each reviewer said the project had made substantial progress to date, with two reviewers expressing confidence that the team's remaining project work was well-planned to meet the project's goals. One reviewer disagreed, though, saying the project appeared to be "behind schedule" and that the two-year timeline may have been "too optimistic" to avoid a future project extension. In terms of the project's collaboration with its stakeholders, two of the three reviewers described it as "excellent" and "extensive," although one reviewer wished the project had included a desiccant or dehumidification unit manufacturer.

Weighted Average: 3.55 # of Reviewers: 3
Approach: 3.67 Impact: 3.33 Progress: 3.33 Collaboration/Coordination: 3.67 Remaining Work: 3.67

Program Response

The Building Technologies Office acknowledges the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project introduces a new dehumidification process that is three to five times more efficient than existing vapor compression dehumidifiers. In this approach, humidify is first absorbed by a desiccant, and then ejected by high-frequency ultrasonic vibration.
- Project approach should address the technical challenges outlined.
- This project builds on a previous successful project to develop an ultrasonic clothes dryer during 2015 – 2017. This previous project showed that high-frequency vibration utilizing piezoelectric transduces can remove water from wet fabric, in the form of a mist without a phase change, could be achieved. The implication of this technology, allowing water to be removed without a change of phase, could allow dehumidification of an air stream, bypassing the additional energy to change phase, possible. If successful, this could greatly reduce the energy required for dehumidification.
- In order to achieve this, a two-step approach was used. That is: 1) capillary condense water out of the air and then 2) mechanically eject the water.
- The approach is well thought out. It has three steps: 1) Pick the best method (based on cost/stability/performance), 2) Fabricate and evaluate the 1stgeneration prototype, and then 3) Fabricate and evaluate a final generation prototype. I believe that the final generation prototype will only document the efficacy of the approach. More development will be needed after this project concludes.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the proposed system can offer substantial energy saving in management of the latent load of future buildings. The proposed system is novel and interesting. It is mentioned that the new system can also offer 30% compactness. However, cares should be taken as the dehumidification process is limited by moisture removal step and not by the desorption stage. The proposed concept increases regeneration efficiency. But the whole process is still limited by the dehumidification step, and thus the size of the system would be similar to existing desiccant-based dehumidification concepts.
- The potential for energy savings of this technology is significant if successful.
- If this process is successful, the impact could be significant with dehumidification energies of ~250 kJ/kg of water removed as compared to the latent heat of vaporization (i.e., ~3000 kJ/kg). The only question that will need to be addressed is the size of the unit for residential and commercial applications. This question was raised; however, the presenter did evaluate this yet.

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- The team had made excellent progress towards achieving the project goals.
- The presentation nicely laid out the work completed on the prototype testing. Good results were demonstrated, along with feedback noted for enhancement of the future testing.

- The project began on October 1, 2017, with an end date of September 30, 2019. The progress to date has been good. This progress included identification of the material to be used, characterization of the adsorption/desorption rates, a vibration model. It appears there are some challenges that need to be addressed. These are the optimization of adsorption and desorption times, the thickness of the sample on the piezoelectric transducer and how to implement the best selection into a first-generation prototype.
- Since: 1) Pick the best method (based on cost/stability/performance), 2) Fabricate and evaluate the 1st generation prototype, and then 3) Fabricate and evaluate a final generation prototype are to be done in year two of the project and the project ends on September 30, 2019, it appears the project is somewhat behind schedule.
- I think the two-year timeline was too optimistic.

D. Collaboration and Coordination

This project was rated **3.67** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant industry stakeholders. Coordination and communication among team members are also appropriate.
- I would like to see collaboration with a desiccant manufacturer or dehumidification unit manufacturer to gauge the level of industry interest.
- As indicated in Slide 14, it appears the coordination and collaboration are extensive, with biweekly with all team members and weekly meetings with the ORNL team.

E. Remaining Project Work

This project was rated **3.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project works are well planned.
- Remaining project work was clearly outlined in the presentation.
- Since: 1) Pick the best method (based on cost/stability/performance), 2) Fabricate and evaluate the 1st generation prototype and then 3) Fabricate and evaluate a final generation prototype are to be done in year two of the project and the project ends on September 30, 2019, it appears the project is somewhat behind schedule.
- It appears the project will need a time extension.

F. Additional Comments and Recommendations

1. Project Strengths

- The current project is built upon a successful previous project on an ultrasonically-driven clothes dryer system. The main novelty of the project is on the regeneration process where latent heat of vaporization is bypassed by high-frequency ultrasonic vibration and mechanical water ejection.
- This is a technology that can replace a very energy intensive incumbent technology. The results of this project could lead to potentially additional applications beyond desiccant regeneration as well.
- The project has a strong team that involves and an industrial partner.

2. Project Weaknesses

- Although the proposed system offers a novel regeneration process, the level of regeneration is not clear. In the case of clothes drying system, the ultrasonic drying process is highly efficient as the fabric is highly wetted during the initial drying process. However, in the final stage of the drying process, the drying efficiency drops as remaining moisture (water) content (RMC) decreases. In the dehumidification process, the system perhaps works in a small RMC range where ultrasonic drying is not highly efficient (or at least as efficient as the case of ultrasonic clothes drying system). It would be valuable to know the RMC range for the dehumidification application and ultrasonic energy consumption at different RMCs.
- There was some concern expressed about the reaction of the desiccant material, in terms of breaking down, with the vibration. This may not be an issue but was not part of the project plan to evaluate initially.
- The project schedule was too optimistic, being only two years.

3. Recommendations

- I would suggest directing the remaining project work to address the following questions:
- Determining the RMC range for the dehumidification process
- Examining the ultrasonic regeneration energy needed at different RMC range
- Examining the durability of desiccant materials while experiencing multiple cycles of absorption and desorption processes. This ensures that the moisture removal capability of desiccant materials is not being deteriorated by high-frequency ultrasonic vibration.
- None at this time. Excellent concept.
- I would recommend they extend the finish date of the project.

Emerging Technologies

HVAC, Water Heating, and Appliances

Assorted HVAC&R Technologies

Project #32223: Modeling Tools for Flammability Ranking of Low-GWP Refrigerant Blends

Presenter: Gregory Linteris, National Institute for Standards and Technology (NIST)
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers generally found the approach for evaluating the flammability of refrigerants to be valid and well-defined, and noted that using the burning velocity of flammable refrigerants is a good metric for evaluation. Two reviewers commented that this approach and the end product of the research will address an important barrier to adoption of low global warming potential (GWP) refrigerants. The reviewers also appreciated the project's combination of experimental and modeling techniques, and applauded the prediction tools for minimizing flammability that are being developed. Although most reviewers commended the project's approach, one reviewer identified the need for more clarity regarding the testing of hydrofluorocarbon (HFC) and hydrofluoro-olefin (HFO) blends.

All reviewers agreed that, if successfully validated, this project and predictive tool would have a large impact in assessing the flammability of refrigerant blends, especially as the industry works to replace GWP refrigerants. Two reviewers made suggestions for areas of continued study that would improve the project's impact – including the effects of humidity and oil, and including a correlation to minimum ignition energy.

The project is making strong progress and is reaching its accomplishments well, reviewers found. As the project continues, reviewers were pleased with the path towards completion, commenting that the remaining work is well-defined and on-schedule. One reviewer again noted that the future work does not indicate testing of HFC/HFO blends. Generally, the reviewers found the project team to be highly diverse and capable, with top industry experts from many relevant organizations. One reviewer recommended continued stakeholder engagement, particularly with industry.

The most prominent strength of the project that the reviewers identified was the strong expertise of the project team, led by a NIST researcher with a well thought out and well-executed project plan. However, a few reviewers did note areas needing improvement. One reviewer commented that the project had limited refrigerants for the experimental testing, while having a wide range of the refrigerants in the modeling task. Another reviewer suggested expanding the project scope to include the prediction of minimum ignition energy and the heat of combustion, while a third reviewer reiterated the need for more data on the effects of humidity and oil.

As the project continues, the reviewers recommended adding accuracy analysis for the experimental portion, and showing the experimental results with error bars to capture the noise of the measured data.

Weighted Average: 3.49   # of Reviewers: 7
Approach: 3.57   Impact: 3.43   Progress: 3.43   Collaboration/Coordination: 3.43   Remaining Work: 3.57

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.57** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Burning velocity is a good metrics for evaluation of flammable refrigerants. Combination of experimental and modeling techniques is a valid approach for the reviewed flammability ranking effort.
- Well done.
- This technology is not my forte, but approach seems to cover the bases
- Approach seems OK. But it is not clear about testing of HFC/HFO blends.
- This is a well-defined approach to evaluate laminar determination of refrigerant flammability and should provide a valuable tool to the industry and help in further selection and evaluation of new lower GWP refrigerants.
- The project approach is to perform flammability experiments on low GWP refrigerant blends by measuring burning velocities, followed by developing prediction tools for minimizing flammability. The final task is to provide input to codes and standards.
- This work will help address an important barrier to adoption of low-GWP refrigerants.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.43** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The predictive tool, if developed and successfully validated in a wide range of parameters and conditions will serve as a perfect guide for industry within the range of possible operating regimes and scenarios.
- Important issue to be studied and resolved.
- Replacement of high GWP refrigerants is an important development. This would certainly ease the efforts to blend such refrigerants for specific applications.
- This project will have good impact. Better to include effects of humidity and oil.
- It will help in the evaluation of new refrigerants, but if it could also include a correlation to minimum ignition energy it would be extremely beneficial.
- The evaluation of the flammability of promising non-GWP refrigerants, both pure and blends, is one of the most important areas of investigations, as HVAC industries work to replace existing GWP refrigerants.
- The design tool should have a big impact in assessing the flammability of refrigerant blends.

C. Progress

Based on current project efforts, the project was rated **3.43** for the degree to which the project has met ***project-specific goals***.

- Strong progress and accomplishments have been presented given the 75% of the project term
- Appears to be on the right main track to me.

- Progress appears to be satisfactory perhaps even better than expected
- Good progress made. A lot of more testing for blends remained.
- Results to date look good. Basic work has been done on pure refrigerants. The next step will be to see how well the work supports the prediction of mixtures of refrigerants.
- To date, numerous flammability experiments have been performed and models have been developed, with additional experimental verification still required.
- The simulation development is proceeding well.

D. Collaboration and Coordination

This project was rated **3.43** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Strong stakeholder engagement and extensive collaboration have been demonstrated.
- Top experts.
- Collaboration is being made with ALL relevant organizations
- Looks very nice global collaboration established.
- Most of the work is being done by the UMD but they are collaborating with the AHRI research effort, ASHRAE and other experts in the industry
- The level of participation and collaboration on this project is extensive, including five researchers from NIST, six different universities, along with a number of industrial and government organizations.
- The project team is diverse and highly capable but perhaps some stakeholder engagement (industry? manufacturers?) might be useful.

E. Remaining Project Work

This project was rated **3.57** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Stated project accomplishments and remaining project work ensure the project completion and anticipated deliverables on time.
- Measured data verification and industry application potential are the keys.
- Path to completion appears well planned on or ahead of schedule.
- It is not clear about testing of HFC/HFO blends.
- The work looks to be on track and approaches are being developed that will allow the results to be shared and used by the industry.
- The remaining project work is fine-tuning and verifying flammability models, followed by working with various organizations to update codes and standards, all of which will greatly assist with the goal of eliminating GWP refrigerants.
- The remaining project tasks are well-defined and follow logically.

F. Additional Comments and Recommendations

1. Project Strengths

- Possibility of optimizing the performance of refrigerant blends while minimizing their flammability.
- Well thought and well executed, with good progresses.
- Researcher is clearly an expert and understands aspects of the project.
- The project can provide a very useful tool for predicting burning velocity of blends.
- Strong expertise of the staff who have been involved in work related to the new refrigerants and understanding of the industry needs and the pull for this type of work.
- The strength of the project is that it is being led by a NIST researcher, who is a world-class expert in the area of flammability, and it has produced extensive, ground-breaking results to date.
- A highly qualified team, performing a well-defined and needed project.

2. Project Weaknesses

- Limited refrigerants for experimental testing while having a wide range of the refrigerants in modeling task.
- None so far.
- None.
- Need more data of R32 blends and effects of humidity and oil
- I would like to see if the project could be expanded to also include a prediction of minimum ignition energy. Also the work is also just focused on laminar burning velocity but often the real world events are turbulent. I'm not sure this can be factored into the work but would be nice if it could. Also if the work could also predict the heat of combustion which is another metric used to classify refrigerants.
- None.
- If there is one criticism to make, it is showing experimental results without any error bars. Are the impacts of buoyancy, stretch, and radiation actually hidden in the noise of the measured data? It would be good to address this wherever possible.

3. Recommendations

- Adding the accuracy analysis for the experimental part as well as extensive validation for the predictive model.
- Well done.
- Get this completed and out to the industry.
- Hope to include more R32 blends and effects of humidity and oil.
- If possible, include MIE, HOC, and turbulent combustion. In the end if it could be included in Refprop or other NIST tools.
- None.
- None.

Project #32291: Adhesive Bonding of Aluminum and Copper in HVAC&R Applications

Presenter: Patrick Geoghegan, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

The project approach of developing adhesives with specific chemistries for bonding to aluminum and copper is well thought out, reviewers commented. One reviewer applauded the team's clear outline and engagement with major manufacturers. Most reviewers found this project to have a huge potential impact on the industry, reducing costs and refrigerant leakage. One reviewer however, found the project team did not clearly analyze the project impact and noted the team will need to quantify reduction of direct emission of refrigerants.

Although the project was delayed, reviewers commented that the team had made good progress, with a clear plan outlined for development and evaluation of concept. Reviewers observed strong collaboration with adhesive manufacturers and partners at Purdue University and Oak Ridge National Laboratory. One reviewer noted the project team should explore more partnerships with coil manufacturers.

Many reviewers expressed concern for the remaining project work, noting extensive work needing to be done to prove quality, reliability, cost, and life-cycle assessment. A particular concern for one reviewer was how the technology will be introduced, as it will require substantial change in production. A reviewer recommended incorporating a plan for support to help manufacturers implement the technology into production to address this challenge. More technically, another reviewer suggested adding sever testing at high temperatures and high pressure under vibration testing, and compatibility with refrigerant and oil.

Weighted Average: 3.42   # of Reviewers: 5
Approach: 3.60   Impact: 3.60   Progress: 3.20   Collaboration/Coordination: 3.60   Remaining Work: 2.80

Program Response

The Building Technologies Office leverages the peer review as an effective program management tool and will use the feedback provided by reviewers to inform updates to this project as appropriate.

A. Approach

This project was rated **3.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project addresses an important issue and potential solution.
- The approach appears to be very well thought out with clear vision of objective.
- Developing adhesives with specific chemistries for bonding to Al and Cu is practical task and will contribute to refrigerant leakage. It is good motivation.
- With the increasing cost of copper and the move to aluminum heat exchangers, this could be a very beneficial project. They have a good outline and have engaged with major manufacturer of adhesives.
- The project approach is to evaluate the use of adhesives to join Cu-Al, Cu-Cu and Al-Al joints, which is important because of reliability limitations of traditional brazing and the increased usage of Al, especially for HXs. The use of adhesives is highly dependent on surface preparations, which is an important part of this study.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.60** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- I see "huge" impact and potential importance.
- Replacing brazing of dissimilar materials with adhesive would be a significant advance in product durability.
- The current impact analysis is somewhat vague. The team will need to quantify reduction of direct emission of refrigerants by applying methodology to be developed.
- If successful and cost effective this could have a huge impact on the industry who is moving to aluminum coils.
- Adhesive bonding is being investigated as a replacement for traditional brazing, which should result in significant cost reductions in manufacturing along with reductions in refrigerant leakage.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- Progress was delayed but it's OK by now.
- Progress with details of making a sound bond appears effective.
- Good technical progress has been made.
- It looks like they have a good plan outlined for development and evaluation of the concept.
- To date, surface preparations and adhesive formulations have been completed. Also, significant interactions with stakeholders and a large number of HVAC companies have been engaged to help determine the extent of the joining/leaking problem and the needs of industry.

D. Collaboration and Coordination

This project was rated **3.60** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This project has well-picked partners and collaboration.
- Program is working with large number of manufacturers.
- The team needs to add HX and system manufacturers in collaboration team.
- There is strong collaboration with adhesive manufacturers. The team probably could do some more with coil manufacturers.
- The project team is Herrick Laboratories at Purdue University, ORNL and a world leader in adhesives, namely 3M Corporation. Stakeholders are numerous HVAC companies and manufacturers.

E. Remaining Project Work

This project was rated **2.80** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This is to be seen.
- I'm not entirely clear how this technology will be introduced as it will require a substantial change in production. An effort to understand and accommodate these changes is necessary.
- The team needs to add repeatability and life time assessment.
- There is still a lot of work to do and to prove quality and reliability and cost.
- The remaining work is identifying adhesive candidates that satisfy joint strength, cost analysis, and prototype testing.

F. Additional Comments and Recommendations

1. Project Strengths

- This project is on a well-applicable topic and potential solution.
- This is a potential game changer in refrigerant systems.
- Extensive review on adhesive bonding material and good progress in testing.
- The team is working with leading adhesive manufacturers and experience of staff in this area.
- The strength of the project is that its success could completely transform how HVAC systems are manufactured and assembled.

2. Project Weaknesses

- Slow in progress due to uncontrollable factors.
- The team needs to be certain there is follow through to ensure the process is perfected and implemented into the industry. It is not clear from presentation that this will be incorporated effectively into the work plan.

- It is better to add sever testing at high temperature and high pressure under vibration testing, and compatibility with refrigerant and oil too.
- Cost and reliability will be the challenge and key success factor.
- None.

3. Recommendations

- This project could be exciting depending on the outcome.
- The team should incorporate a plan for support to help manufacturers implement into production.
- It is better to add sever testing at high temperature and high pressure under vibration testing, and compatibility with refrigerant and oil too.
- I recommend teaming up with HX and system manufacturers
- More interface with coil manufacturers and analysis of the process to implement.
- None.

Project #31254: Cast Heat Exchanger Using the Novel Ce-Al Alloy

Presenter: Ayyoub Momen, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers applauded the project's approach of developing a new heat exchanger technology that uses improved casting processes to manufacture heat exchangers (HXs) as single units. This new approach to HX fabrication could "revolutionize the industry," one reviewer commented. All but one reviewer found the project to have a potentially large and broad impact on the industry. Reviewers commented that beyond reducing costs and extending the life of the heat exchangers, the combination of Al-Ce could allow heat exchangers to be used in broader environments, like high temperature and high pressure. More critically, one reviewer expressed concern on the long-term use of cerium, a rare-earth metal requiring importation, as access to it may be dependent on international politics.

Reviewers were pleased with the progress the project has made and noted that despite its early stage, the progress completing the preliminary HX designs are very good and on track. One reviewer suggested that the materials research take precedent over the design and modelling as these are essential to this project.

Overall, the project team has collaborated with the appropriate stakeholders from industry and academia, reviewers found. One reviewer emphasized the importance of the team members focusing on the development of the material itself, its properties and performance, as the necessary tests and data collections will take time.

The newly developed alloy, the expertise in evaluating it, and the design of the single piece HX are all key project strengths, as noted by the reviewers. The reviewers also found the remaining project work to be well thought out, though one reviewer suggested the project team assess the pressure drop and wall roughness of the microchannel configuration. Though generally providing good scores, the reviewers identified the following potential weaknesses of the project: cost and availability of the new alloy, broad scope, fabrication of HX in one step through casting. To address these issues reviewers recommended collaborating with manufacturers of HX fabrication equipment, conventional fabrication of the HX, and focusing on the evaluation of the material itself.

Weighted Average: 3.23   # of Reviewers: 5
Approach: 3.40   Impact: 3.20   Progress: 3.20   Collaboration/Coordination: 3.20   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.40** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Approach of casting the entire heat exchanger from a new alloy with the advantageous properties (slide 7) seems very attractive while the appropriate design contingency exists.
- This project aims to develop a new HX technology using improved casting process which will allow to manufacture HX as single units, and not in parts. This is a very relevant problem to address in the HVAC industry where HX are key enabler elements.
- Development of a die cast heat exchanger with intricate internal geometry (microchannels) that is corrosion resistant and inexpensive is a compelling idea, and the choice of Al-Ce is an interesting option.
- The proposed approach is detailed clearly. Critical aspects of the projects are identified and the approach to tackle them are also outlined. The team has prior experience with the development of Al-Cr and that will be helpful.
- This seems to be a good research.
- Resolution of refrigerant leak problems is important to the industry. Most manufacturers of unitary products make their own heat exchangers, and they often use methods and technologies that have been used for decades. A new approach to heat exchanger fabrication could revolutionize the industry.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Assuming the continuing Cu displacement trend for HVAC markets, the project results may provide a significant impact given the fact of favorable economics (slide 14) proven for specific applications.
- The impact of the project could be large and in different aspects. It may have the potential to increase efficiency of HVAC systems, reduce costs, and also extend life-time of the HXs in HVAC systems.
- In instances where Al heat exchangers cannot be used (such as high temperature, high pressure) Al-Ce could provide an outstanding solution, and the impact can be significant. The material research part of the project alone can be very helpful in paving the path for widespread use of this material for other applications besides heat exchangers.
- This research could have significant impact in corrosion resistance metal heat exchangers for HVAC and other applications.
- While a successful project outcome may produce a significant impact on the industry, I am not optimistic that it will have a significant direct impact on energy use. I also have concerns about long term use of the cerium since it is a rare earth metal that must be almost exclusively imported. The conservative HVAC industry may be reluctant to expose themselves to the risk of limited availability of a critical component of their product that could be caused by international political strife.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- For early-stage project the demonstrated progress is quite good. Casting feasibility for the identified design geometries has been evaluated and tentatively demonstrated, FE stress analysis is being initiated.
- The progress made as presented is reasonably good. The PIs have completed preliminary HX designs and are in the process of evaluating the thermo-physical properties of the proposed Al-Ce alloy. Efforts also started to optimize the casting design to integrate micro-structures to increase heat transfer area.
- The project is in its early stage, but the work reported to-date is very good and on track. Materials research (corrosion, high temperature strength, thermal fatigue, etc.) should take precedent over design and modelling because these are essential to this project.
- Good progress is being made.
- Given the project has been in place only six months, the progress to date is largely on schedule and has primarily involved early phase scoping efforts.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination with industry and academia seems appropriate at this stage. Industry input obtained from the cooperating vendors. Since there were not any ties to specific application reported - there is no need to bring the OEM on board. When the first appliance type for demonstration will be defined then corresponding OEM has to be brought onboard.
- The project itself is the product of strong collaborations with diverse stakeholders that include all necessary expertise. The team appears to be communicating properly well.
- The team is high caliber covering every aspects of the project, however, it is not clear how much effort each member will spend on this project. As noted, the key to this project is the material itself, its properties, its performance. Only two of the 14 team members seem to be work on the alloy itself. I would recommend this be increased to about 50%. There is a significant amount of work to be done, tests, data collections and these take a tremendous amount of time. Experts from academia can be brought in to help expedite this work.
- A good industrial collaborator is involved.
- The project team is highly qualified to support this work and each group appears to have appropriate contributions planned for the effort.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining work plan seems well-thought and reasonable.
- The project could make significant progress in demonstrating the technical feasibility of the proposed new manufacturing approach for HX, with proper unit yield. If so, this will be a gain to the HVAC industry. The full system integration seems more ambitious enterprise and risky.
- The project is in its infancy so most of the work is ahead. As noted, I would emphasize materials research aspect at the expense of all others. Preliminary fatigue tests, for example, could take months.

- The ability to configure long and narrow fine microchannels (and I assume by microchannel it is meant channels under 1 mm) can be tested along the way to establish minimum feature size (with large aspect ratio) that can be cast. Pressure drop is a concern and wall roughness might be an issue depending on the channel size.
- There is significant work to be done on making actual heat exchangers using Al-Ce alloy.
- The project schedule appears to be appropriate and targets the more favorable applications that are likely to produce significant outcomes.

F. Additional Comments and Recommendations

1. Project Strengths

- New material. Single piece HX with a minimum leaking potential.
- The project strength is the subject itself. Reliable, low cost HX for the HVAC components, to increase performance and lifetime. The proposed advanced manufacturing approach is a solid step in this direction, and the team is experienced in the different aspects of the project.
- ORNL has developed the Al-Ce alloy and much of the knowhow is there and having access to the expertise is the major strength of the project. ORNL also additionally the tools and expertise to carry out the material evaluations needed. The path forward and key challenges are clearly devised.
- Choice of new material and its promising corrosion resistance.
- While there is a lot of work being done on heat exchanger design, there is little being done on heat exchanger manufacturing issues. Since the equipment used for manufacturing finned tube heat exchangers is largely produced by third party companies, most HVAC manufacturers do not produce their own coil manufacturing equipment. As a result, there is little being done to break new ground on how heat exchangers can be more effectively produced. I think it is appropriate to use the national labs as a resource to investigate new methods of manufacturing heat exchangers, and if successful, this information can be disseminated broadly to the HVAC community.

2. Project Weaknesses

- Given the large market for such type heat exchangers the cost and availability of the new alloy may be critical.
- The major weakness of the project is the ample scope. The team may want to focus in demonstrating the enabling technology at the component level, and address system level at a later stage under a follow up effort. There still remains many unknowns, particularly the optimization of the basic components such as micro-fins/channels, pressure drop implications, and final unit costs.
- The project is at its early stages and no major weakness is seen. As noted earlier, most emphasis should be put on the material itself and its suitability to meet the stated specifications.
- Fabrication of the entire heat exchanger in one step through casting is not a sound strategy.
- I would be happier with the project if it did not use an exotic rare earth metal that had to be imported from China. However, the source of that material may produce much less resistance to the technology than I personally fear may result.

3. Recommendations

- Most of the microchannel HX for operating at high temperature and high pressure face the issue of the elevated pressure drop. Healthy balance between thermal performance and pressure penalty should be taken into consideration.
- This reviewer recommends reducing the scope and focus on single component delivery at this stage, including optimization of the casting process for heat transfer and cost performances.
- I would recommend a detailed program to evaluate the material itself unless it is carried out under a different program. Precisely what tests should be carried out to certify it for use as a heat exchanger material in harsh, high temperature, high pressure environments?
- Explore fabrication of the heat exchanger or critical elements of it through conventional technologies, not fully casting it.
- Explore the manufacturers of heat exchanger fabrication equipment and try to get them involved as some meaningful results begin to emerge. It is those companies that make the equipment which HVAC manufacturers use to produce their own heat exchangers. If they can be convinced of its merit, they will develop the heat exchanger manufacturing equipment that will be sold throughout the industry.

Project #32226w: Commercial Refrigeration Expansion Loss Reduction Technique

Presenter: Brian A. Fricke, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers found the project's approach for a CO_2 refrigerator system interesting and innovative. One reviewer, however, expressed concern that the same benefits will be obtained with compressible and 2-phase fluids used in refrigeration systems. While some reviewers commented that the project's impact would be significant, especially in reducing the cost of refrigeration and increasing the efficiency of CO_2, other reviewers noted the benefits may have been overestimated and suggested honest skepticism about the viability of the application.

Reviewers did not agree on the progress of the project; while some described the project as progressing with the modeling of the unit, others found the progress slow and not focused enough on the compressible liquids. Though the project team has identified strategic stakeholders, and has been discussing with experts in the industry, one reviewer suggested further literature review.

Innovation, strong analytics and modeling, and improved efficiency were all listed as project strengths by the reviewers. More critically, the reviewers questioned the cost-effectiveness and potential energy savings for the project given its complexity. As the project continues, the reviewers found the remaining work to be well-defined, but would recommend looking at an annualized model, and working beyond bench testing. Additionally, reviewers suggested the project team investigates alternative methods of pressure recovery, and modeling the complete system on a typical supermarket refrigeration system.

Weighted Average: 2.90   # of Reviewers: 7
Approach: 3.00   Impact: 3.00   Progress: 2.71   Collaboration/Coordination: 2.71   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will leverage the feedback provided by reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project has a very interesting approach for commercial refrigeration application. Similar energy exchange process widely uses in RO applications.
- Very interesting and innovative.
- Acquiring and bench testing a prototype pressure recovery device prior to an operational test is a good approach.
- New approach is proposed for improving CO_2 cycle efficiency.
- The concept is very interesting, but they have based the concept on water recovery where there are incompressible fluids. I have concerns that the same benefits will be obtained with use with compressible and 2 phase fluids used in refrigeration systems. Also, they have not considered that very little operation is at full load and that HVAC&R systems spend considerable time at part load and reduced lift so the benefits will likely be significantly less than they have estimated.
- The project approach is to develop a pressure exchanger for implementation in carbon dioxide refrigeration systems. The critical barriers to achieving project success have been identified and are being addressed.
- This is an innovative approach for a CO_2 refrigeration system.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successfully validated and cost-effectively integrated into selected refrigeration application, the reported technological concept may substantially impact the commercial refrigeration market (specifically CO_2).
- This technology could be of significance.
- While it is useful to carry some honest skepticism about the viability of this application (since there will be some complex issues that need to be resolved), if it is successful, it can be a help to improving overall efficiency of multi-pressure refrigeration systems.
- There is no payback target. The impact can be compared with ejector cycle.
- I think it is only applicable to CO_2 systems and the benefits will be small for HVAC systems due to the low lift. Also, I think the benefits have been over estimated and have not considered part load.
- The impact of this project is that “lost work” in the expansion process can be recovered, significantly reducing the cost of refrigeration.
- Advancement could promote the adoption of CO_2 refrigeration systems and increase efficiency of current CO_2 systems.

C. Progress

Based on current project efforts, the project was rated **2.71** for the degree to which the project has met ***project-specific goals***.

- The progress in system characterization via modeling and open-domain data assessment is adequate to the approved scope. Key stakeholders were identified.
- OK.
- Apparently, a prototype is being manufacture red, but it certainly seems to have taken considerable time to get to this point.
- Design for PX sealing is needed. Heat transfer from gas cooler out stream to suction stream needs to be identified.
- They are just getting started and have done some reasonable analysis, but the focus has been more on incompressible fluids. They need to spend more time on compressible and 2 phase and the HVAC applications include part load and reduced lift.
- The project has made progress in numerical and CFD modeling of the unit.
- The development of the numerical model seems has progressed well.

D. Collaboration and Coordination

This project was rated **2.71** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Strategic stakeholders are identified. NDA is in progress. No significant details on prototype PX development were presented.
- I recommend more literature review.
- Working with the potential manufacturer is good. However, this particular means of pressure recovery may have issues, particularly extra efficiency losses if flows are not carefully regulated. It would be useful to inspect other types of similar devices that do maintain separation to eliminate the potential for low temperature compressor discharge from short circuiting into the low-pressure line or the high-pressure liquid from short circuiting into the medium pressure suction line. This may not be the idea device configuration to manage these flows.
- It seems good collaboration is established.
- They are working and discussing the idea with several experts in the industry and in the refrigerant product industry.
- The project has significant involvements from numerous entities, both institutional and industrial to include ORNL; Energy Recovery, Inc.; Hillphoenix; and UT. This interest by stakeholders is an indication of the project’s value.
- Team is composed of a strong collaboration of experienced partners. The planned publications and meetings should provide adequate stakeholder engagement.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The stated remaining work (especially prototype PX for R744 development and performance evaluation) is critical to the overall project success.
- I look forward to it.
- Keeping the remaining work beyond bench testing open ended to deal with potential issues that arise from these tests is the correct path.
- There is a good plan for remaining works.
- The team needs to look at annualized model and not just full load to see the benefits. Also, they need to consider the impact of compressible and 2 phase refrigerants.
- The future work involves development of a test apparatus and prototype.
- The remaining work seems well defined.

F. Additional Comments and Recommendations

1. Project Strengths

- The major strength is identifying the alternative technique for pressure loss reduction.
- This is a great idea.
- The potential of recovering some work and improving system efficiency with a simple device such as this is an attractive potential.
- This is a new idea to improve CO_2 cycle efficiency at high ambient.
- The combination of analytical and modeling with test results is strong.
- The project strength is its breadth and potential for reducing nation-wide energy use with innovative technology.
- Innovative application of a technology used for a different application.

2. Project Weaknesses

- The major challenge of this effort is cost-effective and energy saving design for the selected application.
- Others may have already explored some of it, so the PIs face the challenge to make a break-through.
- There are many potential pitfalls that could allow the addition of this device to a system to allow short circuiting and dramatic losses of efficiency. The concern is that the resulting system may be unstable and subject to reduced operating efficiency due to flow imbalances.
- The sealing will be challenge. The team will need an annualized benefit evaluation.
- The team needs to look at overall system benefits include part load and the annualized economic model.
- None.

- It is unclear if the energy savings will justify the likely increase in system complexity and the capital and O&M costs.

3. Recommendations

- No comments at this point.
- I hope to see something practical coming out of it as promised.
- I recommend investigation alternative methods of pressure recovery that ensure short circuiting does not occur.
- It is better to compare with ejector cycle for efficiency gain and payback.
- I recommend a model of the complete system on a typical supermarket refrigeration system. Also, I recommend the team takes a closer look at the impact of 2 phase flow and compressible fluids.
- None.
- None.

Project #32225: Evaluation of Safe Refrigerant Charge Limits for Flammable Refrigerants

Presenter: Van Baxter, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

All reviewers highly rated the project's approach of using computational fluid dynamics to develop analytical tools for a quick estimation of safe flammable refrigerant charge limits. Given the extensive use of refrigerants worldwide, this project will significantly impact the ability to safely utilize flammable refrigerants going forward, reviewers comment. The work will help with the adoption of flammable refrigerants, which have significant energy savings potential, another reviewer praises. One reviewer found the team had made "excellent progress towards achieving the project goals," especially now that the project is nearly complete.

The project team demonstrated excellent strategic coordination with relevant stakeholders, as one reviewer noted. Another reviewer applauded the project's collaboration with AHRTI, ASHRAE and other industry stakeholders through an initial workshop to solicit input on needs.

Although the project is nearly complete, with the last major milestone to document and distribute information to stakeholders, one reviewer noted that the project has not yet hit the milestone of developing analytical tools for relatively quick estimation of safe flammable refrigerant charge limits. This reviewer recommended more research to address this project goal.

Two reviewers felt this was a key example of how to develop and distribute key technical information that will be received and adopted by decision makers on codes and standards. One reviewer recommended the project team conduct fundamental experiments to measure some thermo-hydraulic properties of the new refrigerants in the future.

Weighted Average: 3.88   # of Reviewers: 3
Approach: 4.00   Impact: 3.66   Progress: 4.00   Collaboration/Coordination: 4.00   Remaining Work: 3.66

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **4.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project utilizes computational fluid dynamics (CFD) to develop analytical tools for relatively quick estimation of safe flammable refrigerant charge limits. The accuracy of CFD simulations is the key to the success of the project. Particularly, the accuracy of CFD simulations depends on the binary diffusion coefficient which varies from one refrigerant-air to another refrigerant-air mixture. The binary diffusion coefficient essentially tells us how fast a specific refrigerant will travel into an air mixture. This parameter is important in both convective dominated regime (i.e., closer to the source of leakage) and diffusive dominate regime (i.e., far from the source of leakage).

- The project has significant interest and collaboration with industry and technical organizations. There is significant potential for the flammable refrigerants to save energy due to better thermodynamic properties than alternatives. This directly supports the BTO goal to reduce HVAC energy 45%.

- This is an important project to allow the HVAC&R industry to quickly estimate safe charge limits for a flammable charge in HVAC&R applications. The approach executed by the project was well thought out involving industry, AHRTI, and ASHRAE for the dissemination of the information. The engagement involved an initial workshop to solicit input on industry needs and to provide guidance on the R&D approach. This initial meeting was followed up with regular review meetings of the AHRTI Advisory Group. In addition, the team, which was an impressive group of experts, reviewed the literature to assess key technology gaps to identify missing information needed. This was followed by CFD simulations using a validated model to assess release events. Finally, this information was used to develop a ROM for the estimation of quick safe charge limits.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.66** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the proposed project provides HVAC&R industry and other stakeholders with an important and easy-to-be-used tool to estimate appropriate flammable refrigerant charge limits. This is of paramount importance at the moment.

- This project will significantly impact the ability to utilize flammable refrigerants going forward. One of the biggest factors that prevent usage are the safety requirements and charge limit restrictions. This research will directly be applicable for codes and standards to help determine safe operation and thus assist with the adoption of the refrigerants.

- There is extensive use of refrigerants worldwide. The information developed in this project would allow industry to easily determine appropriate "safe" charge limits of low GWP refrigerants that are flammable.

C. Progress

Based on current project efforts, the project was rated **4.00** for the degree to which the project has met ***project-specific goals***.

- The team had made excellent progress towards achieving the project goals.

- The proposal clearly outlined the progress and results to date. The CFD modeling is in alignment with how codes and standards groups would expect this to be done to conservatively estimate room concentrations.

- The project began on June 1, 2016, with an end date of September 30, 2019; hence the project is nearly completed with all deliverables to date being met. The only remaining work is to finalize and document the “fan on” ROM version and to distribute the report to stakeholders.

D. Collaboration and Coordination

This project was rated **4.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant stakeholders.

- The project team has been working with the appropriate channels (AHRTI and ASHRAE) to ensure that the project results are directly applicable to furthering adoption of the flammable refrigerants.

- As pointed out above the collaboration and coordination was effort. This took a lot of effort. This involved an initial workshop to solicit input on industry needs and to provide guidance on the R&D approach, followed up with regular review meetings of the AHRTI Advisory Group.

E. Remaining Project Work

This project was rated **3.66** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Although the team had made excellent progress towards achieving the project goals, one the important target outcomes of the project was to develop analytical tools for relatively quick estimation of safe flammable refrigerant charge limits. It is not clear how this important milestone is planned to be met.

- The project is nearly complete, and the remaining work was outlined.

- The work needed is documented and distribution of the information to stakeholders will be done.

F. Additional Comments and Recommendations

1. Project Strengths

- One of the interesting aspects of the proposed project is to develop a reduced order model (ROM) for relatively quick estimation of safe flammable refrigerant charge limits. This will enable wider use of environmentally friendly refrigerants.

- The strength of this project is it conservatively estimates room concentrations which will be directly applicable for decision makers on codes and standards. The work will help with the adoption of flammable refrigerants, which have significant energy savings potential.

- This project had a strong team and a well thought out extensive engagement with industry and stakeholders. This project is a good example of how to develop and distribute key technical information that will be received and adopted.

2. Project Weaknesses

- I think more efforts need to be dedicated to developing mechanistic analytical tools to quickly estimate safe charge limits for flammable refrigerants in HVAC&R applications. This was one of the initial goals of the proposed project. However, efforts on this aspect of the project have been minimal. It is suggested to dedicate more resources on this task.

- No weaknesses noted.

- None.

3. **Recommendations**

- The proposed work has several interesting aspects in terms of CFD simulations combined with experimental analysis. In the context of the proposed project, it would have been relevant to conduct fundamental experiments to measure some fundamental thermo-hydraulic properties of the new refrigerants; properties such as binary diffusion coefficient that are relevant to refrigerant leakage and propagation behavior in a conditioned room.
- None at this time, the project is nearly complete.
- None.

Project #32226h: Innovative, Low-Cost Ground Heat Exchanger (GHX) for Geothermal (Ground Source) Heat Pump Systems

Presenter: Xiaobing Liu, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers offered favorable reviews of this project's approach to using an innovative ground heat exchanger (GHX) for geothermal (ground source) heat pump systems. Two reviewers specifically cited the potential of this project's approach to result in much lower drilling, installing, and operational costs. Another reviewer commended this project for beginning with lab testing of concept before moving to ground testing. Overall, reviewers concluded that the impact of this project could be far-reaching because of the potential reduction in operating costs. Two reviewers highlighted specific industries/applications that would benefit as well, including rural and standalone applications and the residential and small commercial building industry. However, one reviewer specified that more analysis needed to be conducted that compares the reduction in drilling costs with the increase in costs for the advanced geothermal system being tested.

There was unanimous consent among reviewers that the project is making good progress on its project-specific goals. Reviewers made sure to highlight the testing and evaluation that has been completed to date at the lab-level, though one reviewer wanted to see the overall impact on a typical house and the annual energy savings improvement. Regarding collaboration and coordination with relevant stakeholders, reviewer comments were more mixed. Four out of the five reviewers believed that stakeholders were "limited" as this stage. Two reviewers specifically called out the team for needing more Ground Source Heat Pump / Water Source Heat Pump manufacturers and home builders involved with the project.

Most reviewers believed that the project was on pace to complete the remaining project-specific goals. However, at least two reviewers offered areas where future project work could be focused, including: 1) investigations on effects of humidity in soil and the need to consider frost line depth in middle and upper states, and 2) studies on actual buildings coupled with cost/economic analyses.

Weighted Average: 3.31   # of Reviewers: 5
Approach: 3.60   Impact: 3.40   Progress: 3.40   Collaboration/Coordination: 2.80   Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **3.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Creative and promising.
- Starting with lab test of concept and moving to ground test appears a good approach.
- Good approach using GHX as a thermal buffer.
- Interesting approach and could significantly help with residential building energy savings and efficient system and avoid some of the high cost and operational issues with ground source heat pumps.
- Technology is being developed for ground-source heat pumps to decrease the cost of drilling and installing the ground HX, by using an innovative, prefabricated high-performance unit.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.40** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This project will be very attractive for rural or stand-alone applications.
- It appears that some significant qualifications may be required for climates and loads for which this shallow system will be suitable.
- The project team needs to quantify impact of current technology over state-of-the-art GHP. Not sure how much is drilling cost savings vs. system cost increase. They need a good economic analysis.
- Depending on the capacity that is delivered and the amount of storage, it could be beneficial to the residential and possibly the small commercial building industry. I don't think it will be applicable to the commercial building industry.
- The impact of this project could be that GCHP usage is increased as installation and operating costs are reduced.

C. Progress

Based on current project efforts, the project was rated **3.40** for the degree to which the project has met ***project-specific goals***.

- This project is well on track.
- The program seems to be progressing well.
- Good technical progress.
- The team has designed, built and tested a Prototype UTB, lab. (UTB performs better than GHX, UTB with PCM (9% of tank volume) has a little better), developed 3D Models of UTB and VBGHE, evaluated long-term performance.
- The current progress looks good and they have some data and modeling tools developed. I was not able to see the overall impact on a typical house and the annual energy savings improvement.

- The project's progress is on schedule with a test stand (small scale unit) having been built and key components, parameters and concepts having been evaluated.

D. Collaboration and Coordination

This project was rated **2.80** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This project has excellent team work with committed leadership.
- This project has some industry contact.
- There is good collaboration team but they need GSHP manufacturers.
- Other than work with the Army I did not see any collaboration with WSHP manufacturers or with home buildings which would help validate the interest in the project.
- Stakeholders are limited at this stage; however, they have been identified and collaborators are being approached.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This is well planned and on track.
- Looks like the final work is reasonable.
- The project has a good plan but it would be better to add investigation on effects of humidity in soil and need to consider frost line depth in middle and upper states.
- The focus in the future will be on improving the model and conducting system testing, along with performing a cost analysis.
- I would like to see some studies done on actual buildings as well as cost and economic studies.

F. Additional Comments and Recommendations

1. Project Strengths

- This project has an integrated idea with hard-working execution. It is very comprehensive approach and conduction of the R&D.
- Shallow bores reduce cost of system.
- Excellent idea of using GHX as thermal battery.
- This project has a novel design and lends itself to possibility of significant installation cost reduction.
- The strength of the project is in its goal of reducing GCHP installation and heating/cooling costs.

2. Project Weaknesses

- None so far.
- Load and climate applications are likely to be very limited.
- Need to consider effects of humidity on GHX performance and frost line in UTE design and installation.
- These are fundamental feedbacks that can be learned from GSHP manufacturers.
- I do not support the use of sprinkler water going thru the system as it will result in fouling. I would like to have seen cost studies and full building energy savings studies.

3. Recommendations

- Look forward to it!
- The team should be very specific concerning where and what applications this may be suitable for and benefits should not be dependent on complicated other systems to charge the battery.
- Better to add investigation on effects of humidity in soil and need to consider frost line depth in middle and upper states.
- The team needs good economic analysis. I recommend they partner with GSHP system manufacture.
- Energy studies and economic studies and also interface with manufacturers of WSHP's and with home builders.
- None.

Project #31255: Integration of Piezoelectric Sensor-Actuators into Heat Exchanger Headers to Alleviate Flow Maldistribution in Real-Time

Presenter: Viral K. Patel, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers appeared satisfied with this project's approach to overcoming barriers, technical challenges, and mitigating project risks. The integration of piezoelectric sensors-actuators into heat exchanger (HX) headers was commended by two reviewers as a practical and novel approach to mitigating flow maldistribution. One reviewer was specifically interested in how the location and magnitude of piezo-crystal waves would affect the two-phase flow instabilities. Another reviewer would have liked the project team to provide an overview of the "few viable and cost-effective solutions" that currently exist so that he/she could compare the team's current approach against existing approaches.

All three reviewers believed that, if successful, this project could contribute to program goals by increasing HX capacity for improved system efficiency by more than 10% thereby resulting in important energy savings. However, one reviewer expressed concern that these savings may not outweigh the potential leakage that could occur due to sensors causing additional penetrations in the system. Another reviewer noted that, because of the added complexity of this approach, it would be helpful for the team to measure the effectiveness of ultrasonic waves in mitigating two-phase flow maldistribution.

The reviewers were also convinced that the project team had met its project-specific goals outlined thus far. Two out of the three reviewers cited both the CFD modeling and the setup for the benchtop testing as significant deliverables that would contribute to this project's progress. Similarly, most reviewers lauded the current collaboration and coordination efforts with relevant stakeholders, including HX manufacturers. However, one reviewer was unclear whether these efforts were planned or ongoing from the onset of the project and advised that the project team consider adding an industry partner to the team.

The reviewers unanimously believed that the remaining project work was well-planned and reasonable. However, the same reviewer who was hesitant to affirm the current collaboration efforts, again, recommended that the project team consider adding a manufacturer as a member to the team.

Weighted Average: 3.13   # of Reviewers: 3
Approach: 3.33   Impact: 2.67   Progress: 3.33   Collaboration/Coordination: 3.00   Remaining Work: 3.33

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project utilizes piezoelectric sensor-actuators to mitigate flow maldistribution in heat exchangers. The piezo-crystals are embedded in heat exchanger headers. The approach is novel and interesting. Of particular importance to the proposed approach is to consider the origin of maldistribution locations and the complex interdependency between heat transfer and pressure drop. Two-phase flow instabilities typically originate from the middle of HXs and then propagates upstream into the header. Therefore, it would be interesting to see how the location and magnitude of piezo-crystal waves affect these instabilities and/or enhance the heat transfer rate.

- The project approach outlined was very practical. The initial modeling and then bench testing were well outlined. Additionally, clear goals were established for the results of the project. 15% gain in heat exchanger efficiency and >10% overall system efficiency.

- It has been identified that maldistribution of refrigerant in heat exchangers reduce their performance. Specifically, the performance of the evaporator. The team points to current methods to reduce this maldistribution involves costly redesign of headers and tubes that have limited impact which are operating condition dependent. It the presentation the team says, "few viable and cost-effective solutions exist". It would have been nice to see a summary of some of these approaches so as to evaluate the merit of the proposed approach utilizing piezoelectric sensor-actuators. These sensors would add additional penetrations in the system which could increase the possible of leakage. This was not addressed in the presentation.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.66** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the proposed solution can address refrigerant maldistribution in heat exchangers, thereby enhancing HX capacity and system coefficient of performance. It is understandable that these benefits come with additional complexity introduced and power consumption. Therefore, it would be helpful to experimentally measure the effectiveness of ultrasonic waves in mitigating two-phase flow maldistribution and compare piezo energy consumption with enhanced system COP.

- The project, if successful, will yield energy savings on HVAC applications. This would be achieved by improvements in maldistribution in heat exchangers, which has few current options for improvement.

- If the proposed solution, which would solve the decreased performance due to refrigerant maldistribution, is successful, an 10% improvement in system efficiency is projected, resulting in significant energy savings. It is not clear that these savings outweigh the additional potential leakage that could occur due to additional penetrations in the system. The "Major Findings from Literature" do not adequately convince this reviewer that the benefits outweigh the potential leakage problems. Some of this information is in the references shown on slide 17 that should have been summarized in the presentation.

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- The team had made excellent progress towards achieving the project goals.

- The project has accomplished both CFD modeling as well as the experimental setup for the benchtop testing. The project appears to be on track with the projected timeline and goals.
- The project began on October 1, 2018, with an end date of September 30, 2020. The progress to date that includes Literature Review (more details should have been given in the presentation – see Item 2 - Impact), CFD Simulations and the construction of a benchtop setup appears reasonable given the recent start of the project.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Considering the project start date and the status of the project, it appears that the team members have excellent strategic coordination with relevant stakeholders.
- The project team has included the key stakeholders and had direct interaction with HX manufacturers. This demonstrates the project intent is to demonstrate relevance with solutions for industry.
- On Slide 14 of the presentation – Stakeholder Engagement an "explicit task" of "Direct engagement with HX and equipment manufacturers and Better Building Partners" would be done. It was not clear from the presentation the status of these efforts. I would expect these would have occurred early in the project. Also, I think the project could be improved by having an industry partner. Only ORNL and WPI are the performers on the project.

E. Remaining Project Work

This project was rated **3.33** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project works are well planned.
- The presentation clearly outlined remaining work for 2019 and 2020 which was in alignment with the stated project goals.
- The project has a long way to go toward, conclusion. The remaining tasks are reasonable; however, I would strongly suggest the involvement of a manufacturer as a member of the team in whatever way it is contractually possible.

F. Additional Comments and Recommendations

1. Project Strengths

- Introduction of a novel piezo-driven approach to mitigate two-phase flow instabilities and maldistribution in real time.
- Real-time monitoring of flow maldistribution. This can lead to early detection and mitigation of flow maldistribution.
- The biggest strength of this project is that if successful it provides a solution for maldistribution on heat exchangers, which is a widely known problem, but not something with readily available technologies for improve.
- The project proposes a unique active method to prevent refrigerant flow maldistribution.

2. **Project Weaknesses**

- The complexity and additional cost associated with piezo-crystals that can both sense and actuate are not known at this point. This goes back to a fundamental question of selecting a passive or active enhanced approach. It seems it would be appropriate to include some thermo-economic tasks to analysis interconnected economic-efficiency aspects.

- One weakness of the project is that it is not evident whether the proposed solution would be cost effective for the projected benefits. The solution is complicated and thus add cost to heat exchanger which may not be realized in the savings.

- The presentation did not convince this reviewer that the approach taken in this project is the best solution. Also, the presentation did not indicate how often did the team members interact and the omission of the manufacturer as a member of the team is a shortcoming.

3. **Recommendations**

- It seems it would be appropriate to have some tasks to study two-phase flow patterns with and without the piezoelectric module, and their subsequent effect on heat transfer and pressure drop. This provides a more fundamental understanding of the physical processes involved. Also, maldistribution typically initiates from the middle of channels due to excessive vapor generation. Therefore, it is quite useful to measure how deep the ultrasonic waves can penetrate into the HX module (if possible) (the attenuation degree of ultrasonic waves with length).

- I would recommend some evaluation of the economic aspects be included to better understand potential for adoption by industry.

- A thorough discussion of the benefits of the approach's benefits versus is shortcomings (potential additional leakage sites) and the engagement of a manufacturer as a member of the team.

Project #32226t: Novel Compact Flooded Evaporators for Commercial Refrigeration

Presenter: Kashif Nawaz, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Multiple reviewers commented that the project approach to increase the heat transfer process in flooded heat exchangers (HX), such as evaporators or condensers, by using metal foam surfaces is an appropriate and sound concept. One reviewer encouraged the team to be aware of extensive pool boiling literature on refrigerants, mostly from the spray cooling for electronics community. One reviewer recommended the project team address issues that may arise at the system level, not reflected in controlled lab conditions, such as dry-out locations, and pressure drop typical of the metal foam systems. One reviewer noted that appropriate selection of the extended surface is crucial to provide enhanced heat removal and avoid critical heat flux.

One reviewer remarked that the project team should focus on technology demonstration and leave follow-up efforts to focus on commercialization. Another reviewer suggested developing a narrow sprint path, to get some small element of commercialization complete and then use that information to inform and drive the larger opportunity. A few reviewers noted that the boiling heat transfer on the refrigerant side of the tubes is not the limiting factor on heat transfer in a cooler, it is the single-phase heat transfer on the water side inside the tubes. Thus, some analysis should be done to see if enhancement on the water side is needed.

Reviewers had mixed reviews of project impact. One reviewer commented that the impact of the project towards accomplishing DOE energy efficiency goals could be large and significant. HXs are the key enabling technology for most HVAC systems, thus improvements in their performance could scale to the expected values DOE is projecting for 2030. Another reviewer remarked that this project has a good chance of providing an incremental change in system design and performance. One reviewer expressed some concerns about how broadly applicable the technology will actually be once commercialized. However, another reviewer commented that whether or not this effort will provide a commercially viable product, there is a good probability that this work will enhance the research literature in this important area of heat transfer. One reviewer observed that the research is unlikely to produce any useful results.

Multiple reviewers noted the project appears to be on schedule and has achieved its major milestones to date. One reviewer flagged that most chiller manufacturers make their own heat exchangers for their commercial products. Therefore, manufacturing the enhanced surface materials in commercial quantities may involve major investments that HVAC manufacturers are unwilling to spend, so the commercialization process may take longer or be more difficult than anticipated. Another reviewer agreed that the time frame for commercialization will be longer than expected. Multiple reviewers were concerned about the major uncertainties of the project: cost and manufacturability. One reviewer even suggested another follow-on project that specifically addresses the cost-effective manufacture of such enhanced surface tubing.

A couple of reviewers commented that the team is excellent and diverse, with a very good mix of academic and industrial expertise. One reviewer noted the team is taking advantage of the strengths of the national lab facilities with input from academic and industrial partners as appropriate. Another highlighted the good communication among the different stakeholders, remarking that feedback is being integrated in the development process. One reviewer recommended further peer review to preemptively consider project challenges. Another reviewer commented that further collaboration with the academic and industrial community involved in heat transfer enhancement techniques could add value to the project. One reviewer observed that the project team did not seem to fully understand the basics of the pool boiling process and should therefore add team members with boiling expertise. One reviewer highly recommended a consultation with Carrier or other manufacturers for the remaining project work.

Multiple reviewers noted that the test plan for the remaining work seems appropriate. A couple reviewers highlighted the significant resources of the lab, the broad range expertise of the project team, and the industrial collaborations. A few reviewers were pleased by the innovative and rigorous scientific approach of the project. One reviewer noted that the project concept could drive significant energy savings and have unintended benefits in other areas.

Weighted Average: 2.72 # of Reviewers: 5
Approach: 2.60 Impact: 3.00 Progress: 2.60 Collaboration/Coordination: 2.80 Remaining Work: 2.60

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is a very good project with potential for good outcomes. The challenge the PIs are addressing is to increase the heat transfer process in flooded HX such as evaporators or condensers proposing to use metal foam surfaces. This is a sound concept. The developmental plan is also very good, approaching from fundamental understanding to bench-scale. The team should be aware of extensive pool boiling literature on refrigerants, mostly from the spray cooling for electronics community. The team should also address issues that may arise at the system level, not reflected in controlled lab conditions, such as dry-out locations, and pressure drop typical of the metal foam systems.
- The approach, using extended surfaces, is appropriate aiming at a more compact design with reduced coolant. Appropriate selection of the extended surface is crucial to provide enhanced heat removal and avoiding CHF (critical heat flux).
- Basics of the pool boiling process is not understood.
- The project seems to provide a very rigorous and systematic approach to measuring and physically observing nucleate boiling scenarios for different enhanced surfaces. Whether or not this effort will provide a commercially viable product, there is a good probability that this work will enhance the research literature in this important area of heat transfer.
- Being a more complex project, the approach seems reasonable in its approach. I would have rated it even higher but feel the project would benefit from additional peer review, to reduce project risk.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact of the project towards accomplishing DOE energy efficiency goals could be large and significant. HX are the key enabling technology for most HVAC systems, improvements in their performance could scale to the expected values DOE is projecting for 2030. The proposed technology is within reach of the 10-years mark to contribute to these goals.
- Successful development of a compact flooded evaporator is likely to be adapted if the enhancements are implemented economically and demonstrated experimentally. Fabrication does not seem to be an issue (brazing).
- This research is unlikely to produce any useful results.
- Heat transfer enhancement will almost always provide benefits to system design and performance. Some enhancements may be more long term or incremental in their impact, but all current heat exchangers are the product of many incremental design improvements over many years. This project has a good chance of providing an incremental change in system design and performance.
- Assuming the project specific goals are met the project is likely to have a “Good” impact. I did not give it a “Excellent”, because I have some concerns about how broadly applicable the technology will actually be once commercialized. They should be considered as the project progresses, and new impacts of energy savings made, based on refined applicability.

C. Progress

Based on current project efforts, the project was rated **2.60** for the degree to which the project has met ***project-specific goals***.

- The team is making good progress according to the project plan. The team has completed conceptual designs informed by detail CHT (computational heat transfer) and has tested basic surfaces under controlled conditions. The team is moving now to system level testing. This reviewer does not foresee major barriers based on the progress made. The major uncertainty is cost and manufacturability.
- The laboratory set up to test enhancement options seems appropriate and the experimental results shown indicate reasonable progress. Heat transfer on the water side might benefit from enhancement as well (for example, using one of the internally finned tubes shown in the presentation).
- No meaningful progress was made.
- The project appears to be on schedule and has achieved its major milestones to date. Most chiller manufacturers make their own heat exchangers for their commercial products. Manufacturing the enhanced surface materials in commercial quantities may involve major investments that HVAC manufacturers are unwilling to spend, so the commercialization process may take longer or be more difficult than anticipated.
- The progress looks good; however, my gut would tell me that the project is behind schedule for a 2020 conclusion. The work that has been done so far is great, and the time was needed, but I think the time frame for commercialization will be longer than expected.

D. Collaboration and Coordination

This project was rated **2.78** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team is diverse and includes different stakeholders adequate for the effort. It appears to be good communication among the parts, and feedback is being integrated in the development process.
- The stakeholders listed are pretty good, adequate, and further collaboration with the academic and industrial community involved in heat transfer enhancement techniques might add value. It would be a big advantage to engage manufacturers early on, learn about their capabilities and manufacturing processes, and keep these in mind during the design phase. It is best to avoid solutions that might require significant retooling.
- Team lacks basic understanding of the boiling process.
- This is an excellent team with a very good mix of academic and industrial expertise. They are taking advantage of the strengths of the national lab facilities with input from the academic and industrial partners as appropriate.
- Collaboration is "Good", but more peer review to preemptively consider project challenges, would be a good addition.

E. Remaining Project Work

This project was rated **2.60** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The team seems on track to accomplish the goals previously set.

- There is a significant amount of work yet to be done but the lab team has the basic tools and skills. Design of the enhanced tubes should be finalized (for a single tube, and the arrangement of a bundle of tubes), and a scaled down evaporator (or a small length of a full-scale evaporator) be built and tested. Consultation with Carrier or other manufacturers during this process is highly recommended.
- The test plan is appropriate.
- Much of the remaining work involves lab testing and performance characterization. The final step is commercialization and that may be the most difficult. As was noted, none of the research projects will save any energy if they are never used by customers. I am not an expert on the fabrication of such enhanced tubes and tube surfaces, but there may be a lengthy learning curve for how such products can be manufactured cost effectively.
- The planned work looks logical, but I would like to see the project plan have a bit more detail for the remaining phases. I understand that the plan may evolve or change, but there should be a bit more granular roadmap.

F. Additional Comments and Recommendations

1. Project Strengths

- This project has several strengths; 1) it is addressing a key problem with significant potential for the larger HVAC industry 2) it is innovative 3) the scientific approach is sound; and 4) the team has excellent human talent in the subject areas, and excellent lab facilities.
- The significant resources of the lab, the broad range expertise of the project team, and the industrial collaborations listed are among the project's strength.
- This project has no strength.
- The project is doing a very rigorous and thorough analysis of nucleate boiling associated with a variety of enhanced surface types. As was suggested by a reviewer during the presentation, some past work may have already answered some of these questions, but clearly this work will still contribute to the understanding of boiling from complex surface geometries.
- The concept could drive significant energy savings, and have unintended benefits in other areas

2. Project Weaknesses

- The project has very few weaknesses, mostly related to the broad scope to reach commercialization, which seem a stretch, and perhaps not required at this stage where the focus should be in technology demonstration. Follow up efforts could be focus on commercialization.
- In collaboration with the industry, the team should obtain cost information for the evaporator down to parts, if possible, and tailor the improved design with these costs in mind.
- The results so far show that one has to look at larger pores sizes and (in my opinion) at fin as the means to enhance heat transfer on the refrigerant side. Some analysis should be done to see if enhancement on the water side is also needed.
- Approach and test plans.
- The boiling heat transfer on the refrigerant side of the tubes is not the limiting factor on heat transfer in a cooler, it is the single-phase heat transfer on the water side inside the tubes. The inside of the tubes can be rifled or have other enhancements, but still, the single-phase heat transfer coefficient will be two orders of

magnitude less than the boiling heat transfer coefficient on the outside of the tube. I am not an expert in this field, but I am quite skeptical that this work can lead to a 40% size reduction and a 20% system efficiency boost without addressing other system design issues.

- I worry that the project will lose momentum and die in the commercialization phase.

3. Recommendations

- This reviewer recommends the team continues focus on tech-demonstration to basic component level, with close monitoring of cost impacts of the core technology. This will allow the team to conduct additional needed fundamental studies of boiling processes at the system (basic HX) unit. There still remain fundamental challenges to address about basic manufacturability, HX increased effectiveness, and optimization of the boiling processes at the system level which will be different from control conditions. This will allow for future efforts to scale into full HVAC units testing and commercialization as result of a successful first effort.

- Study heat transfer and its enhancement on the water side.

- Stay in contact with manufacturers of flooded evaporators, seek their input especially regarding manufacturability.

- Explore use of fins on the vapor side and compare them with porous metals (with < 5 ppi or so).

- Review some of the old literature on enhance heat transfer and CHF if this has not yet been done. There are codes that can be used for computing the latter.

- Add team members with expertise in boiling.

- The work will enhance the understanding of heat transfer from surface boiling. How this work will impact the market will depend on how the enhanced tubes can be cost effectively manufactured. There may need to be another follow-on project that specifically addresses the cost-effective manufacture of such enhanced surface tubing (which might have applications for a wide variety of commercial products).

- Develop a narrow sprint path, to get some small element of commercialization complete. Use the learnings of that commercialization, to inform and drive the larger opportunity.

Project #32226q: Oil-less Compressor/Rapid-cast, High-speed Centrifugal Compressor Impeller

Presenter: Patrick Geoghegan, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

All reviewers agreed that the project has a novel approach in comparison to traditional investment casting, as it avoids many of the post-casting processes and could greatly improve some issues with the existing manufacturing process. Multiple reviewers called out that the project team needs to do additional work to verify quality, surface finish, resolution of fabricated parts, porosity, and cost. One reviewer commented that it appears the quality of parts depends on the size of the sands selected for the 3D-printing mold. One reviewer flagged that it is not clear how the proposed thermo-economic features will be realized. Additionally, they noted it is not clear whether the surface finish quality of the proposed casting approach will be better than existing casting techniques.

All reviewers remarked that the project offers a substantial cost saving on impeller manufacturing by combining shroud and impeller fabrication steps. All reviewers observed the significant potential energy savings through isothermal compression and oil-less compression. One reviewer noted that this project addresses challenges with the existing brazing process, allowing for potentially improved yield results for manufacturers. Another reviewer commented on the project ability to be used with alternative refrigerants. One reviewer highlighted that the new process offers manufacturing reliability.

Two reviewers commented that the project seems on-track to meet stated goals, as one reviewer remarked that the team made excellent progress towards achieving their goals and another commented that the remaining scope of work looks good. Another noted they are interested to see the results of the Neutron Imaging, as that has not been done before for this type of process. One reviewer proposed that the team consider the cooling rate offered by embedded cooling channels at different conditions, as it is not clear that the target isothermal compression can be solely realized by the cooling channels. One reviewer suggested that a comprehensive computational fluid dynamics (CFD) analysis might provide detailed insight into the air compression process before actual fabrication and testing. One reviewer recommended including compression testing in the project scope, as it is hard to verify the reliability and performance of the new fabricated impeller without such testing.

One reviewer commented that the team members have excellent strategic coordination with relevant stakeholders, and another highlighted the team strength and expertise. However, other reviewers noted it was difficult to determine the extent of collaboration, especially with Danfoss and Ingersoll Rand. One reviewer expressed that a better understanding of the interest level of the technology from industrial partners would be helpful to determine the practicality of adoption in their manufacturing processes.

Weighted Average: 3.47 # of Reviewers: 3
Approach: 4.00 Impact: 3.33 Progress: 3.67 Collaboration/Coordination: 3.00 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **4.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project utilizes a rapid fabrication approach to cast a compressor impeller into a 3D-printed mold, thereby avoiding many of the post-casting processes compared to traditional investment casting of parts. The approach seems novel and interesting. It seems the quality of parts depends on the size of sands selected for mold 3D-printing. Additional R&D needs to be conducted to verify quality, surface finish, and resolution of fabricated parts.

- The project approach was nicely laid out in comparison to the traditional approach for investment casting. Additionally, the presenter nicely outlined the challenges with the existing brazing process and why this solution would potentially improve the yield results for manufacturers.

- The approach is to develop small-scale centrifugal compressors using new/nontraditional manufacturing processes. Conventional manufacturing involves a three-step process that includes investment casting, CNC machining, and brazing. The implementation of 3D printing appears possible, however issues including porosity, surface finish and cost are issues that need to be addressed.

- The technical approach is sequential and well thought out. It includes 1) modeling of the casting process, 2) casting and 3) validation.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the proposed project offers a substantial cost saving on impeller manufacturing by combining shroud and impeller fabrication steps. The project also offers significant energy saving through isothermal compression and oil-less compression (enhanced heat exchanger performance).

- The impact of the project would help manufacturers with making isothermal compression more cost effective. This may increase the utilization of this type of compression which would yield energy savings for a variety of reasons (oil foiling etc.).

- The team projects the following impacts of the proposed work, if successful. A 20% cost savings in manufacturing of a combined impeller/shroud, the ability to be used with alternative refrigerants, and due to the fact that the compression could go from isentropic to isothermal a 36% energy savings would result.

C. Progress

Based on current project efforts, the project was rated **3.67** for the degree to which the project has met ***project-specific goals***.

- The team had made excellent progress towards achieving the project goals.

- Project team outlined current progress which is on track with the stated project goals.

- The project began on October 1, 2018, with an end date of September 30, 2020. The project is in its beginning stages. According to the Project Plan, presented on Slide 13, the project is on track.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant stakeholders.
- Key collaboration is with Penn State. Would have liked the presenter to expand on collaboration and interest from Danfoss and Ingersoll Rand to further indicate how practical this technology is for manufacturers to adopt.
- The team includes ORNL, the University of Northern Iowa – Additive Manufacturing Center and Metal Casting Center and Penn State University. Additional "Stakeholders" engaged in the project include Danfoss and Ingersoll Rand and there is interest from "other turbine manufacturer". From the presentation, it is difficult to gage the extent of the collaboration and coordination and extent of stakeholder engagement.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- It is suggested the proposed remaining work considers the cooling rate offered by embedded cooling channels at different conditions. It is not clear that the target isothermal compression can be solely realized by these cooling channels. A comprehensive CFD analysis might provide detailed insight into the air compression process before actual fabrication and testing.
- Will be interesting to see the results of the Neutron Imaging, which has not been done before for this type of process.
- The project has a significant amount of work still to do. The scope of work looks good.

F. Additional Comments and Recommendations

1. Project Strengths

- The new fabrication process offers manufacturing reliability and meaningful cost saving on the fabrication of future compressors.
- The target isothermal compression, if realized, can sustainably reduce the work on compression with respect to existing compressor design.
- The project nicely stated how this technology would greatly improve some issues with existing manufacturing processes.
- The team looks strong and are experts in the area.

2. Project Weaknesses

- The proposed project offers several attractive features. However, it is not clear how the proposed thermo-economic features will be realized. For example, the target isothermal compression seems to be optimistic. It is generally understood that the cooling channels lead to a polytropic process which is more efficient than the adiabatic compression. However, an isothermal compression process is not justified. In addition, a detailed cost compression of the proposed fabrication process and traditional approaches is needed to verify target cost saving. Furthermore, it is not clear whether the surface finish quality of the proposed casting approach will be better than existing casting techniques. It is reasonable to expect a higher surface finish quality if the 3D-printed mold utilizes smaller sand grades. However, the surface finish quality of casted parts also depends on the resolution of the 3D-printing process used for mold 3D-printing. Specifically, the target surface finish of 3-6 um needs to be carefully examined.

- Would like to garner a better understanding of the interest level of the technology from the industrial partners, is it practical for them to adopt in their manufacturing processes?
- A more intimate and formal engagement of stakeholders would be beneficial.

3. Recommendations

- It is proposed a 36% energy saving can be realized by an isothermal compression through internal cooling flow channels embedded in shroud and impeller base. However, it is not clear or verified that the heat transfer area offered through shroud and impeller base (and perhaps blades acting as fins) are sufficient to offer an isothermal compression. It is suggested to consider CFD simulations to verify the actual cooling rate offered.
- In addition, no actual compression testing is planned. Without such testing, it is hard to verify the reliability and performance of the new fabricated impeller.
- None at this time.
- A more intimate and formal (i.e., contractual) engagement of stakeholders would be highly desirable. Also, articulation of the extent and nature of the Collaboration and Coordination should be included the next time this project is presented.

Project #32226k: Peel & Stick Sensor for Refrigerant Leak Detection

Presenter: Pooran Joshi, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

The majority of reviewers agreed the project approach is interesting and practical, and could help to reduce refrigerant leakage. One reviewer commented that there is a strong need for low-cost and reliable sensors for sensing refrigerants due to the Kigali agreement. That reviewer remarked that the project outlines a novel new approach that could have important cost reductions and improvements for the sensors using A2L refrigerants. One reviewer complemented the good effort in identifying technologies suitable for this application. One reviewer commented that project weaknesses include limited fluids and low accuracy. Another reviewer suggested incorporating the project with low cost performance sensing/calculating. Other reviewers recommended the team verify lifetime of the sensors and sensor calibration, improve impact analysis, and conduct cost analysis and production evaluations. One reviewer commented that the team should look at the new UL60079-2 standard, which is what the safety standards plan to reference.

A few reviewers applauded the importance of the project, as refrigerant leakage from commercial systems can be significant, as much as 10% to 30%, making it both a cost and environmental issue. They commented that the development of low-cost and accurate leak detection sensors for a range of refrigerant types, especially flammable refrigerants, is an impactful goal, especially since sensors of this type are presently not available. One reviewer noted the key to project success is how well the technology can be reliably applied. However, another reviewer critiqued that the current impact analysis is somewhat vague. One reviewer warned that sensing leakage somewhere in the system may not be sufficient to encourage remedy action. This reviewer suggested that for low charge systems, a means to sense deterioration in performance may be more compelling.

Many reviewers commented on good technical progress, though a few voiced concerns over the lack of evaluating flexible sensor characteristics, including drifts and calibrations. Reviewer comments on remaining work were relatively positive, and one reviewer commented that they look forward to the final results and conclusions of prototype performance. One reviewer suggested adding repeatability and lifetime assessment to the remaining project work. Others observed it will be important to see how the comprehensive evaluation of sensor performance progresses this year.

Reviewers noted the team is working with multiple key industry stakeholders, including the Air Conditioning, Heating and Refrigeration Technology Institute (AHRTI), Emerson and Mexchem. However, one reviewer remarked that the team needs system manufacturers or service organizations, while another suggested increasing involvement with the Air Conditioning, Heating, and Refrigeration Institute (AHRI). One reviewer highlighted that the project team seems to understand the market need. Another highlighted the strength of the staff, especially with their prior work in this area of printed sensors.

Weighted Average: 3.25   # of Reviewers: 5
Approach: 3.40   Impact: 3.00   Progress: 3.40   Collaboration/Coordination: 3.20   Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.40** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Very interesting and attractive.
- Technology appears to be well researched and potential manufacturers have been identified.
- Developing low cost refrigerant leak detecting sensor is a practical project and could help to reduce refrigerant leakage.
- There is strong need for low cost and reliable sensors for sensing refrigerant due to the Kigali agreement and need to move to A2L refrigerants. This project outlines a novel new approach that could have important cost reductions and improvements for the sensors using A2L refrigerants. The work and the approach show an understanding of the need and outlines what appears to be a good approach.
- The project approach for producing low-cost sensors for detecting leaking refrigerants is to develop metal oxide and nanomaterial coatings on flexible substrates. Next, these sensors will be evaluated for use with flammable refrigerants.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The key is how well it could be applied reliably.
- Sensing some leakage somewhere in the system may not be sufficient to encourage remedy action.
- Current impact analysis is somewhat vague. Need to quantify reduction of direct emission of refrigerants by applying low-cost sensors to be developed.
- If successful the market for this could be 3-4 million units per year so it is a very important project if it can be commercialized by 2023.
- Refrigerant leakage from commercial systems can be significant, as much as 10% to 30%, making it both a cost and environmental issue. In this regard, the development of low-cost and accurate leak detection sensors for a range of refrigerant types, especially flammable refrigerants, is an impactful goal, especially since sensors of this type are presently not available.

C. Progress

Based on current project efforts, the project was rated **3.40** for the degree to which the project has met ***project-specific goals***.

- On track.
- Very thorough effort to develop technology into workable solution.
- Good technical progress in identifying sensor manufacturing process but lack in sensor calibrations.
- Progress to date looks good and the staff appear to have experience in this area and understand the market need.

- Much of the project has been completed with the exception of evaluating flexible sensor characteristics, including drifts and calibrations.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Could push further and harder on this regard to verify interest and applicability.
- Have at least one major manufacturer interested in this product.
- Good collaboration team, but needs system manufactures or service organizations.
- They are in contact with key industry stakeholders and some manufactures that have shown interest in the project.
- Over nine (9) researchers are participating in this project with most of them being from ORNL. Important stakeholders are AHRTI, Emerson and Mexichem, with all of them having a major interest in refrigerant operations and safety.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Look forward to the final results and conclusions or prototype(s)' performance.
- Testing now – progress is well underway.
- Add repeatability and life time assessment.
- Will be important to see how the actual testing progresses this year.
- The remaining task is a comprehensive evaluation of sensor performance.

F. Additional Comments and Recommendations

1. Project Strengths

- Simple and clear.
- Very good effort in identifying technologies suitable for this application.
- Cheap sensor will enable leak detection more affordable so that refrigerant leakage reduction is expected.
- Strength of staff and prior work in this area with printed sensors.
- The strength of the project is that it addresses an important issue related to phasing out GWP refrigerants.

2. Project Weaknesses

- Reliability.

- Question how this product would be most helpful. Having an alarm somewhere in the system may not be sufficient for a call to action. For low charge systems, a means to sense deterioration in performance may be more compelling.
- Limited fluids and low accuracy.
- Have not really done any testing unit with sensing the new refrigerants. Also need to probably have more collaboration with manufacturers considering the window where sensors will be required in full production by 2023.
- None.

3. Recommendations

- Hope it could be more specific on some certain outcome and reliable performance.
- Incorporate with low cost performance sensing/calculating.
- Verify lifetime of sensor and sensor calibration.
- Improve impact analysis.
- Team up with system manufactures or service organizations.
- More involvement from manufacturers and AHRI research. Cost analysis and production evaluations. Also, they should look at the new UL60079-2 standard which is what the safety standards plan to reference.
- None.

Project #31253: Fundamental Heat Transfer Physics of Rotating Heat Exchangers and Practical Realization of Non-Vapor Compression Refrigeration

Presenter: Wayne Staats, Sandia National Laboratories
BTO Manager: Antonio Bouza

Brief Summary of Reviewer Comments

The majority of the reviewers found the project approach of using IR cameras to understand and optimize heat flow in heat exchangers to be sound, even though it is at an early stage. More critically, one reviewer recommended the project team design system architecture for the target application first to achieve a meaningful outcome. The presenter did not clearly outline the potential impact of the project, reviewers found.

Given that the project started in October 2018, the reviewers were generally pleased with the progress that had been made. One reviewer suggested that the project team incorporate optional designs and alternative enhancement techniques to analyze at the beginning of the project.

Reviewers noted that not many industry partners were identified in this project, partly because this is a "fundamental" project and likely won't require stakeholder engagement until year two and three. Nonetheless, one reviewer suggested that the team should seek feedback on what industry partners and stakeholders may wish to employ this technology soon. The remaining project work is mostly upcoming as the project is in its early stages, most reviewers noted. One reviewer recommended designing system architecture for target application before fabrication of a prototype.

Reviewers provided feedback on potential areas the project team could strengthen. One reviewer noted that the current design approach may by limited to condensers and radiators. Similarly, another reviewer commented that there may not be widespread applications once successfully developed. As the project continues, one reviewer recommended focusing on low capacity thermoelectric air to air cooling systems, while another suggested the team conduct economic and manufacturing analysis on the design. For the thermoelectric refrigerator, one reviewer suggested the thermal resistance of interface between the TE and rotating heat exchanger (RHX) be carefully addressed.

Weighted Average: 2.76   # of Reviewers: 7
Approach: 2.86   Impact: 2.86   Progress: 3.00   Collaboration/Coordination: 2.27   Remaining Work: 2.86

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.86** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Combining the experimental techniques and computational methods - always a good approach for the basic studies and development of fundamental understanding of physical mechanisms.
- Early stage, to be evaluated.
- Using IR camera to better understand and optimize heat flow/conductance in HX is sound approach.
- Designing system architecture for target application should be done first for meaningful outcome.
- The project is in the early stages of evaluation, but they outline good procedures and tests as well as use of tools to evaluate the technology.
- The approach used is based on using a combination of experimental testing and computational fluid dynamics (CFD) modeling to understand rotating HX behavior and characteristics for the purposes of improving designs.
- This is fairly fundamental research and much work still needs to be done to determine its practicality.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.86** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Given the early stage of the project and initial ("active" - energy consuming) concept-design of the RHX - it is quite premature to estimate the potential impact of the technology under development. It may be worth to consider the "passive" design to enable vanes component rotation triggered by the thermal convection - see vortex chamber 4'22" to 4'30" - https://youtu.be/kKNbKN4bik4
- Based on my knowledge and experience, the impact potential is significant.
- It's not clear that even if successful that any significant improvements in existing system performance will be achieved.
- Impact of energy saving as compared to state-of-the needs to be established.
- The project could have a significant impact on the use of solid-state cooling and the required heat exchangers. Likely application is equipment cooling and small appliances that are already starting to use solid state cooling but with conventional heat exchangers.
- The use of rotating HXs with thermos-electrics has the potential for a 10X volume reduction, along with improved component and system performance. The reduction in energy consumptions and the promotion of increased usage of thermos-electrics has a direct effect on reducing the GWP and the use of refrigerants.
- Questions of commercial practicality need to be answered but the investigators recognize this as future work.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Considering the project start in Oct 2018 the reported progress is consistent with the scope. Optional designs and alternative enhancement techniques would be helpful to analyze at the beginning of the effort to ensure some backup opportunities in case of possible issues with the energy efficiency of the initial RHX concept.
- On track.
- Some progress in understanding heat flows and how to maintain boundary layer has been made
- It seems current target application is TE refrigeration. Impact should be clearly estimated after clearly defining operating conditions of target application.
- Early stage of project so results are still very preliminary, but plans should get to acceptable results.
- The project is in its early stage, to be completed in 2021, so that as of now only the experimental setup design and the CFD modeling has been completed.
- Although in early stages, the project seems to be proceeding well.

D. Collaboration and Coordination

This project was rated **2.27** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Since the topic of this project is "fundamental" there is no need any industrial partners to launch the study. However, looking down the road - the developing RHX is targeted to be applied for the non-VC refrigeration and/or thermoelectric cooling, so it is always great to have OEM on board to provide strategical guidance and practical feedback.
- On the right track.
- Collaboration/industry coordination is a future step, but getting feedback on who might wish to employ this technology (if successful) should be done sooner rather than later.
- No collaboration was mentioned.
- The work is mainly being done by the project staff, but they have engaged with appliance manufacturers.
- To date, the PI and others have only engaged DOE personal, namely Antonio Bouza, with future plans being to engage other stakeholders.
- The key stakeholders have been identified but stakeholder engagement won't begin until Years 2 &3. Some earlier engagement might help them identify and address initial concerns as well as spark interest.

E. Remaining Project Work

This project was rated **2.86** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Project has just started. Most of the work is upcoming.
- Early stage, to be seen and proved.
- Plan steps should keep this project on course.
- Before fabrication of prototype, designing system architecture for target application should be done first.

- Project is in the early stages of evaluation. I think they have a good plan to evaluate.
- The remaining work tasks fit well with project goals, and they are expected to be completed on time.
- The tasks defined on slide 11 for years 2 and 3 describe no stakeholder engagement. Otherwise, the tasks for this research are well-defined.

F. Additional Comments and Recommendations

1. Project Strengths

- Flow swirling approach is a promising one for the convective heat transfer enhancement without adding a significant pressure penalty.
- Sound and promising idea and direction.
- Primary potential application is for thermoelectric heating/cooling in low capacity systems this is a strong potential application.
- Innovative HX design is proposed.
- Good use of tools and early results look good. I think there are some further improvements that will also be found as they work through the evaluate.
- The strength of the project is the approach of improving thermoelectric performance by focusing on improving heat transfer.
- Well-defined research project and a very interesting R&D project.

2. Project Weaknesses

- Extra energy that would be required for vanes rotation.
- The project is only a concept at this moment, could take a good while to accomplish some results.
- It's not clear there will be widespread applications even if this is successfully developed.
- Current design approach may weak for condensate and frost so that application can be limited to condensers or radiators. COP improvement claim in slide 8 needs to be revisited by using condensing and evaporating temperatures of target application.
- It is early in the evaluation. I did not see any cost analysis or economics.
- The major project weakness is that it appears that past rotating HX research, stretching back to the 70's, has not been studied.
- There are some questions about commercial practicality and it would be useful to consider possible stakeholder concerns of the approach, even at this early stage.

3. Recommendations

- Deeper look at the prior work on similar HX concepts and enhancement techniques.
- None and good luck.
- Focus on low capacity thermoelectric air to air cooling systems

- For TE refrigerator, thermal resistance of interface between TE and RHX should be carefully addressed.
- Do some economics and manufacturing analysis on the design.
- Perform a thorough study of early rotating HX research.
- Engage with stakeholders to define specific commercialization opportunities. The work raises questions of complexity and practicality that addressed earlier might help in the design and research of the technology.

Project #322102: Use of Cost-Effective Additives to Reduce Flammability in 2L Refrigerants

Presenter: Jessica Demott, Arkema
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Although reviewers found the topic of identifying a refrigerant with low flammability worthy of investigation, many questioned the project's approach. Two reviewers commented that the approach was not clearly identified in the presentation, or that it provided little detail. Two other reviewers expressed concern with the number of variables the team needs to investigate, and added it was unclear if the project contributes to solving technical challenges.

Reviewers were conflicted on the potential impact of the project. While some noted the potential impact for clean and safe refrigerants that could potentially reduce GWP was high, others raised the point that reduced greenhouse gas emissions does not drive toward energy efficiency program goals.

The presenter needs to clearly articulate how the team is interacting with key stakeholders beyond Trane, two reviewers commented. Another reviewer noted that the project team should focus on engagement with real-life technicians in the field. Although reviewers found the project to be on-schedule, many reviewers made recommendations for refocusing the remaining work. These recommendations include further stakeholder involvement, increased field testing, focus on the long-term effects of the additives. Other recommendations reviewers made were to perform tests under more real-world fire situations, and to complete a more realistic impact of the fully GHG impact of the new refrigerant.

Across the whole project, reviewers applauded the team's excellent credentials, the clear approach, and focus on a problem that could be a leap forward for the next generation of low GWP refrigerants.

Weighted Average: 2.62   # of Reviewers: 5
Approach: 2.80   Impact: 2.60   Progress: 2.80   Collaboration/Coordination: 2.40   Remaining Work: 2.40

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **2.80** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is much needed effort that aims to identify a refrigerant with low flammability in the context of low GW refrigerants. The approach is based on physical processes to reduce flammability and speed of propagation of the flame. The set of variables to investigate are ample, however, the team has a good process to narrow down the prospect candidates.
- The presentation was well done and the approach as presented seems reasonable. But the presentation was short on details and vague making evaluations difficult and based largely on faith in presenter rather than the data presented.
- Nothing about the approach was presented. So, it is impossible to evaluate its potential success.
- The project is certainly worthy of the effort to mitigate the risks associated with the new mildly flammable refrigerants. If the additives can achieve their desired goal, it may be a way to produce a product that overcomes potential safety concerns.
- I do believe that if successful it will significantly help to increase the use of flammable LGWP refrigerants. I am less convinced that project contributes to solving technical challenges and mitigating project risks.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.60** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The potential impact of this project for clean and safe refrigerants is very large. The team is experienced and has a very good approach to identify prospect candidates which could guide future system developments. Impacts on energy efficiency are difficult to assess, but certainly the prospects of identifying safe, and low GW refrigerants is very large.
- Successful implementation will support BTO's goal, help reduce GWP without (hopefully) sacrificing thermal efficiency.
- Again, nothing was presented about the approach. So, it is impossible to evaluate this project.
- While it still remains to be seen how regulatory bodies and governmental agencies may receive such modified refrigerants, this could be enough to convince certain bodies to adopt 2L refrigerants at least as intermediate solutions while other longer-term solutions are being developed.
- This is an enabler for the use of LGWP refrigerants, and while it might reduce GHG, it does not drive materially towards the energy efficiency program goals. Most of the advances in energy efficacy could be achieved without LGWP refrigerants. If I consider the lifecycle effects, and overhead of industry changing to new refrigerants, the impact energy savings specifically driven by new refrigerants, may actually be negative. I do believe that there is a 20 and even 100-year net benefit to GHG, but even that is often overstated when the larger pictures is considered. I.e., the GHG associated with the economic activity, and workforce inefficacy driven by the introduction of new refrigerants is largely ignored when considering the benefit of new refrigerants.

C. Progress

Based on current project efforts, the project was rated **2.80** for the degree to which the project has met ***project-specific goals***.

- The team is making excellent progress towards goals, identifying this far 7 prospect candidates that meet the complex matrix of requirements. This is very good progress. The team is now moving to cost and system level performance assessment, I presume conceptually during this project, which will be reasonable expectation.
- The stated (but not demonstrated) progress seems very good. Given the importance of the subject and the company's business, it is likely that this work gets helped along the way.
- There was only promises. No progress was reported.
- The project seems to be on schedule and has achieved all major milestones to date. It has identified at least one candidate material which provides favorable flammability test results.
- I see material and focused progress against the stated project goals.

D. Collaboration and Coordination

This project was rated **2.40** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It is not clear the interactions the team is having with key stakeholders in the market, including supply chain. There are no specifics in their reporting about who they are meeting, and how their feedback is impacting the research approach. This needs improvements.
- Trane is the sole collaborator of record, but the presenter stated that they are looking at a broad range of shareholders. These need to be identified, contacted, arrangements made, and BTO notified. Involvement in the project of someone from a National Labs or a university can also be very helpful particularly to collaborate on publishing (an effective way to communicate with 'stakeholders')
- Trane is involved.
- The project team has a wealth of experience in refrigerant chemistry as well as refrigeration system design, so they should be able to provide a thorough approach to this problem.
- I feel the project has done a fair job of collaboration. However, I think there should be a greater focus on engagement with real-life technicians in the field. I know there is a former technician working on the project, but this should be amped up, and be a greater part of the project plan.

E. Remaining Project Work

This project was rated **2.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The team is well on track to accomplish the goals set forward. Their project plan is focus which allows to make and measure progress, and this is clearly reflected in their reporting.
- As noted earlier, stakeholder involvement is essential to the success of this project. I am concerned that IP is taking priority over compatibility and performance cost. If possible, some of the steps (such as compatibility and performance) can be done in parallel in collaboration with stakeholders (and if not, then what roles are left for stakeholders?)

- A viable refrigerant remains to be produced.
- The project appears to be on schedule and are at a point where they will soon have one or more specific candidate additives to characterize their detailed flammability performance. Hopefully they will be able to obtain a good understanding of the ways that the additive provides these impacts on the refrigerant flammability properties.
- The project is logically planned, and the milestones are clearly played out along the path toward the goals. I feel some important milestones are missing.
- I think there should be more field testing, or at least testing that simulates situations were in real-life, flammability is big issue. For example, fixing a leak with a blowtorch in a confined crawlspace, with little ventilation. Significant thought should go into, the dumb things real-life technicians do, and unexpected risks when they do “dumb things.”
- I would also like to see more focus on the long-term effects of the additives. How does they affect seals, winding insultations, oil flow, etc. Are there any adverse effects when the additive and refrigerants get mixed with legacy refrigerant systems? Not frequent, but it does happen.

F. Additional Comments and Recommendations

1. Project Strengths

- The project has many strengths:
  - The problem that it is addressing.
  - The scientific approach, that while based on trial and error, it is informed by science.
  - The executing team and resources available to them.
- Timely and well within the core competency of the company.
- Good technical team (apparently).
- Clear path forward, systematic approach.
- Incentive for the company to pursue this project to a successful end and potential market.
- It is not clear.
- The project team has excellent credentials in refrigerant chemistry and in refrigerant requirements for vapor compression system design. The central concept represents a low-cost way to potentially overcome unacceptable flammability issues.
- This project is rifle focused on a narrow target, and success would be a leap forward for next generation LGWP refrigerants.

2. Project Weaknesses

- I did not find any significant deficiency on this particular project.
- Stakeholders to make this project successful are alluded to but not specified: who are they, have they been contacted? What are they supposed to do? Have they agreed? Precisely what will each do? How do these fall into the overall plan? Given the fact that Trane is (?) a partner, would Trane's competitor be invited to be

involved, and which ones are likely to have the interest, resources, and incentive to collaborate? WHEN will these stakeholders be contacted and arrangements made, given the fact that the project ends in May 2020?

- DOE should not use taxpayer money to fund research in multibillion-dollar companies. If the research is promising, large companies will fund it themselves.

- I am a former academic and academics are often accused of "teaching to the test". I am very concerned that this exercise may be little more than "designing to the test procedure" and would produce a mixture that might pass the arbitrary flammability and flame spread tests, but which will still burn and could produce extremely hazardous HF under relatively common household fire situations. More rigorous testing may be appropriate to answer the real safety issues associated with such modified refrigerants.

- Other ideas are in the market, both providing similar functions and leapfrog technologies. These other efforts may squeeze the effective value of this research, which is not a direct or enabling technology for energy efficiency, that could be achieved without LGWP refrigerants.

3. Recommendations

- This reviewer recommends that PIs document and share their interactions with stakeholders with DOE, including how their feedback is impacting the directions of the project, particularly in terms of practical requirements that could lead to new products. This may assist the team to focus on candidates that may have higher acceptability by the markets.

- I assume that the company has sufficient internal resources to pursue the necessary developments and tests for the additives. To further the work, it is recommended to engage the stakeholders rapidly, seek collaboration with an expert from national labs or universities, make sure the tests (including thermal and overall system performance) follow established protocols, begin to publish results to reach a broader community, and commit funds (1/4 of the funds are spent in 1/2 of the life of the project).

- If a large corporation wants to use DOE funds, the results should be fully presented to the public.

- While I think that they should continue to characterize the additives according to the established flammability and flame spread tests, I think they should go beyond the standard test procedures and perform tests under more real-world fire situations to ensure that first responders or even homeowners attempting to put out a fire are not seriously injured by products of combustion. UL and other labs have some experience with such tests using 2L refrigerants and their data might provide a benchmark to compare the modified refrigerants against.

- Focus on better field workforce testing, and better replicate real-life flammability scenario testing.

- As part of the analysis complete a more realistic impact of the full GHG impact of the new refrigerant. Include adjustments for items like, the investment and transition cost to bring refrigerants to market, inefficiency created in the field to follow new refrigerant rules/guidelines/training, reduced energy efficiency because companies will delay buying new more efficient equipment because of the higher cost, greater embedded GHG because equipment life is not as long due to it being more technically complicated, the opportunity costs of effort spent on new refrigerants vs making the units more efficient. This would help to convince many folks that I work with that all this change is really worth the net reduction created.

Project #31252: Low Cost, High Performance Polymer Composite Heat Exchangers Manufactured by Additive Manufacturing

Presenter: Kashif Nawaz, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Calling this project's approach "quite comprehensive" and "nice[ly] plan[ed]," two of the project's three reviewers expressed confidence in this project's ability to overcome the technical challenges associated with producing lower-cost and more compact heat exchangers through additive manufacturing. However, two reviewers questioned how the issue of refrigerant leakages would be handled by these new designs. For instance, one reviewer cautioned that in the development of an air-to-air heat exchanger, polymer de-gassing issues and the effect of water vapor on the refrigerant mixture would need to be addressed by the project team.

Every reviewer agreed that this project, if successful, could significantly advance BTO's goal of reducing the manufacturing cost of heat exchangers. One reviewer noted that the project's estimated energy savings of 500 TBtus would make a significant contribution to BTO's overall goal of reducing building energy use by 45%.

Even though this project had only begun six months earlier in October 2018, all three reviewers agreed that the project had made significant progress to-date, and appreciated the sample heat exchangers that the project team included in their presentation. Two reviewers were confident that the project's remaining work was well-planned and achievable, although one reviewer would have appreciated more information on how appropriate these designs were for some refrigerants that the project referenced, as well as what the optimal pressure rating for the targeted applications would need to be. This reviewer asked that this information be considered in subsequent work.

Every reviewer remarked that the project team was coordinating and collaborating well with its stakeholders so far, although one reviewer would have liked to hear if the project team had established periodic, dedicated meetings with the project's entire set of stakeholders moving forward. If not, this reviewer suggested they add this to their schedule moving forward.

Weighted Average: 3.53 # of Reviewers: 3
Approach: 3.67 Impact: 3.33 Progress: 3.66 Collaboration/Coordination: 3.33 Remaining Work: 3.66

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Fabrication of low-cost, compact polymer heat exchangers through additive manufacturing seems very attractive. These heat exchangers are generally better suited for open systems like air-to-air heat exchanger applications. If the current project targets to demonstrate the development of an air-to-refrigerant heat exchanger, some efforts need to be taken to address polymer degassing issue. In addition, water vapor typically passes through some polymers with time which might change the refrigerant mixture.
- The project team laid out a nice plan to overcome technical challenges. The team has multiple options identified to optimize manufacturability, Sugar Molding, Fused Filament and the Gel Slurry process. The approach of evaluating and optimizing these methodologies along with optimizing various material options will allow the team to narrow on the best possible option.
- To summarize, the approach is well thought out and quite comprehensive. It first looked at possible materials and characterized those materials using X-rays for durability, possible methods utilizing additive manufacturing, optimization of the surface topology to increase heat and mass transfer and finally a techno-economic analysis of the approach and the approach's benefit.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If potential issues are well addressed, the project can have a meaningful impact on the economy of future heat exchanger designs for HVAC applications. It is also reasonable to expect the current technology can benefit several industries beyond HVAC applications such as chemical and drying industries.
- This project indicates a potential for significant energy savings of at least 500 TBTU. This would be a significant impact to goal of 45% energy reduction in building energy usage. This seems to be a viable technology to not only save energy but reduce energy costs as well as manufacturing costs. If successful this would be commercially viable technology for those reasons.
- If successful, the approach promises to improve thermal-hydraulic performance (i.e., better heat transfer with similar small pressure drop) with potential reductions in heat exchanger size, a projected 50% reduction in manufacturing cost and a longer life. In addition, size the heat exchanger higher performance it promises lower refrigerant charge, which is important for new refrigerants and the surface characteristics has better condensate drainage.

C. Progress

Based on current project efforts, the project was rated **3.66** for the degree to which the project has met ***project-specific goals***.

- Although the project started in Oct. 2018, the team had made excellent progress towards achieving the project goals.
- The project team prepared some samples of their heat exchangers which were a nice demonstration of project progress to date. The numerical analysis presented yielded some interesting results with respect to the optimal design of the fin profiles. I would have liked to see some study indicating the likelihood of using these with the A2L and A3 refrigerants that were referenced, the pressure ratings of the heat exchangers seem relatively low compared with what would be required for higher temperature applications. I would like to see some additional research for where the optimal pressure rating needs to be for the targeted applications.

- The project began on October 1, 2018 with an end date of September 30, 2021. Progress on the project has been very good with three areas being investigated simultaneously. These are: Numerical Analysis, to evaluate the heat transfer performance and pressure drop, Manufacturing Process, to determine how to the next generation polymer heat exchanger with improved performance and Material Development and Characterization to determine the mechanical and thermal fatigue characteristics of the materials.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Considering the project start date and the status of the project, it appears that the team members have excellent strategic coordination with relevant stakeholders.
- The project team coordinated nicely with key stakeholders. The presentation highlighted coordination efforts both with the appropriate Technical Standards (ASHRAE) and Industry partners. This should yield good results if successful as they have considered both technical hurdles and commercial interests for the project.
- The team appears to well-coordinated and collaborative. Meetings of the team members are held at meetings and locations where presentations/conference papers are presented. From the presentation, it is apparent if a dedicated meeting involving all stakeholders are held at ORNL or at team member locations. This should have been mentioned in the presentation.

E. Remaining Project Work

This project was rated **3.66** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining work is well planned. Although it would more appropriate if efforts are guided more towards material and manufacturing processes and subsequent reliability tests.
- I would like to see evaluation of optimal pressure ratings included as part of the comparison with the existing technologies. This was not addressed in the presentation.
- The remaining project work is achievable, and the team knows what needs to be done to finish the project.

F. Additional Comments and Recommendations

1. Project Strengths

- Utilization of composite polymer heat exchangers to address issues with conventional polymer heat exchangers.
- Utilization of additive manufacturing to incorporate enhanced heat transfer features reducing the size of the heat exchanger module
- The project has some very good strengths:
    - Greatly reduce the heat exchanger physical size, which will ultimately yield space and cost savings
    - High energy reduction potential
    - Significant cost reduction in manufacturing processes
    - Opportunity for significant charge reduction utilizing low GWP refrigerants.

- The team members expertise covers all aspects needed to make the new heat exchanger a reality. It involves appropriate technical expertise and industry partners to aid in the implementation and use of the new heat exchanger.

2. Project Weaknesses

- There are concerns with polymer 3D-printing resolution; particularly if high heat transfer coefficients and compactness are desired. In addition, the permeability of 3D-printed polymer film is important. Most polymers allow some gas passage through the diffusion mechanism. This might lead to refrigerant leakage at high pressures for example in the condenser module. This issue might be addressed by some special coating. However, this coating might introduce additional thermal resistances and costs. It is suggested to design some tasks to study these effects.

- One weakness would be how well manufacturers would be able to adapt for the new manufacturing processes. Just reducing the heat exchanger sizes on their own would still have some challenges for manufacturers to take advantage on their production lines, it would require significant product redesign. Another weakness is how to address potential leaks in the heat exchangers; traditionally to some extent heat exchangers can be repaired. The project didn't address rework potential for the heat exchangers.

- It is not obvious that there are any dedicated meetings to discuss progress and future tasks. This shortcoming is highlighted in Item 4 – Collaboration and Coordination.

3. Recommendations

- It is suggested that some new tasks are defined to address the following concerns:
    - Water vapor passage issue through composite polymers (which might affect the refrigerant mixture)
    - Polymer degassing
    - Thermo-mechanical properties of 3D-printed polymers at different printing resolutions
- I would like to see some additional research on optimal pressure ratings.
- Periodic dedicated meetings to discuss progress and future tasks.

Project #32226v: Real World Refrigerant Leak Assessments

Presenter: Van Baxter, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

One reviewer commented that the project approach seems appropriate. A few reviewers agreed that this is a critical project to support work in industry to switch to lower global warming potential (GWP) refrigerants. Multiple reviewers noted this project has a good experimental setup to investigate leakage rates of flammable refrigerants, with one reviewer highlighting the well thought out controlled experiments. One reviewer cautioned that while this was desired by the Air Conditioning, Heating, and Refrigeration Technology Institute (AHRTI), it might have been more valuable to the industry if a more controlled scientific experiment had been devised that could be better correlated to other equipment types, sizes and configurations. One reviewer noted that the project team has developed simplified tools, but they need to be further validated.

Multiple reviewers agreed on the importance of this project, as the results could be extremely valuable to the adoption and use of potentially flammable low-GWP refrigerants. One reviewer noted that this project will enable the use of new flammable refrigerants in a manner that eliminates or minimizes flammability issues.
Another remarked that this is needed research to help the industry understand possible implications of the use of flammable refrigerants on system design and maintenance. One reviewer commented that the project is unlikely to address the wide range of concerns of regulatory agencies.

The majority of reviewers commented that the project is demonstrating good progress to-date. One reviewer remarked that the results to date have been inconclusive and have not helped validate the UL60335-2-40 proposed mitigation. This reviewer noted that the next phase of the project is critical, but there are facility issues and conflicts with other projects at Oak Ridge National Laboratory that may not result in the tests that are desired. Most reviewers observed that the remaining project work seems appropriate and can be completed as planned. One reviewer expressed that this is a very high priority project and needs to be completed by late summer to early fall to support code hearings. To do so, this reviewer flagged that the work needs to be accelerated.

Many reviewers noted the primary stakeholder engagement is the partnership with AHRTI. A few reviewers agreed that the project has very good stakeholder involvement. One reviewer remarked that the partnership with AHRTI, as well as the AHRI/ASHRAE/CA/DOE collaboration, is important for codes and standards development. While one reviewer commented that the project team is working very closely with AHRI and industry manufacturers, the majority of reviewers agreed that further stakeholder engagement would be beneficial for the project. Reviewers suggested engaging the system manufacturers, original equipment manufacturers (OEM) engineering teams, and worldwide organizations involved in evaluating the use of refrigerants.

One reviewer commented that the strength of the project is that it is working to solve one of the major issues associated with the use of flammable refrigerants, which is the magnitude and distribution of the refrigerant that is released into a living space when an uncontrolled refrigerant leak occurs. One reviewer noted that presented experimental data does not show any error bars, which are important especially in the correlation work. One reviewer suggested the team needs to characterize liquid line length or initial charge. One reviewer remarked that the project is unlikely to satisfy many in the industry who approve new refrigerants for a wide variety of equipment sizes and types. A couple reviewers observed that it would be helpful to expand the number of tested refrigerants, including low-GWP alternative refrigerants, and test conditions (temperature, pressure, humidity, etc.).

Weighted Average: 3.12 # of Reviewers: 7
Approach: 3.14 Impact: 3.29 Progress: 3.00 Collaboration/Coordination: 3.00 Remaining Work: 3.14

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.14** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Approach seems appropriate for the justified leak assessment using five initially identified and two additional HVAC&R systems operated with two selected refrigerants R410A and R404A.
- OK.
- It is understood that this is what was desired by AHRTI, but it might have been more valuable to the industry if a more controlled scientific experiment had been devised that could be better correlated to other equipment types, sizes and configurations.
- Testing of low-GWP refrigerants is needed.
- This is a critical project to support some of the work in the industry to switch to lower GWP refrigerants. The team is working closely with AHRI and the industry, but the project is late and needs to be accelerated and complete late summer of 2019.
- The project approach to investigate leakage rates of flammable refrigerants is primarily experimental based on taking data on real-world systems, which are rigged so that sudden liquid and vapor leaks can be initiated. Of special importance, the measured leakage rate will affect the formation of flammable mixtures with this knowledge being of paramount importance.
- Good experimental set up that allows testing of a number of factors that can govern leak rates of actual systems. Well thought out controlled experiments.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.29** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Test data and obtained correlations for actual flammable refrigerant release rates will help industry to promote using the low-GWP refrigerants at the HVAC&R market.
- Seriously important topic and potential impact.
- When completed, this will provide some help to those who will regulate the use of potentially flammable (low GWP) refrigerants, but it is unlikely in itself to address the wide range of concerns such agencies will have.
- It is hard, but quantitative impact could be estimated by assuming mitigation of emission based on data from this study.
- The results of the project could be extremely valuable to the adoption and use of A2L refrigerants in the industry which will likely be needed for lower GWP options.
- Achieving the project goals will promote the use of new refrigerants to replace R-410A and other fluids with a GWP. This replacement will enable the use of new flammable refrigerants in a manner that eliminates or minimizes flammability issues.
- Needed research to help the industry understand possible implications of the use of flammable refrigerants on system design and maintenance. Near term tech improvement.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Based on presented materials the reported progress is adequate to the approved SOW.
- OK.
- Work is progressing well within the project parameters.
- Good progress is made.
- The results to date have been inconclusive and have not helped validate the UL60335-2-40 proposed mitigation. They have developed simplified tools but they need to be further validated. Next phase of the project is critical but there are facility issues and conflicts with other projects at Oak Ridge that may not result in the tests that are desired.
- Three of four milestones have been reached on-time, and the last one will be completed this year.
- Project is 50% complete and showing good progress.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Primary stakeholder engagement reported is "via regular meeting with AHRTI". Beyond PMS it would be more helpful to directly engage with specific OEM engineering teams to get the industrial feedback on the obtained results, etc.
- Would encourage more collaboration to push the project more comprehensive and in-depth.
- It would be wise to reach out to others who will be involved in evaluating use of such refrigerants worldwide.
- Better to include system manufacturers.
- They are working very closely with AHRI and industry manufacturers.
- The stakeholders have been engaged at regular meetings with the AHRTI PMS, who also supplied the hardware systems that have been used in the tests.
- Partnership with AHRTI on this project and part of the AHRI/ASHRAE/CA/DOE collaboration. Important partnerships for codes and standards development.

E. Remaining Project Work

This project was rated **3.14** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Based on reported progress the initial objectives were mostly completed, so remaining scope is mostly additional tests (Phase 2). The leak rate correlation is expected to be performed upon completion Phase 2 for the entire spectrum of tested systems.

- Mid-stage and with lots to be worked on and figured out.
- Looks like remaining work can be completed as planned.
- It looks the plan for remaining work can provide R410A correlation. Like to see low GWP refrigerants works too.
- There are some facility issues and priority conflicts. This is a very high priority project and needs to be completed by late summer to early fall to support code hearings.
- The remaining work is correlation development and report writing, which are the logical conclusions to the project. The correlations will be based on Phase 1 and 2 data and will consist of finding correction factors for a series of test parameters.
- Phase 2 testing seems appropriate.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength of this effort is in gaining very important knowledge base for the critical line of the affected equipment.
- Well picked topic and important issue.
- This project appears to directly respond to criteria set by agency with whom collaboration is occurring.
- Systematic leakage tests with various air conditioning products.
- Combined CFD analysis with test verification. Very good collaboration with industry.
- The strength of the project is that it is working to solve one of the major issues associated with the use of flammable refrigerants, which is the magnitude and distribution of the refrigerant that is released into a living space when an uncontrolled refrigerant leak occurs.
- Good stakeholder involvement. Realistic testing conditions.

2. Project Weaknesses

- The weakness is limited spectrum of the low-GWP refrigerants.
- Quite some work remaining.
- This project is unlikely to satisfy many in the industry who will have a voice in approval of new refrigerants for a wide variety of equipment sizes & types.
- Tested with non-flammable refrigerant only (R410A). Need to characterize liquid line length (or initial charge).
- Facilities issues and conflicts with other projects. To date the results have not been conclusive so a close review of future testing is needed.
- None.
- Presented experimental data does not show any error bars. This is important especially in the correlation work.

3. Recommendations

- It would be helpful to expand the number of tested refrigerants and test conditions (temperature, pressure, humidity, etc.).
- Look forward to your final results.
- Recommend reaching out to wider spectrum of industry and find what will be required to obtain approval for refrigerants in various applications.
- It will be great to include low GWP alternative refrigerants.
- Give priority to the testing and find solutions to facility issues. Continue close collaboration with AHRI.
- None.
- The authors report experimental errors on slide 9 but don't show how these uncertainties impact on the results and the correlations.

Project #312112: Non-Vapor Compression

Presenter: Ayyoub Momen, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Generally, reviewers found the project team's approach of developing and promoting non-vapor compression cooling technologies promising and worth further investigation. Though one reviewer commented that the prototype developing is reasonable, another reviewer recommended that the team analyze the decade-worth developments existing in this field and presents an analytical comparison outlining the benefits of this approach.

Many reviewers expressed confusion as to the impact of the project and commented that it was difficult to discern the progress based on the presentation and due to its early stage. However, other reviewers noted that, if successful and cost competitive, the technology may provide significant energy savings benefits to the commercial and residential cooling markets.

To this point, the project team has made good progress on the project's modeling work and beginning stages of experimental work with Galinstan, reviewers found. One reviewer recommended the project team finalizes a target application and system configuration in the future.

The reviewers did not find the project team had adequately collaborated with stakeholders – many recommended more significant strategic collaborations with refrigerator and cooler OEMs. The project team's presentation on remaining work outlined much to be studied experimentally with Galinstan. Reviewers expressed concern with the short timeline given to achieve this work, although the majority did find the plan to be well-defined.

All of the reviewers praised the project's innovative idea to improve heat transfer of magnetocaloric cooling technology. Unfortunately, the reviewers pointed to the cost-effectiveness, loose results, and lack of an OEM partnership as project weaknesses. As the project continues, the reviewers made some recommendations to address these challenges. Two reviewers noted their interest in seeing an assessment or conclusion of the technology, another reviewer recommended first selecting target applications, and working with them for setting up operating conditions.

Weighted Average: 2.89   # of Reviewers: 7
Approach: 3.00   Impact: 2.86   Progress: 3.14   Collaboration/Coordination: 2.57   Remaining Work: 2.86

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach to evaluate the performance benefits of the solid-state medium (over liquid) for magnetic cooling seems reasonable for exploration and characterization. However, it would be suggested to analyze the decade-worth developments in this field and present analytical comparison outlining the benefits of the selected approach. For example (Ames Laboratory, Aeronautics Corporation, and others in US and internationally):
  - https://www.aps.org/publications/apsnews/200305/refrigerators.cfm
  - https://www.eurekalert.org/features/doe/2002-01/dl-nmr061702.php
- Developing a prototype is a reasonable approach.
- Nice idea to improve heat transfer aspect.
- Need more thermophysical properties of liquid metal and its evaluation.
- No comment.
- New approach looks promising and is worth further investigation and study
- The project goal is the development and promotion of non-vapor compression cooling technologies, by providing solutions to the inability of magnetic cooling technologies to deliver acceptable specific cooling capacities and operating frequencies. The approach to solve this problem is to utilize solids rather than fluids to transfer heat.
- As a research project the approach is a good assessment of the technology.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.86** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful economically the reported approach may provide significant energy savings benefits to the commercial and residential cooling markets. However, besides comparison with state-of-the-art VCR systems it would be helpful to also provide the benefits comparison with the MCR systems commercially available, i.e., https://newatlas.com/cooltech-commercial-magnetic-cooling/43874/
- Hard to tell based on the current progress but appears to have some potential.
- This technology, once fully developed, may work well in many appliances requiring heat transfer. Will it be cost and performance competitive?
- Achieving 25% energy saving as compared to state-of-the needs to be verified while including all power inputs by pumps, valves and fan motors. First it needs to set target application.
- I did not see any cost projections so not sure how effective the technology will be.
- The impact of achieving a higher operating frequency is significant in that it may be the breakthrough needed to make magnetic cooling a viable alternative to vapor compression.

- This is very early stage R&D. Energy savings benefit unclear.

C. Progress

Based on current project efforts, the project was rated **3.14** for the degree to which the project has met ***project-specific goals***.

- Based on the presented materials the progress is build based on two milestones - baseline characterization and evaluation with Galinstan. The Milestone 1 has been mainly completed. Milestone 2 work is upcoming in next few months. Employing the solid-state medium raises some technological hurdle related to the surface quality to avoid extra heat generated by the friction forces. Switching to liquid medium departs from the original "solid-state" concept.
- On-track.
- There have been challenges, but there does appear to be reasonable progress.
- Need to finalize target application and system configuration.
- They have made good progress and have some new concepts to evaluate
- Accomplishments to date include a prototype being built and benchmarked with a heat transfer fluid (water), along with developing numerical models.
- Modeling work has proceeded well. The experimental work seems to be in its early stages now that they are concentrating on Galinstan.

D. Collaboration and Coordination

This project was rated **2.57** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- MCM developer does not seem like a key stakeholder best for moving the advanced cooling technology towards to the marketplace. The refrigerators and coolers OEM seem better partner for the technology prototyping and further commercialization. It is always helpful to engage the OEM in the project effort from early beginning to gain their guidance for development as well as marketing and manufacturing feedback.
- Well done, but with limited resources and partner.
- Outreach to OEMs is a task set for a next step.
- Need more significant strategic collaboration with relevant target system manufacturers.
- They are collaborating with suppliers and internal experts and considering the manufacturing process.
- The stakeholders in magnetocaloric cooling technology have been identified and in many cases are already involved with the project.
- The research work is being performed between MCM and ORNL. It is unclear if any additional stakeholder engagement is or will be performed beyond their stated outreach to OEMs, which was not described.

E. Remaining Project Work

This project was rated **2.86** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Slide 19 outlines the remaining work that raises some timeline concerns given the 5-6 months for Milestone 2 work completion, data processing, analysis, publication and OEM outreach. Very aggressive deadlines. Hopefully the project team already has a list of potential OEMs for effective outreach.
- Good research documentation potential and need an update on Galinstan's performance.
- There's a lot left to be done, but the steps seem to be the right ones.
- Remaining work will address questions, but it is better to work with target system manufacturers for clear definition of operating conditions.
- Good plan defined for further investigation. Should also do some detail studies on costs and economics.
- Remaining efforts to advance this magnetocaloric refrigeration technology are more development work on the use of solids as a substitute for heat transfer fluids.
- It appears that there is still much to be studied experimentally with Galinstan and their second prototype, especially given the planned project end date of 9/30/19.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strength is in developing concept/technology potential to help reach the energy savings goals by 2030, if economic feasibility proven.
- Nice to check the idea out.
- It may be a new approach to providing heat transfer in common appliances that does not have the drawbacks of vapor compression systems.
- Great idea to improve heat transfer of magnetocaloric cooling technology.
- No refrigerant needed and very good for environmental impact. Plans to consider manufacturing impact.
- The project strength is that it is evaluating and promoting transformative technologies.
- The modeling work is complete, and their findings have been published.

2. Project Weaknesses

- There are two major weaknesses of the effort at this time:
  - Lack of convincing justification of the approach/concept cost-effectiveness (cost-benefit analysis is needed, at least the preliminary one), and Lack of credible OEM having access to the market for moving technology forward, if feasible.
- Loose results and conclusions to take away.
- Risk – the technology has been known for a long time. There may be reasons it has never been fully developed.

- Not much thermophysical properties and test data provided with metallic heat transfer medium.
- Ability to scale the technology to larger capacities. Cost and economics.
- No comment.
- The experimental work may not be as advanced as planned given the project end date.

3. Recommendations

- Project team to perform a detailed review of the competing MCR technologies and concepts, make comparative analysis and try to collaborate/cooperate with the leading R&D entities in the field (such as Ames, Aeronautics, etc.) to either complement their concepts or invite them to contribute their expertise and experience into developing concept/approach.
- Eagerly waiting for some break-through or integrated conclusions, no matter good or bad news.
- I'd like to see the loose ends tied together and an honest assessment of the technology made so it is either promoted or set aside and we move forward accordingly.
- I would like to recommend selecting target application first and working with them for setting up operating conditions and system architecture.
- Economic studies.
- No comment.
- Depending on how the experimental work proceeds, the project might need to rely more on predictive results from the modeling to provide findings and suggest continued efforts.

Project #32294: Improved Braze Joint Quality Through use of Enhanced Surface Technologies

Presenter: Brian Westfall, Trane
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Most of the reviewers approved of the approach to utilize structured surfaces to wick braze alloy to brazing joint areas, thereby creating stronger braze joints. The research would include all types of joints including braze alloy/flux-phobic or -philic to allow assistance in directing the brazing materials. One reviewer commented that it would have been good to have better controls on the brazing process that was utilized for testing because it seemed to provide unreliable results in the project testing because of poor quality of the joints.

All reviewers agreed that the impact of the project would be seen in the stronger brazed joints. Another big impact from the project would be the reduced manufacturing costs. As one reviewer pointed out, since the performance of refrigerant systems are less effective as the refrigerant charge decreases, 10-50 TBtu cost savings are projected.

Two reviewers agreed that the inconsistent results of some of the testing are questionable due to the lack of quality control on the test samples (brazed joints). Interestingly, all joints (treated and untreated) failed in base metal and not in braze joint. The other reviewer noted that there is a significant amount of work still to be done.

Reviewers agreed that there appears to be collaboration and coordination with stakeholders, but reviewers disagreed on the extent of the collaboration. One reviewer highlighted that the team members have excellent strategic coordination with relevant stakeholders. However, another reviewer expressed concerns that there was a disconnect sometime during the middle of the project. In particular, the automated brazing facility being developed by UIUC appears not to be feasible.

Reviewers pointed out additional remaining work, including utilizing the automated brazing machine, creating and brazing larger-scale braze joints, conducting an initial assessment of manufacturability, performing reliability testing of the new brazing process to compare to current brazing techniques, conducting cost analysis of the new brazing process, and implementing a commercialization plan. The additional testing utilizing the automated brazing machine should help to shore up some of the unreliable results. One reviewer praised the team for the well planned out remaining project work.

Weighted Average: 3.05   # of Reviewers: 3
Approach: 3.67   Impact: 3.00   Progress: 2.33   Collaboration/Coordination: 3.00   Remaining Work: 2.67

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project utilizes structured surfaces to wick braze alloy to brazing joint areas, thereby creating stronger braze joints. The idea is inspired by research conducted on interfacial heat and mass transfer. Fundamentally speaking, the idea is interesting and new to the proposed problem space.
- It would have been good to have better controls on the brazing process that was utilized for testing. It seemed to provide unreliable results in the project testing because of poor quality of the joints.
- The technical approach was to use engineered surfaces to promote wicking flux and braze alloy into joints to create stronger and more robust braze joints. The research would include all types of joints including braze alloy/flux-phobic or -philic to allow assist in directing the brazing materials.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, the project leads to stronger brazed joints for HVAC&R applications while using less braze materials. This can have a positive impact on HVAC&R OEMs.
- There is indirect energy savings impact for the improved brazed joints due to implications on critically charged systems. It seems the biggest benefit to the project is really the reduced manufacturing costs.
- If successful, this research would lead to a reduction in braze joint refrigerant leak. This would like to reduction in the number of inspections as required by EPA 608. Also, since the performance of refrigerant systems are less effective as the refrigerant charge decreases, 10-50 TBtu cost savings are projected.

C. Progress

Based on current project efforts, the project was rated **2.33** for the degree to which the project has met ***project-specific goals***.

- The project progress has been partially slowed down by the inconsistent results across surfaces, braze alloys and tube ODs. It is interesting to see that all joints (treated and untreated) failed in base metal and not in braze joint. It would have been helpful to use very thick metals (or tubes) (and/or short braze joints) to switch the failure point from tube side to braze joint. Also, it seems burst tests did not show any differences between plain and treated surfaces. Fundamentally speaking, it is expected to see a difference between plain and structured braze joints (simply due to a higher degree of mechanical engagement in case of the structured surface). However, if the braze joint creates a gap between the two joint surfaces, then the strength of the braze joint is dominated by mechanical properties of the braze material. In other words, even though the braze material is strongly bonded to each of the two joint surfaces, the failure happens within the braze material by itself. This might completely defeat the whole purpose of using enhanced structures. This needs to be extensively investigated.
- The results of some of the testing are questionable as the lack of quality control on the test samples (brazed joints).
- The project began on October 3, 2016, with an end date of October 1, 2019. There is a significant amount of work still to be done. See Remaining Work.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant stakeholders.
- No comment.
- The team includes Ingersoll Rand as the lead with UIUC. From the presentation, it appears there was a disconnect sometime during the middle of the project. In particular, the automated brazing facility being developed by UIUC appear not to be feasible.

E. Remaining Project Work

This project was rated **2.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project work is well planned out.
- The additional testing utilizing the automated brazing machine should help to shore up some of the unreliable results.
- There is a significant amount of project work remaining. This includes 1) larger scales braze joint creation and brazing, 2) initial assessment of manufacturability, reliability testing of the new brazing process as compare to current brazing techniques, 3) cost analysis of the new brazing process, and 4) commercialization plan.
- From the presentation, it appears Ingersoll Rand will continue the work in this area with or without DOE Support.

F. Additional Comments and Recommendations

1. Project Strengths

- The project pursues a novel approach to strengthen braze joints that are commonly seen in many HVAC&R systems.
- Trane, as an HVAC OEM, has extensive relevant experience in the problem space defined.
- The project showed some results that yielded improvements, however those results will need to be verified through the additional testing proposed.
- The team has very competent members.

2. Project Weaknesses

- Although the project approach is interesting, it would have been helpful to initially investigate the exact failure mechanism. In general, there are two possibilities when a braze joint fails. One possibility is that the failure happens at the interface of the braze material and the metal surface. The other possibility is that the failure happens within the braze materials. The first failure mechanism can be improved by the proposed approach. However, the second failure mechanism cannot be improved by the proposed concept. As of now, it is not clear which failure mechanism is dominant.
- The project has potential to help minimize refrigerant leaks which will in turn help with energy efficiency on critically charged equipment.

- It appears there was some lack of coordination during the middle of the project.

3. Recommendations

- I would suggest dedicating substantial resources on the following items:
- Identifying the exact failure mechanism and location (failure at the interface of the braze material and the metal surface vs. failure within the braze materials).
- Use very thick metals (or tubes) (and/or short braze joints) to switch the failure point from tube side to braze joint.
- The quality control process in preparation of the test samples is being addressed.
- None. It appears Ingersoll Rand will continue the work in this area with or without DOE Support.

Project #32297: Design and Manufacturing of High Performance, Reduced Charge Heat Exchangers

Presenter: Reinhard Radermacher, University of Maryland - College Park
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

All reviewers approved of the approach to design and manufacture high performance, reduced charge heat exchangers (HX). This is a promising project with huge ramifications to the industry for the reduction of refrigerant use and for performance and efficiency improvements. Reviewers commented that the approach for making and testing prototypes and sending several for independent validation is good, and the team has a good understanding of the challenges for commercialization.

In general, reviewers agreed that the biggest impact will be seen in the smaller coils (lighter and less expensive) and the reduced charge (30%). The project goals of reducing refrigerant charges by 30% or more are impactful in that this will be a significant step toward promoting the use of non-GWP refrigerants that may otherwise be flammable in larger quantities. Reviewers generally agreed that this project is of importance and significance because if successful, it can bring good savings and improvements to the market.

Most of the reviewers agreed that the project is showing excellent progress. The project seems to be proceeding on-track in the design and fabrication stages, and they have engaged with major tooling suppliers and manufacturers. One reviewer commented that new PPFSA design optimization and fabrication of the targeted prototypes have been initiated according to the project scope.

Overall, reviewers praised the project's collaboration and coordination, particularly with industrial partners. The project team has engaged with the major suppliers and manufacturers and they have made very good efforts in publishing results. One reviewer recommended having some AC equipment manufacturers involved in the development of these products.

Many of the reviewers agreed that the remaining project work is well-planned. Most of the remaining project work is constructing HX prototypes and performing experimental evaluations, and the outlined remaining scope corresponds to the project targets and anticipated outcomes. One reviewer highlighted that the manufacturing process and costs are critical, so the full cost study needs to be part of the project.

Weighted Average: 3.48   # of Reviewers: 6
Approach: 3.50   Impact: 3.67   Progress: 3.67   Collaboration/Coordination: 3.33   Remaining Work: 3.17

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach to miniaturize the heat exchangers (HX) for air conditioning and heat pump applications seems quite important. The selection of non-round tubes and arrangement optimization deserves significant attention.
- This project is well picked and super promising.
- The approach for making and testing prototypes and sending several for independent validation is good.
- This is a very interesting project with huge ramifications to the industry for the reduction of refrigerant use and for performance and efficiency improvements. It is a very novel design and could have significant impact.
- The approach of optimizing HX designs, followed by prototype construction and testing to evaluate HX performance, while reducing HX volume, is worthwhile.
- This is a well-designed project with a good understanding of the challenges for commercialization.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.67** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Reduced charge (30%) and reduced weight (>25%) may significantly impact the A/C and HP markets by reducing carbon emissions and cost savings potential.
- This project is of importance and significance.
- This project has coils that are smaller, lighter and less expensive with reduced AC contributions to GWP sources.
- Coils are the number 2 cost of HVAC and where most of the future efficiency improvements will cost from. Also, with the change to lower GWP refrigerants, the cost of refrigerant will increase. Charge reduction is very important.
- The project goals of reducing refrigerant charges by 30% or more are impactful in that this will be a significant step toward promoting the use of non-GWP refrigerants that may otherwise be flammable in larger quantities.
- A well-designed project that if successful can bring good savings and bring improvements to the market.

C. Progress

Based on current project efforts, the project was rated **3.67** for the degree to which the project has met ***project-specific goals***.

- New PPFSA design optimization and fabrication of the targeted prototypes have been initiated according to the project scope.
- This project is well on track so far.

- The progress is excellent with tube design being finalized and potential issues being tackled effectively.
- It looks like great progress is being made and they have engaged with major tooling suppliers and manufacturers.
- The project progress to date is excellent with the framework for HX optimization having been developed, along with investigations of non-round tubing manufacturing techniques having being studied.
- It is still the early stages of the project, but the project seems to be proceeding well in the design and fabrication stages.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The qualified project team was complemented with an extensive list of industrial partners will ensure the successful project outcomes. The special focus should be made on non-round tube fabrication (possible - extrusion) and quality inspection methodology to prevent leaks and shape distortion.
- No comment.
- It would be useful to have some AC equipment manufacturers involved in the development of these products.
- The project team has engaged with the major suppliers and manufacturers.
- Numerous industrial partners, along with ORNL and the University of Maryland, are involved with this project. All of these parties are working together, either providing project expertise or being continuously updated on the project progress.
- The project team has made very good efforts in publishing results. They have identified and are working with a good set of industry partners.

E. Remaining Project Work

This project was rated **3.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The outlined remaining scope corresponds to the project targets and anticipated outcomes.
- The project is well planned.
- The remaining work of full system testing appears well planned and reasonable.
- The manufacturing process and cost are critical, so the full cost study needs to be part of the project. Also, the team should consider that future refrigerant will likely be more like R22 pressures.
- Most of the remaining project work is constructing HX prototype and performing experimental evaluations.
- Team is on track on this well-defined research work.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths include combined design development and optimization along with the manufacturing technology.
- This project is creative and promising.
- The project has a good approach to reducing refrigerant charge in AC units without adding cost or losing efficiency.
- The project strengths are the staff at UMD and partners involved in the project.
- The project strength is its goal of reducing HX size, which will in turn reduce the required refrigerant volume, while improving HX performance. Also, the number of participants and stakeholders is impressive.
- This is a well-defined project with strong industry links.

2. Project Weaknesses

- Given the only non-circular tube shape the advanced design improvisation is quite limited. So, the heat exchanger type designs (even best optimized) can be still considered as incremental improvement but not transformational.
- None so far.
- I have concern with potential leakage from minor impacts to coils.
- The manufacturability and cost analysis need to be very robust.
- None.
- At this stage of the project, none.

3. Recommendations

- The consideration of other tubular shapes (oval, twisted, etc.) and HX design types (mini-channels, hybrids, etc.) could be beneficial for the ultimate project outcomes.
- I look forward to it.
- I recommend involving AC equipment manufacturers now to get their feedback on best way to incorporate this new approach into their products.
- This is a well thought out project and most aspects were covered. They should consider new refrigerants and possibly refrigerants with glide and use of heat pumps and the impact on coil circuiting.
- None.
- None.

Project #32299: Hydrogen/Metal Hydride Based Heat Pump System for Large HVAC Applications Utilizing an Ionic Liquid Desiccant Subsystem

Presenter: Bamdad Bahar, Xergy
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

In general, the reviewers approved of the project's approach to develop a new HVAC system that eliminates most mechanical systems by using the combination of an electro-chemical compression (ECC), a heat exchanger for hydrogen solutions, and a liquid desiccant system which takes advantage of the wasted heat from the ECC-based heat pump. The approach does seem to be making progress in solving the many technical challenges and the overall approach is on-the-mark. However, one reviewer disagreed and stated that the absorber configuration is fundamentally wrong and won't deliver a reasonable performance.

Many reviewers agreed that, if successful, this project's impact could be significant for improving energy savings and vapor compression technologies. The scope of the work is broad, and it seems that any of the three technical areas discussed could have derivative applications in addition to the stated heat pumps and the ULT freezers. However, two reviewers disagreed and stated that project goals won't be met with this absorber design and the parts and the whole unit appear too early stage and complex.

The reviewers were split on their feedback on the project's progress, with some reviewers praising the project for its good progress. Other reviewers criticized the presentation, commenting that it was not well organized, and it was hard to tell from the presentation the expected milestones and achievement relative to those goals. Another reviewer explained that the dehumidification performance and its associated system integration are not done because the developed absorber will short-circuit the cold and hot sides of the cooling cycle and kill the system performance without doing dehumidification.

Two reviewers agreed that the project team includes a range of expertise, but most of the reviewers agreed that the project is lacking collaboration and coordination. While the work reportedly is making significant progress, it is not clear what some of the other partners are doing, such as Haier and Delaware, who were both mentioned, but no information was provided on what they are doing. Reviewers would also like to see more team members with a good scientific background on this subject and more field-experienced individuals.

Overall, reviewers agreed that the remaining work includes a path to commercialization, but reviewers disagreed on whether this path is reasonably achievable. The remaining project work is to make this technology real, so it will be interesting to see if the compressor and other systems will truly be a good fit for the window unit and the low temperature freezer, but it is difficult to assess the commercial viability and market readiness of such unit. Another reviewer stated that this project will not achieve the promised dehumidification function.

Weighted Average: 2.53   # of Reviewers: 5
Approach: 2.60   Impact: 2.80   Progress: 2.60   Collaboration/Coordination: 2.20   Remaining Work: 2.40

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project's main goal is to develop a new HVAC system that eliminates most mechanical systems by using the combination of an electro-chemical compression (ECC), a HX for hydrogen solutions, referred as metal-hydride HX, and a liquid desiccant system which takes advantage of the wasted heat from the ECC based heat pump. The project expects to demonstrate a full integrated system as it develops the individual components. This overall, seems like a very complex system with multiple, new components.
- The overall approach, making progress in each of the three areas in parallel and combining the three technologies into products, is on the mark.
- The absorber configuration is fundamentally wrong and won't deliver a reasonable performance. The dehumidification achieved was 1-2% (about the typical error of humidity measurement sensors) at a very high relative humidity of ~80%.
- An electrochemical compressor will be a unique option for vapor compression technology and this system has made significant progress since their original SBIR origins. The project team seems to constantly be on the lookout for innovative options which adds to the prospects for success.
- While there seem to be many technical challenges being solved at the same time, the approach does seem to be making progress in solving the issues. I do think that the tip of the spear planning to improve mitigation of project risks should be increased.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- It is very difficult to assess the potential impact of the proposed technology with an optimistic view. The parts and the whole unit appear too early stage, and complex. Assuming the technical yield results in a working prototype, it is difficult to forecast an economic viable unit with current technology.
- The scope of the work is broad and it seems that any of the three technical areas discussed could have derivative applications in addition to the stated heat pumps and the ULT freezers.
- Project goals won't be met with this absorber design. This can be theoretically shown.
- There may yet be unforeseen elements that might prevent complete success, but it appears that the direction this technology is going might result in significant impacts on many vapor compression technologies.
- If the project goals were met, there would be significant energy savings, with improvements in comfort, that would increase adoption rates.

C. Progress

Based on current project efforts, the project was rated **2.60** for the degree to which the project has met ***project-specific goals***.

- The team appears to be making good progress according to the projected work plan, with reasonably good successes at the components level for the GEN-XII hydrogen EEC, coupled to the HX units and packaged into a single lab-scale heat pump system. The system has been tested for limited period of times. Progress was also reported in the liquid desiccant unit, with the membrane identified, partially tested, and packaged. The next steps will include full system integration.

- Unfortunately (and unlike other personations in the track) this presentation (written and oral) were not well organized. I have not read the prior year report on this and it was hard to see what is new and what is not, and what is supported by this award and what is not. It seems, however, that the project with the stated goals is on track. The 750-psi reached is excellent, the MHHX and ILD work are in good shape, and the system integrations possible at this stage are being pursued.
- The dehumidification performance and its associated system integration are not done. Basically, the developed absorber will short circuit the cold and hot sides of the cooling cycle and kills the system performance without doing dehumidification.
- The team has made very good progress to date and the project team has generally met timelines and deliverables as desired.
- It was hard to tell from the presentation the expected milestones, and achievement relative to those goals.

D. Collaboration and Coordination

This project was rated **2.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This element was not addressed in the reporting by the PIs, and difficult to assess by external reviewers. The team does seem to include a range of expertise related to the project development, including system integration and R&D, one can assume these interactions are producing productive feedback.
- While the work reportedly is making significant progress, it is not clear what some of the other partners are doing. It is not clear what their roles are. For example, Haier is mentioned in name, but I do not see what they have or will be doing. The same goes for Delaware.
- A team member with a good scientific background on this subject could have saved DOE funds.
- There is good collaboration with national labs and industry, and the project team has been willing to bring in technical expertise as needed. They have made good use of their own areas of specialization and arranged to take advantage of what the national labs are good at doing.
- As some of the technologies move closer to commercialization, I would like to see more field experienced individuals be included in the project. I feel there are some great ideas here, but worry some of them get a bad reputation, due to unexpected failures do to field implementation issues.

E. Remaining Project Work

This project was rated **2.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This reviewer considers that the team will demonstrate technical performance of a basic integrated unit. It is difficult to assess the commercial viability and market readiness of such unit.
- For the remaining one year in the life of the project, there are some technical decisions to be made (and options to take) but the overall path is clear (and impressive). Some of the technical decisions might be helped by including external experts in respective fields (heat exchanger design, salt selection, etc.). National labs have vast experience in some of these areas.
- This project will not achieve the promised dehumidification function.

- The remaining project is the real meat and potatoes to make this technology real, so it will be interesting to see if the compressor and other systems will truly be a good fit for the window unit and the low temp freezer. The ORNL team should be a good fit to work up these systems and test the system performance.
- There should be a clearer path to commercialization and a timeline. Even if the timeline cannot be held, or the plan has to change, it will be necessary to hold stakeholder interest. The ideas are very cool to technical folks, but going to wear thin on financial types, that cannot see the forest through the trees. I would hate to see the funding spigot crank down to the point the project fails.

F. Additional Comments and Recommendations

1. Project Strengths

- The project has degree of innovation on its components and as a whole, and builds from a very good expertise by the team in the development of EECs.
- There seems to be a significant amount of knowhow and development emanating from this project on several fronts. Xergy seem to have a good and enthusiastic team and excellent collaborators (even though the precise functions and contributions of them was not listed). The prospect of early commercialization is a definite plus for this project. The team seems familiar with the market and has a reasonable path towards commercialization.
- The project strengths are not clear.
- A gas compressor with no moving parts is the holy grail for vapor compression cycles. And if it is more efficient than conventional mechanical compressors, that is even better. This compressor could truly be a disruptive technology in vapor compression systems.
- There are some revolutionary advantages to the technologies here, that solve issues created by technology patches to reach regulatory standards. I look at this like and LED solution compared to fluorescent solution for an incandescent light bulb replacement. Fluorescent had some advantages, but were held back from full adoption because of their disadvantages. LED has become the dominate player, because it is just fundamentally better than incandescent and fluorescent. As just one example, simply the idea of separating the latent and sensible cooling coils, is a true disrupter and better than anything else we are doing today, and could inspire quick market transformation, like LED has seen.

2. Project Weaknesses

- The projected whole system is complex, presenting high risks in its development, and likely with limited economic feasibility. The team is not addressing practical issues of economics of the parts, manufacturability, and market acceptance, yet it is projecting commercialization.
- The scope of work is too broad (I am not complaining), and the final outcome hinges on success in the three areas (and sub-areas) outlined.
- There is a chance that the team's enthusiasm and self-confidence prevent them from seeking out external help and securing critical reviews they need to complete the project.
- The project has a fundamentally incorrect approach.
- I would like to see a major manufacturer on board who would be ready to commercialize this compressor. The Xergy team may have their ideas for keeping control of manufacturing, they clearly are not a large-scale manufacturing company. If this truly does satisfy most of the project objectives, it will need to be made in a commercial scale as quickly as possible. While patent protection is important, we don't want to wait 20 years for this technology to have a significant impact.

- I worry that the project planning is not looking far enough into the future. I worry that early adopters will have trouble getting the field to implement with the same success as in the lab, and technology will get "run out of town," before being fully adopted. Resistance to change will be high. There are a number of market participants, that will not like the uncertainty these technologies could inject into their revenue flows and margins.

3. Recommendations

- This reviewer recommends for the team to approach the problem incrementally; to demonstrate full technical and commercially viable integration of the ECC with the MHHX, and then further considers additional improvements such as heat recovery elements. The liquid desiccant is an expensive proposal to add.

- I think the project is going well but given the aspirations of the team, I would seek the full involvement of the stakeholders, and also, I would organize a quarterly review of the work progress by external experts.

- The current approach cannot be improved. It requires a fundamentally different approach which is basically a different project.

- The project needs to get a major manufacturer on board. I'm not sure if Haier intends to be the compressor manufacturer, but it would be good to have a U. S. based company in line to build this system. It would be unfortunate if U. S. research funds were used to support the development of this technology only to have a foreign company bring it to market.

- I recommend the team finds a tip of the spear opportunity to commercialize. They should focus on a couple narrow opportunities to commercialize, then make sure they are successful, with glowing end user reviews. Use that foothold to learn from mistakes and expand the market and introduce all the technologies under development in this project.

Emerging Technologies

HVAC, Water Heating, and Appliances

Appliances and Water Heating

Project #32226r: Ultrasonic Clothes Dryer (CRADA – GE)

Presenter: Viral K. Patel, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

The project clearly outlines a well-formulated and thought-out approach to develop an ultrasonic drying technology using piezoelectric elements that vibrate fabrics at high frequency to remove water, reviewers noted. One reviewer applauded the project's innovation, saying the utilization of the piezoelectric elements was a significant departure from incumbent technology that relies on evaporation of the water.

Unanimously, reviewers agreed this project could have a substantial impact and could revolutionize the clothes drying industry. Beyond dryers, this technology could be applied to desalination, heat exchangers and dehumidification, one reviewer noted. Again, all reviewers agreed the project staff had demonstrated strategic partnerships with manufacturers, particularly GE Appliances and Virginia Tech, through the cooperative research and development agreement (CRADA).

Of the remaining project work, reviewers commented that the project was on-track, with one reviewer recommending the team dedicate substantial resources to the design and evaluation of a dryer configuration that leads to the highest energy factor possible. As the project continues, another reviewer recommended dedicating resources to investigate the expected remaining moisture content from the proposed technology.

Weighted Average: 3.75 # of Reviewers: 3
Approach: 3.67 Impact: 4.00 Progress: 3.33 Collaboration/Coordination: 4.00 Remaining Work: 3.67

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed ultrasonic clothes dryer uses piezoelectric elements to de-wet fabrics at high frequency. By doing so, the latent heat of evaporation is bypassed. This results in a highly efficient clothes dryer system.
- Presenter clearly laid out the project timeline and goals. Utilization of the piezoelectric elements is a significant departure from incumbent technology relying on evaporation of the water. The energy savings potential is tremendous.
- The objective of the approach is to develop an ultrasonic drying technology using piezoelectric elements that vibrate fabrics at high frequency to remove water eliminating a phase change that normally occurs drying operation. This project, which is a CRADA with GE Appliances, builds on previous work done by ORNL on a mid-scale prototype ultrasonic clothes dryer.
- Specifically, an approach first is to fully understand the operation of the ultrasonic transducer through modeling couple with high-efficiency amplifier development. This work then will lead to a compact printed circuit board with ultrasonic modules. This will be followed by prototype fabrication and testing to determine the performance evaluate the improvement over conventional, state-of-the-art drying.
- The approach is well formulated and thought out.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **4.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The proposed system introduces a new approach to clothes drying industry. If successful, it is expected the new dryer system will be highly competitive in terms of energy consumption. It seems the proposed EF is conservative. The proposed EF is very close to heat pump clothes dryer systems. To my understanding, it is logical to expect a higher target EF from the proposed concept.
- This technology is a complete departure from incumbent technology which could revolutionize the clothes drying industry. This technology if successful has significant potential for energy reduction.
- This project has the potential revolutionize clothes drying, resulting in significant energy savings of 280 TBtu for all 2030 energy markets in all climatic zones. The presenters indicated that this may be applicable to desalination, heat exchangers and dehumidification (being pursued by another project).

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- The proposed CRADA project is built upon a previous mid-scale prototype ultrasonic clothes dryer. Considering the start date, it would have been helpful to see some activities on dryer form factor evaluation (Q6 deliverable) and full-scale dryer scoping (Q8 deliverable).
- The project is building on the success of previous projects, but has also clearly demonstrated progress towards further commercialization efforts.
- The project began on July 12, 2017 with an end date of July 12, 2020. Progress has included ultrasonic transducer modeling, amplifier development and initial fabrication of the experimental setup used to evaluate

the technology. It appears the project is on track with full dryer design done and parts ordered in 2019 and testing and final documentation of performance done in 2020.

D. Collaboration and Coordination

This project was rated **4.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant stakeholders.
- The project has obvious interest from manufacturers under a CRADA agreement.
- This project, since it is a CRADA, involves close collaboration with its industrial partner, GE Appliances and Virginia Tech.

E. Remaining Project Work

This project was rated **3.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining works are logically planned. To my understanding, your EF will be substantially affected by the dryer form factor. Therefore, it is suggested to dedicate substantial resources of the remaining work on the design and evaluation of a dryer configuration that leads to the highest EF possible.
- None.
- The project is on track with full dryer design done and parts ordered in 2019 and testing and final documentation of performance done in 2020.

F. Additional Comments and Recommendations

1. Project Strengths

- The proposed project offers a new ultrasonically driven dryer concept to bypass latent heat of evaporation.
- The project has an excellent collaboration with the relevant industry.
- The project takes a novel approach to clothes drying. It replaces an energy intensive incumbent technology with a new lower energy technology. The project has demonstrated great industry from industry collaborators.
- This is a strong team and the fact it is a CRADA involving GE Appliances could enable this technology to enter the market.

2. Project Weaknesses

- One aspect of the proposed concept that has been less considered is the expected drying degree with the proposed ultrasonic drying concept. As ultrasonic vibration proceeds, water trapped in large fabric pores is initially ejected. Then, at later drying stages, the remaining water is trapped in nano-scale pores where ultrasonic vibration might not be very efficient due to large surface tension forces. Theoretically, there might be some water trapped in small pore size that cannot be ejected by typical ultrasonic energy used during early drying stages. Therefore, it might be appropriate to dedicate some resources and investigate the expected remaining moisture content (RMC) from the proposed technology.

- The biggest weakness is that the project may be limited in application depending on the level of "dryness" the clothing needs. It may be limited to "pre-drying" the clothing and then still rely on existing technologies to fully dry the clothing.
- None.

3. Recommendations

- I would suggest dedicating substantial resources on the following items:
    - Optimizing the dryer form factor of an ultrasonically driven dryer for a maximum possible EF
    - Examining the remaining moisture content (RMC) at the end of ultrasonic drying, and investigating whether an additional thermal drying is needed (if the RMC is above 4%).
- None at this time.
- None.

Project #32226s: Max Tech Efficiency Electric HPWH with low-GWP Halogenated Refrigerant (A.O. Smith)

Presenter: Kashif Nawaz, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers gave their highest marks in this project to its approach, even though no other aspect of this project earned more suggestions for improvement from the reviewers than this one. While every reviewer expressed confidence in the approach's comprehensiveness and feasibility, one reviewer was not convinced that the team's heat exchanger design had the right form factor to effectively reduce the refrigerant charge limit. Instead, the reviewer suggested that the project team consider redesigning the condenser module and/or water-tank. Another reviewer recommended that the project team focus more on non-HFO refrigerants (R290 and R600) than A2L and A3 due to environmental concerns.

Despite these misgivings, every reviewer expected this project to have a significant impact on the energy performance of high-performance water heaters (HPWHs) and the diffusion of alternative refrigerants. Additionally, every reviewer remarked that the project team had made significant progress both on the modeling and experimental components of their project.

Reviewers did not express any concern about the project's remaining work, nor the team's strategic collaboration and coordination efforts. Several reviewers remarked that the project team had identified and included the key industry stakeholders, and that their work was being heavily cited in academic publications and conferences.

Weighted Average: 3.60 # of Reviewers: 3
Approach: 3.67 Impact: 3.33 Progress: 3.66 Collaboration/Coordination: 3.66 Remaining Work: 3.66

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The proposed project targets to optimize an already mature pump water heater (HPWH) system to address future industry needs. First, the project optimizes the HPWH for next-generation hydrofluoroolefins (HFO) refrigerants. Second, the project optimizes individual components and the overall system to maximize the performance.
- The project approach outlined is good.
- This project is focused on developing the next generation water heating technology using HFOs as alternate refrigerants to replace R134a. Since water heating accounts for 10% of all residential and commercial energy use this is an important effort as conventional refrigerants begin to be phased out. This project is addressing a gap since limited research has been done the use of alternate refrigerants in HPWHs.
- The technical approach will look at appropriate substitutes for R124a including R1234yf and R12234ze. It is anticipated that this approach would lead to small design modifications lead to a reduction in total refrigerant charge and performance improvement. This would include frost mitigation on the evaporator, oil management, smaller evaporator with an advanced external surface, new compression selection suitable for the new refrigerants and an improved condenser design to promote thermal stratification.
- Overall the approach is quite detailed and well thought out including feasibility, pre-commercialization and commercialization stages.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The current project advances existing HPWH systems. If successful, the project can facilitate deployment of A2L and A3refrigerants for HPWH systems. The proposed system also offers a substantial improvement in the energy efficiency of HPWH systems.
- Hot water heating is a large energy consumption overall. Thus, the technology has potential to significantly contribute to energy savings, with 250TBTU.
- The project, if successful, should lead to 1) an improved refrigeration technology, and 2) the ability to use A2L and A3 refrigerants. This work could also allow adaptation to other processes with a 250 TBtu projected energy savings.

C. Progress

Based on current project efforts, the project was rated **3.66** for the degree to which the project has met ***project-specific goals***.

- The team had made excellent progress towards achieving the project goals both on the modeling and experimental sides.
- Progress is on track with the stated project goals and timeline. Good summary results were shown for the modeling and testing.

- The project began on October 1, 2018, with an end date of October 1, 2021. The progress to date has been significant. It has included numerical modeling, followed by parametric analysis and experimentation. Given the short time since the start of the project, progress has been outstanding.

D. Collaboration and Coordination

This project was rated **3.66** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It appears that the team members have excellent strategic coordination with relevant stakeholders.
- The project team indicated they have had good collaboration with relevant technical committees with ASHRAE as well as presentation at multiple relevant conferences. Additionally, many key manufacturers, industry stakeholders, and SCE are engaged.
- The team, which includes ORNL and AO Smith, also has Rheem and Southern California Edison as key stakeholders. The stakeholders are engaged with the development of the technology, including refrigerant selection, developing the experimental test procedure, and frost formation and oil migration issues.
- Meetings are held at ASHRAE Meetings and a Purdue's conference. Also, information has disseminated through journal publications and targeted conference papers. Published papers have been frequently cited.

E. Remaining Project Work

This project was rated **3.66** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining works are well planned.
- Remaining work largely involves prototyping and testing, and key industry partner is outlined to assist in this respect.
- The remaining project work presented on Slide 22 is comprehensive and realistic for the two years remaining on the project.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths are:
    - Optimizing existing HPWH systems based on future industry needs
    - Optimizing HPWH systems for new HFO refrigerants
    - Reducing the refrigerant charge limit of the system
- The key strength of this project is that it has a high potential for energy savings. Additionally, it has the benefit of utilizing lower GWP refrigerants and should help with the adoption of those.
- The team is strong, there is a close collaboration with key stakeholders and a significant amount of information have been disseminated and published.

2. Project Weaknesses

- The typical design strategy to reduce the refrigerant charge limit is to use microchannel heat exchangers. An HPWH system uses a wrapped condenser heat exchanger which is not the best shape factor to be optimized for a reduced charge limit. Therefore, it is not clear the strategy that is being taken to reduce the charge limit.
- I would prefer to see more focus on R290 and R600 as the HFO refrigerants do have some environmental concerns. Another weakness is a higher GWP and potential safety issues with combustion byproducts.
- None.

3. Recommendations

- I would suggest dedicating additional resources on re-design of the condenser module and/or water-tank form factor for a reduced refrigerant charge limit. Reducing the refrigerant charge in the evaporator module by utilizing a microchannel heat exchanger is less complicated. However, offering a reliable solution that optimizes refrigerant charge limit, thermal stratification, and energy efficiency can have a positive impact on the HPWH industry.
- I would put additional focus on R290.
- None.

Project #31250: A Natural Gas-Driven Highly Efficient Thermo-Vacuum Clothes Dryer

Presenter: Kashif Nawaz, Oak Ridge National Laboratory
DOE Manager: Antonio Bouza

Brief Summary of Reviewer Comments

Reviewers found the project's aim to develop a new commercial scale dryer using a natural gas boiler and an ejector technology a promising approach and a good concept. One reviewer questioned the practicality of using ejector technology in commercial locations, with the associated challenges of size and noise, and recommended an implementation plan to address these challenges.

Reviewers were split on the value of the project's impact, with some commenting that, if successful, the technology could greatly contribute to DOE objectives and have an impact beyond the commercial clothes drying market. Half of the reviewers, however, expressed concern regarding technology adoption. Up to this point, the project has progressed well, with promising preliminary data and technical feasibility making the project worthy of continuation, reviewers found. One reviewer cautioned the project team may encounter challenges in field deployment.

Although the project is in its early stages, reviewers were pleased with the linkages made with potential stakeholders, adopters, and manufacturers. The reviewers recommended that the project team include more industry experts and add experts to study potential structural and safety issues.

Overall, the reviewers were pleased with the remaining project work and acknowledged the future phases will be the most challenging, and therefore PIs should allot more time to those activities accordingly. The reviewers highlighted the project's sound technical concepts that could readily be adopted if successful.

However, market acceptability is one of the noted project weaknesses. Two other notes of caution moving forward were made: one reviewer recommended purchasing components that are already commercially available, and another reviewer questioned if the project team is adequately considering the impact of the 12 pound-force per square inch (psi) vacuum on a large container. To address some of these challenges, reviewers recommended defining specific market requirements for large-scale deployment of commercial drying systems, and leveraging the expertise of a dryer manufacturer to determine if this design is functional, manufacturable, and cost-competitive.

Weighted Average: 3.40   # of Reviewers: 4
Approach: 3.50   Impact: 3.00   Progress: 3.75   Collaboration/Coordination: 3.50   Remaining Work: 3.25

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project aims to develop a new commercial scale dryer using natural a gas boiler coupled to an ejector technology. The rationale is that the ejector allows for high temperature steam-air mixing which increases drying efficiency, claimed to be 8-10X more efficient that conventional, reducing both energy and drying time from conventional processes. The proposed unit also has heat recovery units which can be used for heating water for washing processes, resulting in an overall system improvement.
- The few drawbacks observed relate to the practicality of using ejector technology in commercial locations, and the challenges of size, and noise associated with these intentions. Further, the separation process of steam/air is not well defined. PIs should present to DOE an implementation plan to address these possible challenges.
- Interesting project approach. Vacuum ejectors are widely used and the team will not have any problem incorporating it into their dryer. The technology is robust and can proceed along once some key assumptions in the project are validated.
- I did not fully understand the results presented on page 11. Are they calculation or experimental? How were they obtained? If calculated, are there published date to corroborate or validate them?
- This is a promising approach, and worthwhile fully exploring its potential.
- Good concept, good partners, and good choice of a non-moving parts vacuum source. Still some challenges to overcome, but certainly a feasible concept.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project is likely to contribute to DOE goals of energy efficiency goals of 45% by 2030 in building components including appliance. This will depend on the acceptability of the market to adopt the proposed system, including new and retrofit installations.
- If proven, the technology can go beyond the clothes drying market. In fact, an early market for it might be in other areas such as pharma (capsule drying, for example).
- If this project is successful it could greatly contribute to DOE objectives.
- I am not sure that people identify their clothes drier as a major energy consumer, so I am not optimistic that many people would pay more for a more energy efficient drier. Given the pressures at which this system will operate, I fear it may be very heavy, and consequently somewhat expensive.

C. Progress

Based on current project efforts, the project was rated **3.75** for the degree to which the project has met ***project-specific goals***.

- The team has made excellent progress on the project since starting by mid-2018, completing successfully Phase I of the project and, so far, well into Phase II. However, challenges may result in the field deployment, and PIs should anticipate those.

- The team has moved along in the phase 1 of the project, reviewed the state of the art in dryer technology, market potential, market players, and has conducted the preliminary research as described in its plans.
- I did not understand the assumptions made to arrive at the values listed on page 7 of the presentation.
- Preliminary data are promising.
- Progress to date has shown technical feasibility of the concept and the major components to make it worthy of further continuation.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team is making excellent linkages with potential stakeholders including potential adopters and manufacturers. It is recommended that these interactions remain as the project progresses and adapt according to their feedback.
- It is too early in the project to see the results of contributions with the stated stakeholders. Coordination with external collaborators are indicated but not specified, perhaps because the project is about 6 months old.
- Project team could be enhanced with inclusion of additional experts to study potential structural and safety issues with implementation of this vacuum-based drying approach.
- Good team at ORNL but would like to see more industrial involvement at this early stage of development. Project team seems to have tasks well planned and coordinated.

E. Remaining Project Work

This project was rated **3.25** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The team appears to have accomplished the goals set for Phase I and are well underway to accomplish Phase II goals. However, these next phases (II & III) are likely be the most challenging ones. PIs should build time cushion as well as mitigating plans to anticipate these challenges of system performance, and customers acceptability.
- Future plans are clearly laid out, with fabrication of sub-components being the next in line. When possible, it is best to purchase rather than fabricate components, and it seems that a significant number of components are commercially available.
- There is still significant work to be done such using multi-staging ejectors, analysis of drum mechanical stability, safety, noise, etc.
- I fear that the team is underestimating the impact of having 12 psi vacuum on a large container. That translates to about 1700 pounds of force per square foot of surface area and is not something that can be achieved with conventional sheet metal or fiberglass tubs. If the seal is lost, the drying effect will be greatly diminished with no obvious reason why.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths are:
  - The simplicity of the solution to achieve higher drying performance without adding moving parts.
  - The use of well-known technology such as thermal ejector.
  - The experience and technical depth of the team.
- The team is technically strong, and the project seems very likely to succeed.
- If the energy saving, water saving, and the fast drying (low temperature) propositions are demonstrated, especially for commercial drying, the technology could readily be adapted.
- The project benefits from a sound concept.
- This is an innovative concept that would be quite energy efficient if all practical design and cost issues can be successfully resolved.

2. Project Weaknesses

- The major weakness is anticipation of possible road-blocks for market acceptability. While the team appears to be interacting with stakeholders, the feedback does not seem to be impacting the development process. This is clearly evidenced in addressing noise issues in the workplace and design for these requirements.
- Too early to point out any weaknesses. I am not certain about the stated water-saving proposition, but I think these will be sorted out in due course.
- There isn't a particular weakness.
- I fear that the structural requirements to ensure tight vacuum conditions and be able to withstand the pressure forces on the container will make the system too bulky and heavy for it to compete with the lightweight conventional driers.

3. Recommendations

- The team should define far more clear specific market requirements for large scale deployment of commercial drying systems; size, noise, functionalities, and eventually cost. What is the market willing to accept? and for the design/development process to take these requirements into consideration. This was not clear from the review.
- The components of the proposed systems have been available, so I wonder if the team has determined why this system has not been developed earlier and if it has been, why it has not reached the market.
- Markets other than clothes drying should be looked into especially given the fast low-temperature features of the proposed system.
- Tackle some of the critical implementation questions early.
- Get a drier manufacturer involved with the preliminary design concepts to make sure the first working design is manufacturable and could be somewhat cost competitive. If the final version can't be sold, there is little reason to demonstrate the performance of an impractical prototype.

Emerging Technologies

Windows and Building Envelope

Project #236907: Electrochromic Auto-Darkening Windows

Presenter: Prasanna Chandrasekhar, Ashwin-Ushas Corporation
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewers acknowledged that the project overcame some barriers to transferring the methodology used to darken sunglasses to windows. Reviewers also noted a number of technical obstacles the project still needs to overcome. Although the data shown indicated electrochromic cycling durability greater than 1 million cycles and also acceptable temperature and physical stress durability, reviewers cited challenges related to durability including problems related to all-plastic construction issues associated with visible transmission; whether glare reduction would be adequate; high solar heat gain coefficient (SHGC) in the dark state; and infrared (IR) blocking.

Some reviewers stated that the project demonstrated the methodology is feasible, but one felt SHCG performance would be poor. Besides the challenges noted above, one reviewer highlighted transparency as another issue to be resolved. Two reviewers expressed concern about whether a retrofit market will be available. One reviewer noted that the project concept appears to be cost effective and useful for after-market applications. Additionally, this reviewer thought the concept might be applicable to glare reduction on skylights or the non-vision parts of windows. Another reviewer also highlighted the cheaper manufacturing process, while a separate reviewer commented that the project is quite promising with a clear potential impact.

Four of the reviewers judged that the project has progressed towards its project goals. One reviewer commented that applying the methodology to larger size windows would not be feasible due to expenses related to resolving grid lines, although another reviewer stated they had no concerns about grid lines. Reviewers generally felt the project's collaborative efforts are good, but one reviewer felt the project had not obtained clear guidance from industry partners concerning glazing requirements.

Although some reviewers felt the project has some potential for achieving its goals, the number and nature of the challenges as described above affected the score for remaining project work. One reviewer felt it was unclear if the project methodology would translate to sufficient production capability or be feasible. Another reviewer felt that enhancements to the product would be required such that no cost savings would be achieved; product quality would be suboptimal as well.

Weighted Average: 2.70   # of Reviewers: 5
Approach: 2.60   Impact: 2.80   Progress: 3.00   Collaboration/Coordination: 3.00   Remaining Work: 2.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The switching speed is fast, assuming that the conductive lines at 15 cm are acceptable. This should be assessed. Also, the window is too dark in the bleached state, if the dark state is to provide privacy. For glare reduction purposes the dynamic range might be acceptable.
- Good to build off of baseline experience.
- See below for overall comment.
- Successful sunglasses technology was transferred for window use. The few pivots in Ag deposition have only brought the cost down and has the potential to make the gridlines thinner and more aesthetically pleasing.
- Possibility of low power is good. Faster switching is OK but not a factor in energy saving. Energy saving performance of this technology will not be great. SHGC in dark state will be high since films don't attenuate near infrared. Can't claim to provide privacy due to significant visible transmission in dark state. Can't block glare. Should not base project viability on perceived lower production costs. Key factors on production cost are throughput and yield, which can't be determined at this point. All plastic construction with no moisture barriers looks like a long-term durability problem.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project has demonstrated it is feasible to deposit grid structures necessary for the concept to succeed. Depositing indium tin oxide (ITO) over the lines seems to be the best approach. Demonstration of market acceptability remains.
- I am concerned about the assumption of a retrofit market without knowledge of a power source.
- Price is an order of magnitude cheaper than competitors (would have liked to see numbers in spreadsheet to verify). This could lead to this product being adopted more widely than other products of this type. Retrofits could enhance product adoption.
- Looks like sunglasses for windows. Won't meet energy saving objectives due to poor SHGC performance, particularly if this is just a retrofit film with no low-e.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- The project has demonstrated it is feasible to deposit grid structures necessary for the concept to succeed. Depositing ITO over the lines seems to be the best approach. Demonstration of market acceptability remains.
- Progress appears to be solid for timing and results.
- Project completed, just needs commercialization partners.
- One of the goals was to get to larger sizes. This was met with aesthetically unappealing grid lines. To make grid lines near invisible, they will have to be much closer together and much more expensive.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- There appears to be no clear influence or guidance from the industry partners concerning glazing requirements.
- Good to see glass and window manufacturers involved.
- Collaboration with industry partners in early stage discussions.
- Good automation and prospective windows partners.

E. Remaining Project Work

This project was rated **2.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining goals seem realistic to achieve.
- Unclear on production capability or feasibility.
- This approach will not be useful for energy saving unless combined with low-e and some kind of conduction barrier. By the time this is incorporated into a quality window there will be no significant cost savings and the performance will still be sub-optimal.

F. Additional Comments and Recommendations

1. Project Strengths

- The concept appears to be cost efficient and useful for after-market applications. If adhered films remain stable over time under ambient conditions (ultraviolet (UV), heat, humidity), the concept might be applicable to glare reduction on skylights or the non-vision parts of windows.
- Based on current technology and success.
- This is quite a promising project, which builds upon an already marketed technology. The potential impact of the project is clear: low cost electrochromic windows. The team has a lot of experience in the field, having developed the same technology for the sunglass industry. The technology is already ATMS-tested, hence there are few concerns regarding its durability. So, overall, I do not see any major issues with the project, which is worthy and should be continued. I have a couple of suggestions, though. The reviewers expressed concern about grid lines (too thick/too dense), IR blocking, UV degradation and poor transmittance. In my opinion, the most urgent task is to find a way of blocking IR. The presenter has thorough knowledge of the field (he is the author of a couple of textbooks on conducting polymers). Therefore, it is likely that he and his team will find a solution. However, I emphasize that a solution must be found, otherwise we will get sunglasses but not windows. The second major issue (in my opinion) is transparency. Seventy-five percent light transmission in the "clear" state may be too low; tinted glass often has acceptance issues. The grids are, in my opinion, a non-issue. There are many ways of making them invisible. Same for UV degradations. I know the field of conducting polymers, I am not overly concerned about UV. One thing that should be addressed, though, is cycling at high temperatures. Dopant loss may become an issue under those conditions.
- Building off of successful technology. Met all Phase 1 goals. Cheaper manufacturing process. Retrofit product.

- Faster switching, which is a marginal benefit. The product has low power usage.

2. Project Weaknesses

- Market acceptability of conductive lines. Dynamic range. Possible durability issues.
- No involvement of homebuilders or installers. How the product will be integrated into the power needs of the building or home should be considered.
- No solid industry partners demonstrated yet (lots of potentials).
- Poor SHGC in dark state. Organic technology with little or no moisture barriers. Need many gridlines for large panes.

3. Recommendations

- Survey potential customers concerning aesthetics and dynamic range. Conduct durability tests for window applications. Develop a full implementation (application to windows) cost analysis.
- The project should add specialists such as electricians, builders, and specialists in electronics.
- Secure stakeholders soon through the use of field demonstration projects.
- Not a good film retrofit technology. It would be best to combine the approach with high performance insulating glass, although even clear state transmission may be attenuated.

Project #237405: Lightweight and Thermally Insulating Nanowood (SBIR)

Presenter: Amy Gong, Inventwood
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

The reviewers were divided on their opinions of the project approach. Many reviewers expressed concerns about the project's ability to attain the very low thermal conductivity targets of this program. There are still many questions that need to be answered and it is unclear whether the presented approach will lead to the proposed outcomes. However, some reviewers praised the project and stated that the group is working to develop an insulating material with high mechanical strength, which could allow reducing thermal bridging through structural materials. If all claims are true regarding strength and insulation value, it was touted as a potentially exciting new product.

Reviewers also provided mixed opinions of the project's impact. Many reviewers highlighted the project's potential for reducing thermal bridging and possible appeal in the market as a "green" product. While it may ultimately be a niche product, it does have the potential to be a new building material with unique properties compared to standard building materials. However, one reviewer pointed out that the project could contribute to the program goals if it were to be successful, but the success of this project, as presented, is uncertain.

Overall, most reviewers agreed that the project has made significant progress, but additional efforts are needed to reach the target thermal conductivity. The team has demonstrated progress in hydrophobicity coatings, improvement in mechanical performance, and improvement in thermal performance, but the thermal properties of the material must be verified by an independent party. One reviewer critiqued the team and by emphasizing that if the goal was to achieve very low thermal conductivity, they should have spent more time on that part of the project.

Many reviewers praised the project's collaboration and coordination, particularly their work with potential customers of the product. This project is engaging stakeholders, but not necessarily building insulation stakeholders, so one reviewer suggested taking advantage of the structural properties of the material and using it for window frames, door frames, and other structural components that need to be better insulating. Another reviewer commented that it was not clear from the presentation how the various members of the team were interacting.

Multiple reviewers noted that the project seems on-track, with remaining work focusing on continued process development and exploration of manufacturing processes and market opportunities. One reviewer recommended the project team get third-party verification of both thermal properties and mechanical strength.

Many reviewers agreed that the concept is interesting with unique material properties. Multiple reviewers commented on the strength of having low-cost and wood-based coatings that are both structural and highly insulating. Different applications for the project were noted, including new construction, retrofits, flowing and window framing. One reviewer found that the use of natural wood could be viewed as both a strength and weakness of the project, depending on carbon intensity and environmental impact of treating the wood, and the balance of wood harvesting and planting new trees.

Weighted Average: 2.54   # of Reviewers: 7
Approach: 2.57   Impact: 2.43   Progress: 2.71   Collaboration/Coordination: 2.43   Remaining Work: 2.57

Program Response

Reviewer feedback was critical of the potential to achieve the thermal conductivity goals within the stated project timeline. The project team also acknowledged that the original thermal conductivity target was overly aggressive and hence relaxed that requirement during the course of the project (new target: 0.012 W/m-K). Moving forward, this project was selected for a Phase II SBIR funding award and as a result, the project timeline will be extended to help achieve new goals.

A. Approach

This project was rated **2.57** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is a Phase I SBIR project and there are still many questions that need to be answered. However, there is some promise that the team will produce some insights on how this insulation product would fit.
- There was limited discussion of their approach to achieving the thermal conductivity targets. The testing method was not described.
- It is not clear how they plan to increase strength and decrease thermal conductivity.
- Most of the focus was on processing.
- The project team is making good progress for this one-year SBIR project. The testing of thermal and strength properties for the nanowood materials has been performed and showed good potential. The main issue is that the current thermal conductivity value is significantly higher than the targeted value of 0.01 W/m-K.
- It is unclear whether the presented approach will lead to the proposed outcomes.
- The group is working to develop an insulating material with high mechanical strength, which could allow reducing thermal bridging through structural materials.
- The project approach will aim to solve challenges related to material fabrication, mechanical properties, material decomposition, hydrophilicity, and flammability.
- If all claims are true regarding strength and insulation value, it seems like a potentially exciting new product.
- The basic process to de-lignify the wood is already demonstrated. Their approaches to fine tune chemistry and protect the wood form ultraviolet and water seem reasonable and doable. It is unclear if this will in fact attain the very low thermal conductivities necessary for R-12/inch or greater insulation.
- If there is some way to expand the wood (as opposed to non-compression or compression), it may attain the very low thermal conductivity targets of this program.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.43** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Assuming that the team's claim of an R-5/inch (or greater) product can be met, products with similar thermal performance already exists. Polyisocyanurate board, that currently is manufacture in large scale, for example, delivers R-6/inch. There are, however, specific applications of an insulating wood product that could be of interest and could have a great impact. The use of such product in wood framing of windows could significantly reduce thermal bridging. If the process could be used in studs with acceptable structural performance, it would also reduce thermal bridging from the framing.
- It has the potential to be a new building material with unique properties compared to standard building materials. The best application may not necessarily be determined at this stage.
- There are some questions about sustainability. It is unclear whether the end product is more raw material intensive than wood.

- The proposed nanowood material would be potential low-cost and a somewhat "green" material for building envelope applications including outer coating for walls. However, the need for applying some chemicals to enhance its properties as fire and water vapor retarders as well as to ensure its performance is not affected by high humidity levels put the claim of "green" materials in doubt.
- The project could contribute to the program goals if it were to be successful, but the success of this project, as presented, is uncertain.
- It is not entirely clear what problems this project is solving – the team should really focus on applications where the mechanical properties of the material are a key advantage, such as framing and siding, where the material could reduce thermal bridging.
- The material could function as a sustainable, environmentally friendly insulation material, assuming the source wood can be sustainably harvested at scale.
- While it may ultimate be a niche product, it does seem to have some real market potential.
- The reviewer likes this project. Creating a strong, lightweight, and thermally-insulating material out of wood is very appealing. However, it’s not clear that this will reach the program’s goals for insulation materials. This material doesn’t appear to be insulating enough to reach the program’s R-12/inch + goals. Insulation materials are not load-bearing and so mechanical strength is not important. Combining mechanical strength and thermal resistivity is certainly important for other applications though. They mention that this could potentially be used as a structural material, however it is not clear whether heat infiltration through structural materials is significant. Furthermore, if they were doing structural materials, they should be aiming for different dimensions other than 1 m x 1 m panels (i.e., they should be making long and narrow samples that resemble 2 x 4 beams).
- This project is achieving important impacts that are not necessarily captured in the programmatic goals (i.e., use of natural, renewable, and green materials like wood).

C. Progress

Based on current project efforts, the project was rated **2.71** for the degree to which the project has met ***project-specific goals***.

- The de-lignification process was developed.
- Hydrophobic surface treatments are important for exposure to water.
- Impregnation treatments were developed.
- The product is much stronger than natural wood.
- The thermal conductivity values are very low.
- They changed the deliverable of the panel size to a smaller length.
- The initial results are promising. They still need a 3x reduction in thermal conductivity to reach their target. It is unclear whether they will make this. It seems like there may be applications for this material based on its strength alone. Thermal conductivity may not ultimately be that important for commercial success.
- Overall, the project team did make a significant progress for the amount of time (less than 1 year) including some testing analysis. Additional efforts are needed, however, to reach the target thermal performance. The

team needs to also evaluate the ultimate cost for producing this material to be competitive to other conventional alternatives.

- Significant progress has been made to date.
- The team has demonstrated progress in hydrophobicity coatings, improvement in mechanical performance, and improvement in thermal performance.
- The team has completed some energy modeling, although more information would be needed to assess the assumptions in order to validate the quality of the model. For example, passive cooling was described, but it was not clear what the target application was, or whether it would be realistic.
- The team has some extremely preliminary cost modeling, but the model appears to be minimal.
- The project seems to be making good progress. However, all test results to date are from team member Professor Bao Yang. The thermal properties of the material must be verified by an independent party.
- The project has made some progress towards their goal. However, it seems they have not made nearly as much progress as they proposed. Furthermore, it seems that they spent a good deal of time focusing on material strength: weight ratio. If the goal was to increase very low thermally conductivity, they should have spent more time there. It does appear that they did start studies on non-pressed woods (Slide 9) and this achieved a significant decrease in thermal conductivity (which likely came with a tradeoff in strength, but as mentioned above, strength is not that important for insulation materials).

D. Collaboration and Coordination

This project was rated **2.43** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project team is primarily conducted by InventWood and University of Maryland. There is a collaboration with the U.S. Department of Agriculture and there have been contact with potential partners.
- Their stakeholder engagement is great. There is a surprising number of potential customers given the early development stage of this material
- While the testing of the product has made good progress, actual involvement of potential stakeholders is rather limited which may be expected at this stage of the project. However, some active involvement of potential users (including builders and contractors) for the product should be made in parallel with the development and refinement tasks to better assess the needs of the industry and the potential market.
- It was not clear from the presentation how the various members of the team were interacting. Since progress has been made, it seems appropriate to rate this question as good.
- The team has met with several different potential customers for the product, but it is unclear how extensive these discussions have been or whether significant product or manufacturing feedback was obtained.
- To date, it seems they have been focused on making the samples of the material. There are some potentially interesting commercialization partnerships to explore. One idea brainstormed after the session was really taking advantage of the structural properties of the material and using it for window frames, door frames, and other structural components that need to be better insulating.
- This project is engaging stakeholders, but not necessarily building insulation stakeholders. There is an excellent opportunity for this to have coupled applications, perhaps, where appearances and aesthetics are important (i.e., window frames and floors).

E. Remaining Project Work

This project was rated **2.57** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project work through June 30th, 2019 seems challenging to get complete.
- An important goal on scale-up was noted. This is probably most critical for this being a viable product.
- The steps on how they could get to their tensile strength and thermal conductivity goals is not clear. It would seem that they are not compatible: whatever steps (compaction?) increase strength would also likely lead to increased thermal conductivity.
- Significant challenges remain to be solved to achieve the target of the project including the thermal performance of the nanowood product. Moreover, the involvement and the input of potential users of the product should be accelerated to adjust the development of the product according to the industry needs and potentially find the niche market for the product.
- The project seems to be on track.
- The remaining work focuses on continued process development, exploration of manufacturing processes, and exploration of market opportunities.
- The project seems on target. However, it is important to get third-party verification of both thermal properties and mechanical strength.
- Given that this project is nearly over (i.e., they only have 2.5 months of their 1-year project left), it is highly unlikely that they will achieve all of their goals.

F. Additional Comments and Recommendations

1. Project Strengths

- The concept is interesting and introduces a new product based on wood.
- The low thermal conductivity wood could deliver excellent thermal performance to window frames, doors, and stud framing. There could be great potential to explore these.
- It is a unique material with quite different properties compared to untreated wood. They may find interesting applications in buildings.
- The material treatment process is relatively non-toxic.
- They are actively working to overcome material deficiencies (water absorption, ultraviolet damage).
- The main strength of the proposed project is the possibility to have low-cost and wood-based coatings to protect and insulate building envelopes. The application of the product can be suitable for both new constructions and retrofits.
- The idea of using wood under the nanotechnology concept for building insulation is a project strength.
- The potential for insulation in structural applications is a strength.
- It is potentially an interesting new insulation that is both structural and highly insulating. The fact that it is derived from natural wood can be viewed as both a strength and a weakness, depending on the carbon

intensity and environmental impact of treating the wood, and the balance of wood harvesting (deforestation) and planting new trees.

- The chief strength of this product is in applications where insulation needs to be combined with aesthetics (and to some extent mechanical strength). Applications for flooring and window frames make sense.

2. Project Weaknesses

- The team failed to back up the claimed thermal resistance of the product with actual data and how the data was collected.
- The team should focus on applications where there could be more suitable and tested products in the market.
- The thermal testing methodology was not clear. There were limited results presented on thermal conductivity.
- The approach to achieving mechanical strength and thermal conductivity goals was not clear. Much of the work focused on synthesis.
- Significant challenges are remaining to reach the targeted thermal properties as well as to find the niche market that can drive demand and further development for the product. The specific production and delivered costs for the materials are also not well defined and need to be clearly considered if commercialization of the product is sought.
- The team needs to find the technical solution to moisture transfer related issues.
- The sustainability issue of replenishing the harvested wood is a potential weakness.
- There is a lack of clear focus on specific market opportunities that take advantage of the differentiating aspects of the material. It does not outperform other insulation materials from a thermal standpoint, and it is difficult to see it competing on cost with continuous fabrication methodologies. The key distinguishing characteristics are mechanical strength and environmental impact.
- All test results to date are from team member Professor Bao Yang. The thermal properties of the material must be verified by an independent party. They need to ensure chemical treatments for fire retardant and moisture protection are environmentally benign.
- It is still early stage, but they need to prove that the product can be manufactured at a larger scale.
- The fact that the raw material is wood is both a strength and a weakness.
- This product does not seem to meet the goals for use as a pure insulation material.

3. Recommendations

- The team should consider applications where there is a great fitness for use of the product. Wood framing of windows, doors, studs, etc. are possible applications.
- The team should include extensive testing of the apparent thermal conductivity of the product in documentation.
- The project team should consider comparing the thermal conductivity results for strong white wood to natural wood (as was done for mechanical properties).
- The team should accelerate the engagement of potential stakeholders (users) of the product to find the required properties and costs to make it competitive.

- The long-term performance of the product should be tested to better quantify weather impacts.
- A better estimate of the production and delivery costs of the product should be determined.
- The team should look deeper into the moisture issue. If moisture enters the wood, the potential for a high R value fades.
- They should focus on applications that require mechanical strength, particularly related to thermal bridging (such as window frames).
- They should consider getting a 3rd party lab to test performance.
- As initial markets, the team should think about where the structural integrity of the material can be viewed as an asset. So rather than thinking about it as a foam board replacement, they should consider the following applications: 1) window and door frames; 2) insulating structural components of buildings (typically where, say, ladders, balconies, or other exterior components are attached, which can lead to thermal bridging. This material can potentially act to break the thermal bridge because it is insulating and structural); and 3) insulating boxes that must hold significant weight.
- If there is some way to expand the wood (as opposed to non-compression or compression), it may attain the very low thermal conductivity targets of this program.
- The reviewer likes this project. However, it does not seem to directly impact building energy use as a pure insulation material. It would be interesting as a window frame material and perhaps may be better suited to be funded in the windows program.

Project #31353-31352-31356: Solid State Tunable Thermal Energy Storage for Smart Building Envelopes

Presenters: Chris Dames and Roderick Jackson, Lawrence Berkeley National Laboratory & National Renewable Energy Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewers found the solid state tunable thermal energy storage (TES) project for smart building envelopes to be promising and commented that it was a well-conceived approach. Several reviewers commended the team for investigating numerous use cases, thermal storage media, and thermal switches as well as for the project's multi-scale modeling and systems analysis effort. Specifically, one reviewer stated that the chosen approach would help to mitigate risk and overcome technical barriers to the technology. Some challenges were mentioned with regards to integrating the switching method with the selected use-cases.

In general, reviewers applauded the potential impact of the project with four reviewers rating the area as "Outstanding." The reviewers highlighted the transformative nature of the project and remarked at the extent to which the project could save energy in both new and existing buildings. It was noted that the project also has applications outside of the building envelope in HVAC systems. However, one reviewer listed the main challenges that face the team moving forward and included controllability, durability, and cost of the phase change material (PCM) product.

The team's progress on the tunable TES building envelope project was well received by most reviewers with others concerned that the project was behind schedule. Reviewers indicated that the team was progressing on the following tasks: defining the scope of the project, identifying potential candidates for the solid-solid PCM, and modeling potential energy savings. One reviewer expressed concern about the added complexity to install and operate a building envelope system like the one proposed. They continued by stressing the importance of the long-term performance of the system and described it as one of the most important criteria for development.

In terms of the project's collaboration and coordination, reviewer comments were positive and complimentary to the large team that was formed across national laboratories. While the majority of reviewers noted that the stakeholder engagement was appropriate for this stage in the project, others suggested involving industry partners earlier than planned in order to receive feedback on cost, control, and other challenges.

Multiple reviewers noted there were few details provided about the remaining project work and consequently, it was difficult to accurately assess. Multiple reviewers commented that the project is novel, delving into unexplored research directions with the potential to open up new doors for the building energy field. A few reviewers called out the project as being high risk, though also noted it could be high reward if successful.

Weighted Average: 3.09   # of Reviewers: 6
Approach: 3.17   Impact: 3.50   Progress: 3.00   Collaboration/Coordination: 3.33   Remaining Work: 2.17

Program Response

The project team took note of reviewer feedback regarding the lack of details provided about the remaining project work and will better highlight and communicate this information in future project evaluations. The team will also consider stakeholder engagement in earlier project stages to receive key feedback to inform future project work.

A. Approach

This project was rated **3.17** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Tuning the transition temperature of PCMs is a novel idea that deserves support. The different options being considered by the team are impressive. While there are several details that were not presented, the metrology concept that can determine the thermal conductivity of insulation may lead to innovative methods to determine thermal performance.
- The approach to developing the variable thermal storage material is the most completely described. The methodology is robust, including a few different potential systems that could deliver the desired effect.
- The thermal switching goals are a little incongruent with the switching method selected (contact-no contact). A switch ratio of 2-5 should be easy with this approach; the challenge will be to integrate with the selected use case. I would think that contact-no contact within a building envelope application would be difficult, probably less so for an equipment integrated application.
- This project has two main parts: modeling analysis and applications (NREL) and technology development and testing (LBNL). Both parts of the project are well defined even though some challenges remain and need to be well identified and discussed.
- A well-conceived approach was presented. The approach was fully explained.
- This is a large project with a multidisciplinary team doing multiscale work. The project just started but there are a few things to consider: 1. The approach is not clear with respect to how all the multi-scale component are going to work together. Slide 3 and 17 just show expertise per area and all levels but they don't really show how everything is connected. Will the energy models drive the design and feed data into the lower scale (materials) and higher scale (grid) models? How are the PIs going to address the gaps between each scale or pass information from building level to material level? How will the models/data iterate? This is critical to be defined before any actual work happens. It seems strong on the bottom-up approach but the higher level seems to be lagging; 2. This approach seems to combine bottom up and top-down approaches that converges somewhere. Would it include optimization to find optimal properties and location in buildings?
- The project is incorporating multiple ways to achieve their goals. They are looking at three different thermal storage use cases, two different thermal storage media, and three different types of thermal switches. They are also doing multiscale modeling and systems analysis. This collection of approaches will mitigate risks and help them overcome technical barriers.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact of tunable PCMs is probably high if applied at ideal locations of the building. The team evaluated that it can increase energy savings by at least 5 times.
- Bringing these two technologies (thermal switching and tunable thermal storage) to fruition would have a major impact on how buildings are heated and cooled with a large effect on energy efficiency.
- If the tunable or switchable PCM product can be developed and controlled as outlined as part of the project goals, there are a wide range of applications for both building envelope systems and HVAC systems specific to new as well as existing buildings. The main challenges remain the controllability, durability, and cost of such tunable PCM products.

- Insulation of this nature would be transformative. The research project is well aligned with program goals.
- Combining thermal switches with tunable PCMs could unlocked great opportunities around (and beyond) buildings and this project could potentially provide that. DOE should continue funding this project.
- This project aims to create a dispatch-able thermal storage whose transition temperature can be actively tuned to appropriate temperatures depending on the time of year. This could definitely have an impact on reducing building energy consumption.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Solid-solid PCMs were identified as potential candidates. Concepts of contact/no contact systems are being considered. Metrology to determine thermal properties is proposed.
- They have done a good job so far defining the scope of the project and the impact on energy savings if successfully deployed.
- Overall, good progress has been made for both parts of the project (modeling and development of tunable PCMs) considering that the project started only about one year ago. However, some issues should be considered by the team in terms of the required properties and factors to be accounted for any commercial viability of this product. It adds significant complexity to install and "operate" building envelope systems, which typically last a significantly long period of time compared to other "systems" of the buildings including the electrical and mechanical systems. The long-term performance of these systems is one of the important criteria when developing this product.
- Based on material presented, significant progress has been made to date.
- The project started in October 2018 but the postdoc arrived around December/January. It seems 1-2 months behind schedule so not much work was shown. The team should really work on having all parts well-coordinated and having a clear idea how each model will feed into each other.
- This project is about 0.5 years into a 3-year project. They have just finished hiring their postdocs and in the meantime have accomplished some basic modeling and experimental data. This is a reasonable amount of progress.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This is a large collaboration between two national laboratories and several universities. While it lacks industrial partners at this point, the team covers several research areas of importance to make progress.
- This is a large team with varied expertise. The stakeholder engagement is fine for this stage of the project.
- Good collaboration between researchers at NREL and LBNL has been shown through the specific division of the project into modeling of the applications (NREL) and the development of the tunable PCMs (LBNL). The involvement of industry partners should be sought even at this early stage to provide better feedback about the challenges of such systems when considering costs and control requirements.

- This is a large team with many more members than "usual". However, collaboration and coordination seem to be going very well.
- Based on the interactions on the meeting, the team seems like it is well coordinated with frequent communication. However, the project has just started and probably still needs to figure out a few important parameters.
- This project is both very early stage research and also early in the project duration. It may be important to contact external stakeholders when they are closer to a prototype, but at this point in time it is not necessary.

E. Remaining Project Work

This project was rated **2.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The team did not detail the remaining project work, maybe because the project just started.
- Very little is provided on the specific next steps of the project
- There is a large sub-team dedicated to modeling. There was minimal detail on the form or the model(s) that will be used to drive progress on the project.
- While the progress and expected results have been outlined in the presentation, the remaining tasks are not clearly discussed especially related to the challenges of tunable PCMs (including costs, control needs, durability, maintenance requirements, and long-term performance), some the risks of the project, and any mitigation solutions.
- A rating of fair was given because a timeline is missing.
- The project just started with postdocs arriving later, so at this point it is hard to assess if they will finish on time or not. The team has strong/active members so it has the potential to deliver.
- Few details were given about the remaining project work, the corresponding timeline, and the go/no-go milestones. Consequently, it is difficult to accurately assess this aspect.

F. Additional Comments and Recommendations

1. Project Strengths

- The strengths include 1) comprehensive team collaboration, 2) disruptive concepts that are expected to generate new ideas, and 3) can the concept be a thermal storage and an electrical storage at the same time? If so, it is very novel.
- The strengths include 1) a strong team; 2) well-conceived plan on the tunable thermal storage side of the project; and 3) the impact of this project was well-documented and described.
- The main strength of the project is the potential development of the tunable PCMs and its application to shape the thermal load profile of buildings and its application to both new constructions and retrofits. The installation cost and the long-term performance remain the main risks of such technology.
- The strengths include the expertise, the team, and the methodology that has been put in place.
- It is a strong multi-disciplinary team.
- It is a multi-scale team that covers most of relevant scales.

- Combining thermal switches with tunable PCM could unlocked great opportunities.
- Nice bottom-up/top-down combined approach.
- This team is exploring several unexplored high risk/high reward research directions, solid-solid phase transitions, actively tunable transition temperatures in phase change materials, thermal switches, etc. This has the potential to open up new doors for the building energy field.
- This reviewer is particularly excited by the team's exploration of actively tunable transition temperatures in phase change materials. The phase change material field has traditionally had difficulty gaining traction because of its underutilization (i.e., as the investigators point out on Slide 5, the phase change material is inactive during most of the year). The ability to change the phase change temperature to appropriate set points throughout the year fundamentally changes the game and creates much better thermal storage opportunities in buildings.
- The project team has a wide array of expertise ranging from deep fundamentals to utility-scale power. This will serve them well in exploring this research direction.

2. Project Weaknesses

- It is a risky project; even if a tunable PCM is developed, the impact may be smaller than expected.
- PCM segregation needs to be resolved in solid-solid choice of PCM.
- Details of the measuring of thermal properties is unclear.
- High-throughput metrology seems a bit tangential. Justification could be better for how this will be used. It doesn't seem applicable to thermal storage materials. A contact-no contact thermal switch would need to be measure at this level of detail.
- The specific approach is minimally described. It is hard to gauge how well this large team is organized around the various tasks.
- Modeling task is fairly nebulous.
- The weakness is the lack of clear discussion of remaining work and especially the challenges of the technology in order to be adopted by the building industry. The tasks for both the modeling and the testing parts could be expanded in more details.
- No timeline was presented.
- The approach needs to be improved with clear steps about how data will flow between levels and team members. Presentation mostly focused on material level, so the team needs to clearly show how all levels will be connected.
- It is unclear how they are going to select the best properties. The team should also connect with ORNL's effort analyzing active systems.
- It's not clear why thermal switching and thermal storage needs to be directly integrated into the building envelope. There seem to be other simpler ways of achieving this goal. The investigators seem to be aware of this too. On Slide 17, they discuss a case 2, "equipment integrated storage," and a case 3, "stand alone storage."
- Integrating into the building envelope would have many weaknesses:

- Thermal switching can be achieved by opening and closing doors, window shades, and windows themselves. Why is this not good enough?
- The thermal switching in the walls is largely necessitated by the need to control the charging/discharging of the thermal storage in the walls (i.e., so that they discharge during peak hours and charge during non-peak hours). Why must the thermal storage be integrated into the walls? Why shouldn't the thermal storage be done as a stand-alone unit (e.g., an insulated box full of phase change material)?
- If the thermal storage were done as a stand-alone unit, controlling the heat flow into and out of the thermal storage unit would be much easier to accomplish (i.e., essentially turning on/off air flow through the thermal storage unit). This would allow you to easily charge and discharge the thermal storage at optimal times.
- Furthermore, integrating this technology into the building envelope seems to be high risk. The building envelope is very long-lived (perhaps 30-50 years). Consequently, one would also want these systems integrated into the building envelope to be similarly long-lived. This is because any necessary repairs would likely be require opening up the walls and therefore be intrusive and expensive. I am not convinced that these dynamic systems would have a life span of sufficient length.

3. Recommendations

- They should consider alternative concepts to develop.
- None.
- Clearly show the modeling assumptions for tunable PCMs and tools used to assess the proof-of-concept, especially when applied to building envelope systems (type of buildings and loads considered, control rules for each wall, response time of the PCMs, and others).
- The team should discuss the potential cost of the tunable PCMs that are being tested and the testing plan for durability (long-term performance) especially when integrated into building envelope systems exposed to various weather elements.
- The team should identify the challenges and the potential mitigation solutions in various steps of the technology development and testing as well as modeling.
- They should involve industry representatives (especially in PCMs) to have better feedback about the product requirements in terms of costs and performance.
- The presentation concentrated on space cooling load only. What are the expectation for space heating? Information on south facing and east facing walls was provided; west facing wall is also very important.
- They should work on the following questions: How will the project define what properties the materials scientists should try to obtain? How will this be connected to building and grid level results?
- DOE should continue focusing on this. Next year's review should have results to show progress done with a clear approach.
- This project makes more sense as an equipment integrated application or a stand-alone option. An envelope integration option creates unnecessary challenges.

Project #31355: Dynamic Phononic Metamaterial (DPM) for Building Envelopes

Presenter: Ralph Muehleisen, Argonne National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

The reviewers had a variety of perspectives on the project as several reviewers commented positively on the new approach for fabricating building envelope material. While the approach was considered intriguing and well-established by two reviewers, a third reviewer expressed doubts about the experimental realization of the project's simulations. The approach was also described as risky, but the reviewer followed up and mentioned that the project was appropriately scheduled for only one year. Another reviewer noted that the principal investigators are still uncertain how to accurately measure thermal conductivity for small samples. This was stated multiple times by reviewers as a potential concern as the project progresses.

Most of the reviewers were in consensus as to the potential impact of the new building envelope material. Several reviewers remarked that if the project accomplished its goals, it would result in a transformative material that would have a significant impact on energy usage. It is important to note that a few reviewers were skeptical about whether the project team could successfully reach the targeted R-value.

The reviewers were pleased with the project's progress especially with regards to modeling. Two of the five reviewers expressed their hope to see further results. With regards to collaboration, one reviewer approved of the team's internal composition of experts, while several of the other reviewers emphasized the room for improvement with stakeholder engagement as the project moves forward.

Given the early stage of the research, reviewers were concerned whether the team would be able to fabricate a sample material in the remainder of the project term. As previously mentioned, two reviewers reiterated the issue of successfully measuring the low thermal conductivity of a sample.

Weighted Average: 2.95   # of Reviewers: 5
Approach: 3.00   Impact: 3.20   Progress: 3.00   Collaboration/Coordination: 3.00   Remaining Work: 2.40

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is an intriguing approach to increase thermal resistance of a new material.
- The modeling approach seems good for this exploratory research. There are some questions about whether the models capture all of the necessary physics to realize the thermal conductivity decrease. It looks like they are adding parts that may be missing.
- The proposed manufacturing approach is extremely ambitious. It’s hard to believe that they can achieve the quoted throughput rates. It will impact cost estimates. They need to better justify cost projections.
- This is a well-established approach. The explanation was clear. The presentation and slides make the concept easier to understand.
- This is a very risky project but 1-year limits the risk. The approach is okay for 1-year project but it is vital that at the end of the project, the PIs can produce material with substantial lower thermal conductivity.
- Principal investigators still don't know how to accurately measure low thermal conductivity values for small samples.
- The investigators will likely be able to simulate a material with their targeted low thermal conductivity. However, these simulations will likely assume perfect periodicity in the 10’s of nanometer length scale. Any true experimental realization of what their simulations say will be extremely difficult and will likely fail.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- This is a high-risk project with unclear properties of the insulation developed. The impact may be large or small depending on the insulation that gets produced.
- An insulation material with R-28/in would have a huge impact on energy usage. There is insufficient justification that they can get to this high on an R-value, but it is still early in the project.
- The impact would also be affected by whether they can hit their cost targets or not. It’s unlikely without the 3-D printing speed increase mentioned during the presentation.
- If the proposed insulation were to be developed and produced, it would be a transformative technology, which would result in a high impact because the outcome is well-aligned with program goals.
- This is a high impact, high risk project. If successful, it could be a game changer.
- If the project specific goals are met, this would lead to new thermal insulation with very high R-values. This would help the program reach its energy reduction goals.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals.***

- A literature review was performed. The project is new and the modeling is being developed.

- Some progress has been made on modeling. I would like to see more results as this is only currently funded for a year.

- Based on proposed Project Plan and Schedule and what was presented, the progress is outstanding.

- Principal investigators have validated the model with other well-known data but need to finish this. It is vital that at the end project, they have a sample.

- The project is about halfway through a 1-year timeline. In this time period, they have hired a postdoc and begun some basis simulations on bulk PMMA using molecular dynamics. They have also done some basic COMSOL simulations as well that show band gaps in the ~200 GHz range. This is decent progress for six months, however, this is also the easiest part of the project.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It is early stage and there is not much collaboration external to the team. The team assembled involves several organizations and research areas.

- The stakeholder engagement is okay for what is an early stage / low technology readiness level project.

- It's an excellent team of experts. They seem to be able to work together very well.

- It seems that this multi-disciplinary project is working fine but it's not clear how all the moving pieces are working together.

- They are assembling a technical advisory group and have talked to some early stage R&D investors as well as had intellectual property discussions.

E. Remaining Project Work

This project was rated **2.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals*.**

- FEM should deliver results fast. The fabrication of a sample using photon printing is the challenge.

- It's not clear why there is a different design target for the FEM simulation (R28/in) compared to the LAMMPS simulation (R14/in). It's unclear whether the LAMMPS simulation contains additional physics that reduce the R-value.

- The fabrication portion of the remaining work will be key. It's unclear whether they can deliver that material and the target thermal conductivity at the cost and processing time consistent with their cost estimate.

- The Project Plan and Schedule presented seem outdated (FY2013 - FY2014) and nothing is proposed past the 3rd quarter of FY 2013.

- It is hard to know if the principal investigators would be able to achieve the goal and also figure out a way to measure the low thermal conductivity.

- The end goal is to simulate some designs with $k < 0.005$ W/m-K using FEM and $k < 0.01$ W/m-K using molecular dynamics. Finally, they will fabricate something with an 80% reduction in k relative to bulk. Assuming a $k = 0.2$ W/m-K, this would be a $k < 0.04$ W/m-K.

- Assuming they can scale up their additive manufacturing approach 10 million-fold as they say their partner can, they will likely manage to create something with a low thermal conductivity. However, I suspect they won't have a thermal conductivity much lower than any other highly porous polymeric material.

F. Additional Comments and Recommendations

1. Project Strengths

- This is a bold project with high risk. The project has extensive collaboration.
- They claim to be able to leverage a 3-D printing breakthrough to produce a nano-printed material with extremely high R-value at reasonable cost.
- A project strength is that this project uses a two-method simulation approach with iterative design coupled to the FEM simulations.
- One project strength is their expertise.
- This is a very innovative and high impact project. This is right at the metric where DOE wants to be with respect to low thermal conductivity and low cost.
- They have a strong multidisciplinary team with a technology committee.
- The strength of this project is that it attempts to use new fundamental science (wave interference) that has not been attempted before in the building insulation community.

2. Project Weaknesses

- The project weakness is the uncertainty about target apparent thermal conductivity. Also, the material characterization may be challenging for the small samples produced.
- There is very little evidence provided to justify the bold claims made on R-value and cost.
- There was some carelessness in putting a timeline together.
- They have no idea on how to measure low thermal conductivity.
- It's very risky. It is vital to have a sample before Stage 2 is approved.
- The weakness of this project is the extreme difficulty of realizing wave interference for phonons that transport heat at room temperature. I believe that the investigators can realize their targeted low thermal conductivities in the simulation environment, however for them to achieve this in reality will require 2 simultaneous miracles: 1. They need to increase the speed of additive manufacturing by a factor of 10 million-fold. They do claim that their investigating partner can achieve this and so I will take them at their word for this; and 2. They need to achieve additive manufacturing at the 10's of nanometer length scale with extreme precision. To truly obtain wave interference, they must have near perfect periodicity at this very small length scale. The investigators mentioned achieving 20 nm pores. While this might be the right length scale, it's unclear whether they can achieve this with high precision. It's also unclear whether the resulting pores will be 20 nm +/- 0.5 nm (i.e., 2.5% precision) or 20 nm +/- 5 nm (i.e., 25% precision). If this is in fact 20 nm +/- 5 nm, which is the likely the case, then they will not achieve a phononic metamaterial (i.e., won't have wave interference effects) and it will not be any different than other similarly porous material. In the end, I suspect they have a nanoporous material made via additive manufacturing that will have similar thermal conductivities to nanoporous materials made via other simpler manufacturing means.

- If they really can get 20 nm +/- 0.5 nm precision additive manufacturing at a 10 million-fold faster rate than present technology, it would be absolutely amazing. That technology would have applications in building insulation and many, many, many other applications.

3. Recommendations

- They should consider producing a sample large enough so it can be tested for thermal conductivity.
- No recommendations.
- Conducting simulations in conditions other than a controlled laboratory setting should be considered. The concept may work differently under full weather conditions.
- They should define what the next step would be with respect to test small samples and get accurate results. It is critical to have a sample, which achieves the target goals.
- The authors will likely be able to simulate materials with their target metrics. However, an experimental realization down the road will be extremely difficult. For me, the most important thing to see for further funding is whether or not their manufacturing process can achieve the speed they are targeting (10 million times faster), length scale they are targeting (10s of nm), and precision they need (i.e., 20 nm +/- 0.5 nm).

Project #236884: Adaptive Weather Resistant Barrier for Building Envelopes to Control Moisture Ingression and Increase Energy Efficiency

Presenter: Joseph Trentacost, EA Membranes
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

The project approach to develop an adaptive weather resistant barrier to control moisture levels in building envelopes was generally well-received. Reviewers appreciated the team's project design and remarked on the project's progression from small-scale to building-scale demonstration. One reviewer agreed with the team's decision to pause their technical research to focus on the economics and market potential of the technology. However, a different reviewer expressed concern about the safety of the membranes as they may short circuit if punctured, but the reviewer continued by noting that the team was accounting for this in the design.

With regards to the project impact, comments varied as some reviewers disagreed on the project's potential to contribute to DOE goals. Several reviewers found the membranes to be an interesting product idea that could extend the life of highly insulating building envelopes. On the other hand, some reviewers noted that the project would not directly reduce energy usage, but instead, it would address the embodied energy in a building. One of these reviewers stressed that the project would add value to buildings and suggested that DOE determine how to quantify the benefits of decreasing embodied energy. In addition, a reviewer described the solution for shedding absorbed water as "unnecessarily complex" and proposed applying the technology to other applications.

While reviewers were complimentary of the project's current progress, they emphasized the importance of the building-scale prototype and validating market interest. A couple of reviewers questioned whether the team would finish the remaining work in the allotted time. In addition, the team's collaboration and coordination were highlighted by the majority of reviewers as areas of strength for the project. These reviewers applauded the team's work with Oak Ridge National Laboratory and the partnering private companies. However, one reviewer recommended additional commercialization support that could assist the project team in identifying other applications for the technology.

Weighted Average: 2.92 # of Reviewers: 5
Approach: 3.00 Impact: 2.40 Progress: 3.00 Collaboration/Coordination: 3.20 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach is the development of robust thermal envelopes that involves managing moisture flow. This project may lead to a tunable vapor permeance of a weather resistant barrier. The project started at Dupont and continued development outside.
- The design and testing approach is good.
- They have had good progression from small scale to building scale demonstration.
- This is a good, sound approach. It may solve some problems. The membranes could still be easily damaged.
- It's a simple idea and project, but it's nicely done. It might go over budget but the principal investigator seems to have additional funds. They also seem to be putting the technical side on standby after finishing the first stage and taking a hard look at the economics and market share. This sounds like a good idea.
- There are safety concerns in using 500-1,000 volts to switch these membranes and so this creates concerns about hazards to building occupants and potential short circuiting (i.e., penetration with a nail). However, the principal investigators appear to be taking these considerations into their design plans.
- They are also conducting analyses on manufacturing and cost.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.40** for the degree to which the project is ***expected to*** contribute to ***program goal(s)*.**

- While not directly influencing thermal flow, for durability purposes, moisture flow is critical. The product developed by this research can enable the use of highly insulated assemblies.
- It is an interesting product / idea, but it seems like there are better ways to shed absorbed water. It seems unnecessarily complex. It might make more sense for other applications.
- The proposed design would contribute to program goals. Market share could be key.
- Moisture control is critical for sustainable envelopes (with/out GIB). Having a dynamic WRB makes it even more attractive and impactful, especially with all the other tunable technologies that might increase moisture issues. Having a technology like this could have potentially synergies with other tunable materials.
- The technology also seems very simple to control and principal investigators are working on addressing the cost issues.
- This adaptive weather resistant barrier would certainly add value to buildings, however, this value is not adequately captured in the program's goals (i.e., reduce energy per square foot of building by 45% relative to 2010). This project will not reduce the operational energy consumption of buildings.
- However, this project could certainly prolong the life of buildings and decrease building repair/maintenance costs. In this sense, it addresses the "embodied energy" of buildings (i.e., the energy that goes into creating the building materials, transporting them to the site location, and creating the building itself). As buildings become more and more efficient, the fraction of embodied energy in a building will only increase because 1) operational energy consumption will go down; and 2) creating an energy-efficient building generally adds capital costs to the building and consequently increases embodied energy.

- Based on this important, but largely non-quantified embodied energy, this project may or may not be integral to reaching BTO's goals. However, how to quantify and address embodied energy needs to be determined first.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals.***

- The main progress was on the WUFI simulations and the testing of the small-scale membrane.
- The experimental results look promising. Their progress on building-scale prototype is impressive.
- They have had excellent progress to date.
- Nice progress done although it seems to be 1-2 months delayed. However, major technology milestones have been successfully passed.
- This project is nearly over. They have completed about 10.5 months of a 12-month project. They have demonstrated a reasonable amount of progress and developed a prototype system.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- EA Membranes collaborates with Oak Ridge National Laboratory (ORNL) and Dow Dupont.
- The collaboration team is sufficient for this stage of the project.
- They could use more commercialization support (potentially to identify other, more promising applications).
- There is excellent collaboration between the parties involved.
- It looks like ORNL and PIs are coordinating efforts and the numerical results support the lab work.
- The investigators themselves are a company and they are also working with Dow, Dupont, and other companies. In addition, they are in consultation with ORNL. They are engaging the right entities.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- A lot of work is needed in the next two years to scale the concept.
- The work on a building scale prototype is important.
- Validating the market interest (next steps) will be critical.
- A well-detailed plan to complete the project was presented.
- The project has about 1.5 months left and still has to test new 4 ft. x 8 ft. panels. This process might take longer than the 1.5 months but other than that everything is okay.

- This project is nearly over. They only have about 1.5 months left on a 1-year project. They do appear able to finish their goals. They appear to have already built a 4 ft. x 8 ft. prototype and so that is all that remains to test.

F. Additional Comments and Recommendations

1. Project Strengths

- This is a novel concept. Dynamic moisture permeance would be of interest.
- It is an innovative approach to create an active building material.
- There has been logical development steps and good progress demonstrating effectiveness of the mechanism.
- A project strength is the expertise of the team members.
- The team members know the limitations of the proposed technology.
- It is a nice simple technology that could improve moisture control in buildings.
- It nicely fits into GEB technologies and could even have synergies with many of the tunable technologies.
- It has the potential to become cost-effective, although current options are pretty cheap.
- This seems to be an interesting product that can potentially prolong building life and reduce maintenance and repair costs to buildings. This would ultimately improve the “embodied energy costs” of the building.

2. Project Weaknesses

- The cost of the product may be excessive.
- There are difficult control parameters that need to be identified.
- The product may only be needed in specific climates, limiting its impact.
- It is unclear whether building vapor barriers are the most appropriate application for this technology.
- There are concerns about high voltage potentials around moisture (currently being address in the project).
- There are concerns about failure mode (fail open vs. fail closed) of the device and cascading failures for different sections of a building exterior.
- The technology would still be vulnerable to being easily damaged during installation.
- It still needs to be seen if it can deliver proper performance in the 4 ft. x 8 ft. sample.
- The following is a technical problem: residual polarization (the PIs are already aware of this).
- There is concern about the large voltages that this would need to employ. This leads to occupancy safety hazards. Failure mechanisms such as stray nails, etc. can also cause the system to fail. The investigators do seem to be aware of these hazards and are working to mitigate them.

3. Recommendations

- Using a passive system to control open/close of the pores should be considered.
- An evaluation of costs in detail should be considered.

- Alternative ideas for making the concept work should be considered.
- Reducing the complexity of the project should also be considered.
- If possible, testing prototypes under different climates should be considered.
- If more funding will be available for another 1–2 years, durability and/or field tests and cost analysis should be considered.
- The primary investigators should consider where in the U.S. the technology makes more sense to use.
- Analysis of what kind of "embodied energy" costs this project could save would be helpful in evaluating the energy benefits of this project. This could better demonstrate the value of this project with respect to DOE goals.

Project #EE0008223: Development of R-12/in Isocyanurate-based Super Insulation at Atmospheric Pressure

Presenter: Jan Kosny, Fraunhofer CSE
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Overall, reviewers approved of the approach to analyze production costs paired with efforts to increase the R-value of nanoporous polyisocyanurate (PIR), while aiming to both reduce the cost and improve the long-term performance of foam insulation. The freeze-drying approach to making insulation should be able to yield their target nanoporous material morphology. Most reviewers agreed that this is a very well-established approach.

Reviewers generally agreed that, if successful, the results of this project could lead to significant improvements in energy efficiency and industry adoption. This project seems like a good path to making a better foam board and new insulation materials such as this will be critical to reducing building energy use. One reviewer pointed out that this material is not as exotic as some of the other materials which have been presented in this review, but this is a good thing because it means that the time-to-market can be much quicker in this case.

Most reviewers highlighted that the project has so far achieved an R-value as high as R-10/inch. Significant progress has been made to date, even though it is still lower than the project target of R-12/inch. One reviewer praised the project team for developing and running a cost model to estimate economic feasibility, showing cost-competitiveness with current poly-iso insulation, and demonstrating scalable manufacturing processes with successful freeze-drying.

All reviewers praised the project team for their great collaboration, particularly with manufacturers from industry. There are additional key team members from the research community, academia, and industry, and there is good collaboration between the members of the project team, which is impressive considering that various institutions are involved and that the principal investigator has been recently changed. One reviewer was impressed with the collaboration to produce potential commercialization pathways and great intel on actual costs at-scale, while another reviewer praised the team's close work with companies to conduct their techno-economic analysis.

Many reviewers expressed concern about whether they will be able to get to R-12/inch by the time the project is completed. It is unclear whether the project team will be able to achieve the targeted R-value level for the insulating samples and test their long-term performance without significantly affecting the production costs. Other reviewers agreed that the remaining work will meet the project-specific goals, stating that it appropriately focuses on continued optimization of material synthesis and processing, it can be completed within the established time frame, and it seems much closer to market than some of the other projects.

Weighted Average: 3.33 # of Reviewers: 6
Approach: 3.33 Impact: 3.33 Progress: 3.33 Collaboration/Coordination: 3.67 Remaining Work: 2.83

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- It is a thorough analysis of production costs paired with efforts to increase the R-value of nanoporous polyisocyanurate (PIR).
- They were unable to provide details on processing specifics (due to confidentiality), but results look promising.
- Overall, the development, testing, and manufacturing tasks for the PIR nano-foam samples are well defined and demonstrated through the reported results. Some of the challenges such as achieving the R-value of 12 per inch as well as the cost reduction may still need to be addressed.
- It is a very well-established approach. The team is known for their expertise in this area.
- This project aims to improve the performance of existing insulation, using chemistry that is well-known by industry.
- The project aims to both reduce the cost and improve the long-term performance of foam insulation.
- Eliminating blowing agents would yield a variety of environmental benefits.
- This approach seems very grounded in a solution that is possible today both from a feasibility and cost perspective.
- The freeze-drying approach to making insulation should be able to yield their target nanoporous material morphology. They are also doing a careful techno-economic analysis to assess whether the somewhat slow and expensive freeze-drying process can maintain affordability targets.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- It shows strong potential for producing a high R-value insulation at industrial scale. A widely-deployed, high R-value insulation would have significant impact on energy efficiency
- If successful, the proposed products can provide inexpensive insulation options for new and existing building envelope systems to make them cost-effective measures to improve energy efficiency and reduce peak demand of the building stocks.
- The project is well-aligned with Program goals. In addition, the participation of industry partners is key for market acceptance of a successful technology.
- The insulation being developed lends itself to easy industry adoption, while increasing thermal resistance at a reduced cost.
- It seems like a good path to making a better foam board.
- New insulation materials such as this will be critical to reducing building energy use. This material is not as exotic as some of the other materials, which have been presented in this review, but this is a good thing. It means that the time-to-market can be much quicker in this case.

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals.***

- They have developed quite detailed production cost estimates.
- They have produced samples with an R-value as high as R-10/inch.
- Despite the change in the principal investigator, significant progress has been demonstrated so far with good thermal performance of the prototypes (even though it is still lower than the project target of R-12/inch) with competitive production costs.
- Significant progress has been made to date.
- The team developed and ran a cost model to estimate economic feasibility, showing cost-competitiveness with current poly-iso insulation.
- The team characterized the thermal performance and demonstrated the potential for R10/inch.
- The team demonstrated scalable manufacturing processes with successful freeze-drying.
- The project has made a lot of progress showing manufacturability and cost effectiveness. The samples seem to at best be R-10/inch, and many are below that. Even at R-6 – 8/inch, this could be a useful technology, but there is still some work to get to R-12/inch.
- This project is about 75% complete based on duration (i.e., about 6 months left on a 2-year project). They have already achieved about 2-3 inch diameter pucks with R/inch of approximately 10, which is commendable.

D. Collaboration and Coordination

This project was rated **3.67** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- They have met with a number of manufacturers of foam insulation and are in a pilot line production process.
- Despite the fact that various institutions are involved and that the principal investigator has been recently changed, there is a good collaboration between the members of the project team. Moreover, the industrial partners are regularly involved and consulted.
- The team has key members from the research community, academia, and industry. The team seems to work well together.
- The team is well-coordinated with manufacturers of materials and suppliers of processing technology.
- There is excellent collaboration with potential commercialization pathways and great intel on actual costs at scale (the fact that they were able to get those large-scale cost savings speaks to the quality of their collaboration and relationships).
- They are in talks with a wide variety of global companies and presenting in conferences and meetings. They also worked closely with companies to conduct their techno-economic analysis. This techno-economic analysis is highly important since freeze drying is a relatively slow and expensive process.

E. Remaining Project Work

This project was rated **2.83** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- The future work is a bit open-ended. It sounds like they have tried a number of approaches to get to R-10/in. It is unclear whether they are able to get to R-12/in.
- The remaining project work was described in some details, but it is unclear whether the project team will be able to achieve the targeted R-value level for the insulating samples and test their long-term performance without significantly affecting the production costs.
- Because it seems that significant work has been made to date, the remaining work could be completed within the established time frame. The team is highly likely to produce what was proposed.
- The remaining work appropriately focuses on continued optimization of material synthesis and processing.
- They have made good progress on manufacturability and cost, but are still far from the R-12/inch goal.
- There still seems to be a large variety of knobs to turn for optimization of the product in terms of R-value and other important peripheral properties. The researchers have some amount of time (but not a ton of time) to explore this space. Importantly, this project seems much closer to market than some of the other projects in this review meeting, and so engaging companies will be important. They appear to be doing so.

F. Additional Comments and Recommendations

1. Project Strengths

- There is strong emphasis on manufacturability (at scale) and cost.
- The approach builds off of commonly used insulation technology (PIR).
- The project has followed a systematic analysis and testing approaches and has shown promising performance results to date.
- Industrial participation is a project strength.
- The emphasis on materials and manufacturing approaches that are familiar to industry eases the adoption potential for manufacturers with existing expertise and supply chains.
- This project hits a number of high notes: a higher R-value, a lower cost, manufacturability, eliminating the blowing agent and solvent recycling.
- This project is a refinement on PIR materials that are already widely used in the field. Consequently, it has the potential for very near-term market adoption.

2. Project Weaknesses

- Unable to share many of the details about their technical approach to increasing R-value is a project weakness.
- The main weakness (in addition to the potential impact of the change in the principal investigator) is the lack of a clear path to achieve the targeted thermal performance with the desired low cost.
- The upcoming change in leadership is a project weakness.

- The freeze-drying process is a batch process, which despite being a common method, may be challenging for large scale manufacturing.
- While the insulation materials offer improvement on existing materials, it is not clear that the ceiling is very high, offering minimal room for further improvement.
- They are not yet showing any results over R-10/inch (though at the right cost, even R-6 – 8/inch could be able to be commercialized).
- They are still using poly-iso, so while environmental concerns about blowing agents are eliminated, there may still be other environmental concerns.
- The reviewer thinks freeze drying would be a slow and expensive process for creating building insulation materials. However, the reviewer is not an expert on manufacturing or techno-economics and so could be wrong here. The investigators appear to have done their homework here and think it can work.

3. Recommendations

- No recommendations.
- The approach for the future steps and tasks to improve the thermal performance of the PIR nano-foam prototypes should be clearly defined.
- The risks involved in the remaining tasks and any potential mitigation solutions should be identified.
- A clear plan should be created for the industry involved to pursue the development and the commercialization of the products.
- Concentrating on keeping manufacturing costs low is recommended.
- No recommendations.
- Given the clear path to manufacturability, the project team should focus on making "better poly-iso" even if they do not achieve R-12/inch. By eliminating the blowing agent and getting up to R-6 – 8/inch, this is still a product that can potentially be commercialized.
- Engaging companies and transitioning this work to them is very important at this stage in the project. The investigators appear to be doing so.

Project #313110: Stationary Concentrator Daylighting System

Presenter: Chris Gladden, Glint Photonics
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

In general, the reviewers approved of the project approach and recognized that the team has done well in identifying the relevant risks. The team anticipated possible difficulties and has sound plans to overcome them. Two reviewers expressed concerns about developing a prototype that can last more than ten years of operation, since the concentrators are made of acrylic materials.

Overall, the reviewers agreed that the project will reduce energy use and lighting costs. However, two reviewers recognized that there are some major barriers to adoption. A building owner would have to buy this system in addition to a traditional lighting system since it does not produce light at night and this could be a significant hindrance to market adoption.

Most of the reviewers agreed that the project is showing good progress, despite some minor delays. This project is about 2.5 years into a 3.5-year timeline and many of the key risks were mitigated. One reviewer described the progress, stating that an integrated motor platform was developed, the panel sealing process was created, which survived thermal cycling, and the tests of the panel at nine different incidence angles and five different temperatures were satisfactory.

The reviewers generally praised the project's collaboration and coordination, particularly with lighting designers and industry experts. The feedback from industry was incorporated into design iterations. All the steps required major coordination from team members, and it seems as though all are working fine.

Overall, the reviewers agreed that the remaining project work is appropriate for this stage in the project. Their plan for the remaining period of time is reasonable and the data from field installation will be invaluable. However, one reviewer highlighted that the principal investigator did not provide a plan to catch up or ask for an extension, but building interface and operational demonstration are still not finished.

Weighted Average: 3.33 # of Reviewers: 5
Approach: 3.60 Impact: 3.20 Progress: 3.00 Collaboration/Coordination: 3.40 Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will use the feedback provided by reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Concentrating solar light can save energy. Sunlight is collected and focused between the two lenses, which are made of acrylic.
- Sun tracking is critical for success.
- The team recognizes the relevant risks.
- They have done well in the identification of key risks and mitigation strategies.
- It is a well-developed approach. It was explained very well. The team has anticipated possible difficulties and have sound plans to overcome them.
- The acrylic catadioptric optical system is well designed.
- It is a very good use of mirrors on floating coupler sheet.
- It is a solid approach but perhaps needs accelerated testing to see if it can last 10-30 years.
- The reviewer does not see any insurmountable hurdles for the development of a working prototype. The concentrators are made of acrylic materials, which brings up concerns about lifespan. However, the investigators claim they have an acrylic that is rated for 20 years of operation and this will be taken at their word.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)*.**

- The prospective cost of the system is small compared to other ones, but it is also more complex than the skylight in drywall shaft, delivering less peak lumens, while occupying less space.
- It is essentially a commercial building device, since it does not produce light at night.
- It has a clear impact on energy usage for lighting. It supplants electrically-derived lighting.
- The project is well-aligned with program daylighting goals to reduce energy use and costs in lighting systems.
- This technology has a huge potential to reduce lighting cost and energy use.
- The ability to use natural daylight for lighting inside of buildings has a significant potential to decrease lighting energy consumption. Obviously, it is way more effective to use the sun's light directly for light as opposed to something like turning light into electricity via a photovoltaic and then turning that electricity back into light via traditional lighting.
- The investigator's argument that increasing worker productivity is an effective way to reduce utility costs is a compelling one. If workers are more productive, you need less workers and therefore less building space. Moreover, the cost of a human worker far outweighs the energy costs associated with that worker.

- The reviewer is concerned about the total addressable market for this product since a building owner would have to buy this system in addition to a traditional lighting system (i.e., to provide lighting at night). This could be a major barrier to market adoption.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals.***

- An integrated motor platform was developed. The panel sealing process was created, which survived thermal cycling.
- Overall, the tests of the panel at nine different incidence angles and five different temperatures were satisfactory.
- The test results look promising.
- Many of the key risks were mitigated.
- The team has completed the proposed milestones, but there are some minor delays.
- The project is slightly delayed, as stated by the principal investigator, but, overall, it is a solid plan with solid progress. The panels have been tested under high and low temperatures with working control systems. The next step is actual field tests.
- This project is about 2.5 years into a 3.5 year timeline. They have achieved a reasonable amount of progress in that time period.

D. Collaboration and Coordination

This project was rated **3.40** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- They have engaged a few designers.
- The team does not include external partners.
- The feedback from industry was incorporated into design iterations.
- The collaboration and coordination are excellent.
- There has been extensive interaction with lighting designers and industry experts.
- All of the steps required major coordination from team members and it seems as though all are working fine.
- They have been talking with numerous light designers and industry experts. In turn, this engagement has provided a substantial amount of input (Slide 16). This is excellent collaboration and coordination.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- The remaining project work is consistent with the project stage.
- The remaining work is appropriate.

- The data from field installation will be invaluable.
- A project plan progress was presented that explained, in terms of percentage of completed work, where each stage is at. There seems to be an agreement that the team will complete the work that was proposed and in time.
- Principal investigator did not provide a plan to catch up or perhaps ask for extension. The key parts are building interface and operational demonstration, which are still not finished.
- This project has about 1 year left on a 3.5-year timeline. Their plan for the remaining period of time is reasonable.

F. Additional Comments and Recommendations

1. Project Strengths

- This is an interesting concept.
- There is an attractive trade-off with photovoltaic roofing panel in commercial buildings.
- There are alternative places to position the collector.
- It is a unique approach to daylighting.
- The size of building penetration is reduced relative to other daylighting technologies.
- It provides higher quality light and no electrical energy cost.
- The knowledge and expertise of the team members is a strength.
- Their planning is also a strength.
- This is a cost-effective technology, with exceptional performance compared to competition.
- The system has done environmental testing and the performance was still good after thermal testing.
- The use of natural daylight for lighting and the ability to guide this light deep (i.e., 30 meters) into the building is very appealing. The fact that this concentrator naturally filters out infrared and ultraviolet is also a selling point (i.e., visible light without the heat).

2. Project Weaknesses

- Active tracking is a risk.
- Challenging market acceptance could be a weakness.
- None.
- None.
- The durability needs to be addressed with additional cyclic testing under extreme conditions.
- The actual performance should be tested in an actual building to assess actual savings and performance.
- One major problem for this product is that it cannot replace traditional lighting systems. Building operators would still need to have a traditional lighting system because this system is not useful during nighttime and/or

early morning hours. Building lighting needs to be operational 24 hours/day, 7 days/week, and not just 9 a.m. – 5 p.m. (and during winter, many places do not even have sunlight during that entire time period).

- Consequently, a building owner needs to buy a traditional lighting system AND this daylight delivery system. This is a major barrier to adoption. It is uncertain whether this system will be worth it from a cost and/or energy savings standpoint. This could be a major selling point hurdle down the road.

3. Recommendations

- Working with grow-houses should be considered. They use a lot of energy and they need sunlight.
- A contact with daylighting experts at National Renewable Energy Laboratory (NREL) should be considered.
- The team should consider creating an advisory board to help with the project.
- None.
- The project should concentrate on bringing the product to market.
- The project team should add durability tests with accelerated testing to see how it behaves under ultraviolet and high/low temperatures. The principal investigator has done some but it needs longer duration/cycling.
- The principal investigator should consider marketing and determine how and what markets they are targeting. This needs more work.
- None.

Project #313108-313111: Robust Super Insulation at a Competitive Price

Presenter: Sumanjeet Kaur, Lawrence Berkeley National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Overall, the reviewers approved of this approach to deliver an insulating material at a low cost with a decreased thermal conductivity. The material design approach, which aims to develop insulation with thermal properties like aerogels, while avoiding the requirement for supercritical drying, is based on a strong theoretical framework and would significantly reduce costs. Reviewers emphasized that a better understanding of the interfacial heat transport of nanoparticles or in nanocomposites as it applies to building insulation systems would be beneficial. They also noted that risk mitigation strategies did not appear to be discussed.

Many reviewers agreed that the biggest remaining challenge for this project is reaching the R-value target (R-12/in) with acceptable production costs. Most reviewers also praised the project's potential impact and stated that significant gains in thermal insulation performance will reduce energy use in buildings in large scale and it is possible that the new insulation could replace a part of the share of the current building insulation market. Using the properties of two solids in contact and tuning them to yield better performance than either material on its own is a good concept and if the approach works, it would enable much lower cost insulation materials with properties like aerogel.

Reviewers agreed that the team has made good progress with reducing the thermal conductivity to R-9/inch, despite facing several setbacks. It is exciting to have both a rigid and flexible material already manufactured, but as one reviewer pointed out, this project was sidetracked/delayed by the difficulty in measuring small sample sizes with high R-values. Another reviewer highlighted that significant challenges remain and are not clearly outlined to reach the targets set for the project in terms of R-value and cost.

Many reviewers praised the project's collaboration and coordination, particularly their work with the industry advisory board. The project seems to have good industry partners, but it is unclear whether there are partners to manufacture the product. One reviewer expressed concern that the project team has obtained adequate input from relevant industry representatives (i.e., insulation companies) throughout the project.

In general, reviewers agreed that the remaining work will focus on improving the thermal conductivity from R-10/inch to the target of R-12/inch. The remaining work seems on track, with a good combination of ideas to pursue higher R/inch values toward R-12, and they have a variety of parameters they can vary to try and reach this target in the remaining eight months of the project. One reviewer highly recommended a more detailed description of the remaining project challenges as well as of the production costs expected for the material.

Weighted Average: 3.20   # of Reviewers: 7
Approach: 3.43   Impact: 3.14   Progress: 3.14   Collaboration/Coordination: 3.00   Remaining Work: 3.14

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.43** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project is aiming at R-12/inch. The approach is to make changes to insulating material to decrease its apparent thermal conductivity. The approach is to increase solid volume fraction, manipulating thermal transport in solids and avoiding wet chemistries.
- Weak interfaces may lead to lower thermal conductivities (lower diameter leads to lower thermal conductivity).
- The material design approach is based on a strong theoretical framework.
- There is a clear focus on reducing cost.
- Overall, the used methodology is well documented and consider fundamental principles to develop low-cost but high insulating materials. The use of the new Lawrence Berkeley National Laboratory set-up to measure R-value of small samples is particularly useful and valuable.
- The approach of designing an insulation product with a high solid volume fraction in which the thermal transport could be manipulated, while avoiding wet chemistries seems appropriate and doable at low scales. It is possible that the thermal conductivity in nanocomposites could be manipulated as a function of interfacial bonding, but at the expense of mechanical properties, which may be secondary for the proposed technology. A better understanding of the interfacial heat transport of nanoparticles or in nanocomposites as it applies to building insulation systems would be beneficial.
- The project aims to develop insulation with thermal properties like aerogels, while avoiding the requirement for supercritical drying, which would significantly reduce the cost.
- The approach is to achieve high R values using acoustic mismatch, relying on three parameters: particle size, acoustic mismatch, and surface energy.
- The approach uses silane chemistry, which is a heavily used (non-exotic) industrial chemistry.
- It is a practical approach to delivering a highly insulating material. It could potentially overcome issues with vacuum insulated panels (VIPs).
- This project leverages fundamental knowledge from the nanoscale heat transfer community (i.e., phonon scattering and interfacial thermal resistance) to engineer the heat transfer in the solid component of insulation materials (i.e., as opposed to engineering higher pore fractions and/or attempting to achieve vacuum in pores). Achieving this will be very useful.
- Risk mitigation strategies did not appear to be discussed, however this project is very near the end stage of their project timeline and so this may not be critical.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.14** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- Significant gains in thermal insulation performance will reduce energy use in buildings in large scale.
- The impact of high R-value insulation on energy efficiency is clear.

- While the project has approached its last few months, several challenges remain including reaching the R-value target (R-12/in) with acceptable production costs. There is no effort throughout the presentation to discuss the expected production costs of the proposed materials. Moreover, there is a lack of the involvement of insulation industry representatives in the project (even in the industry advisory board) to provide some valuable feedback about the technology and the potential adjustments needed to make it commercially viable.
- If the technology is developed and it performs as expected or even close to expected and it is manufactured, it is possible that the new insulation could replace a part of the share of the current building insulation market.
- If the approach works, it would enable much lower cost insulation materials with properties like aerogel.
- Using the properties of two solids in contact and tuning them to yield better performance than either material on its own is a good concept. It has been used in other thin-films to good effect.
- Obtaining a very high R-value material clearly has strong alignment with the program goals. Even if this project does not necessarily obtain R-values during its three-year time period, the knowledge gained will expand the possibilities within the building insulation community. This is because the insulation community mainly focuses on increasing the pore volume and/or using vacuum. This project focuses on engineering the solid itself, which will be an integral part of any building insulation. Moreover, the lessons learned in this project are complementary to existing approaches to better insulation (i.e., it is possible to do all three approaches to building insulation (a) increase pore volume fraction, (b) use vacuum, AND (c) engineer the solid fraction).

C. Progress

Based on current project efforts, the project was rated **3.14** for the degree to which the project has met ***project-specific goals.***

- The team explored ways to measure the thermal performance of its insulation systems in collaboration with Oak Ridge National Laboratory (ORNL). There were challenges faced by the project with shifts in approach to deliver progress. The team has an approach to thermal metrology that, if successful, will deliver results in two minutes.
- The team is using silanes to reduce surface energy.
- Their current progress results include R-9/inch for rigid insulation and R-8.16/inch for flexible.
- They have made good progress on reducing the thermal conductivity of their material despite some setbacks around material characterization.
- They were able to demonstrate how progress on increasing R-value is related to theoretical predictions
- The progress made so far is commendable, especially to produce a sample with R-9/inch as well as to be able to test the thermal conductivity of small samples after a significant effort. However, significant challenges remain and are not clearly outlined to reach the targets set for the project in terms of R-value and cost.
- Their efforts to date, as presented, seem to be good despite a few setbacks that were encountered.
- The team has made significant progress producing materials and reducing the thermal conductivity to R-9/inch, which is similar to aerogels.
- The team has manufactured 2 in samples, and are in the process of scaling up to 5 in.
- The team has developed testing protocols for the high R materials.

- They had to overcome several challenges (hot plate, etc.), but it is exciting to have both a rigid and flexible material already manufactured.
- This project got highly sidetracked/delayed by the difficulty in measuring small sample sizes with high R-values (naturally the ORNL efforts to develop a standardized metrology for high R-value samples, project 31312e will help address this, but that project is still ongoing). It does appear that they overcame these hurdles and have already demonstrated an R-value of 9/in, which is notable.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team is working with some collaborators, but there is room for improving the list. It is unclear whether there are partners to actually manufacture the product.
- They have an industry advisory board to help with commercialization.
- While the collaboration is clear and solid between researchers in ORNL and Lawrence Berkeley National Laboratory, especially for testing the R-value of small samples, it is not clear that the team has the adequate input from relevant industry representatives (i.e., insulation companies) throughout the project. The involvement of the industry should be strengthened in the remaining period of the project.
- From what was presented, it seems that all participants and their organizations are working together as expected. An advisory board was constituted. The group is in talks with companies that will test the resulting products.
- The team has an industry advisory board with both commercial insulation manufacturers, insulation users, and thermal experts
- It seems to have good industry partners.
- They have engaged an industrial advisory board as well as begun talks with companies to provide them with samples. This is notable given that this is early stage project (low technology readiness level).

E. Remaining Project Work

This project was rated **3.14** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals*.**

- It is a good combination of ideas to pursue higher R/inch values towards 12.
- 5 in. x 5 in. is still not very large for thermal evaluation.
- They are continuing to push R-value higher through material optimization and have a number of potential strategies identified. This is well described, but a bit open-ended. It is unclear whether they will be able to get from R-9/in. to R-12/in.
- The tasks around scale-up are appropriate.
- The remaining tasks of the project are well outlined even though the challenges to complete these tasks are not well described. A more detailed description of these challenges as well as of the production costs expected for the material is highly recommended.
- The team seems to be on track to deliver what was proposed.

- The team will continue to optimize the fabrication process to get from R-10/in. to R-12/in.
- They need to do more stability, performance, and flammability testing.
- The flexible material especially needs more testing. But, it is close to R-10/in. already, which is impressive.
- The project has about eight months left on what is a 39-month project. They have already achieved an R/inch of nine and are targeting an R/inch of twelve. They have a variety of parameters they can vary to try and reach this in the remaining period of time.

F. Additional Comments and Recommendations

1. Project Strengths

- The presentation was very good and honest.
- The project shows significant promise of delivering very high R-value at decent cost.
- The creative ideas are being tested and considered.
- It is a very systematic approach to material design and improvement.
- It is a thorough synthesis and characterization approach.
- The main strength is that the project was able to develop rigid as well as flexible materials with relatively low thermal conductivity even though the expected production is not well defined. The R-value measurement set-up and its demonstration for this project is also a good contribution of this project.
- The team was constituted because they bring the necessary experience and resources.
- The possibility of developing a better understanding of heat transfer in nanoparticles that could be used in the building insulation field is a project strength.
- The achievement of a high R/inch material without supercritical drying or the low volume fractions associated with aerogels is a project strength.
- Successfully creating a material with close to R-10/inch in both rigid and flexible form is a project strength. It seems like a promising technology.
- The lessons learned in this project are also complementary and can be combined to existing approaches to get better insulation materials (i.e., increase pore volume fraction and/or attain vacuum in pores).
- This project is also complementary with the ORNL project on hollow silica particles (31312g). It would be very interesting to combine their hollow silica particles with the efforts in this project.

2. Project Weaknesses

- Working with an insulation manufacturer could prove useful. It is possible that this is already taking place.
- The small sample size makes it difficult to evaluate the actual thermal performance.
- Minimal justification of cost targets is a potential weakness. It is uncertain whether there were any updated cost estimates.
- The main weakness of the project is the lack of relevant industry representatives as advisory members of the team resulting in fuzzy estimation of the production costs of the technology.

- The fact that experimentally it may not be possible to achieve the R value proposed is a weakness.
- The primary goal of the project was to develop high R/inch at low cost, but no cost estimation was presented. There were two key objectives: aerogel-like thermal properties, and low-cost. The former has been demonstrated, but there was nothing presented regarding the latter.
- Silane is toxic. It is uncertain whether they can minimize or even eliminate its usage.
- They need to prove manufacturing can scale to large sample sizes (5 in x 5 in is next, but they need to be able to get much bigger than that, too).
- It is not clear to me what is holding the nanoparticles together into the 2-inch diameter puck (Slide 12) and the other samples they showed. It is unclear whether they are using some sort of binder. If the molecules shown on Slide 11 are covering the particles, then it should just be van der Waals forces holding the particles together, which should make the overall material very weak (i.e., it should crumble apart very easily). It is uncertain whether this would pose a problem for building construction and/or usability. Although insulation is non-load bearing, extreme mechanical weakness could still cause peripheral drawbacks elsewhere. It is a question best posed to a building construction company and/or a building materials company.
- The authors do address the mechanical stability question somewhat in Slide 13. However, this is mechanical data for compression, and is consequently misleading. It is possible that the material will perform much more poorly in tensile and/or shear stress.
- They do show in Slide 14 their attempts to make a “flexible” insulation through the incorporation of fibrous material. This fibrous material would introduce benefits for tension/bending and so could help address the potential mechanical weaknesses discussed above.

3. Recommendations

- Involving an insulation manufacturer should be considered.
- They should continue to work with partners on improving metrology.
- They should consider potential byproducts of the effort. They should look into whether any of the metrology techniques could be used in lower R-value/inch insulations.
- None.
- They should better define specific steps needed to reach the R-12/in target for the proposed insulating material.
- The industry advisory board should be strengthened by involving insulation industry representatives.
- The expected costs should be tackled more specifically for the technology relative to the existing insulation materials.
- After Q&A during the presentation, it seems that this team has a good understanding of what needs to be done. Several strategies have already been explored. This reviewer has no extra recommendations.
- Developing a plausible cost model is more important than demonstrating incremental improvement from R-10/in. to R-12/in. They should determine whether the materials are plausibly cost-competitive, and if not, they should identify key strategies to improve the cost.
- The flexible material is particularly novel. They could potentially spend more time on this material, by testing and confirming its properties, and also looking for applications where its flexibility is a benefit that can be

exploited (and for which there might be a price premium that end users would be willing to pay). There are perhaps industrial blankets or other applications that would be interesting first markets. It could also be potentially interesting if it could be rolled out onto walls, rather than sold in boards.

- The researchers may or may not have time to explore this but silane chemistries can form either molecular monolayers on surfaces and/or molecular multilayers on surfaces. The molecular multilayers that silane chemistries form happen via a crosslinking/polymerization process. A google search on "silane polymerization" and/or "APTES polymerization" provides some images.
- Whether you get a monolayer or multilayer depends on the details of your processing method and often times, researchers try to avoid formation of multilayers. However, in this case, it could benefit you (i.e., forming a low-density silane-based coating on the particles).
- On the flipside, if the researchers are forming multilayers, it may be difficult to recognize the differences between the three molecules, Slide 11 (i.e., due to the possibility of varying degrees of multi-layering).

Project #31312h: Active Insulation Systems

Presenter: Florian Antretter, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Overall, reviewers expressed some concerns regarding the project approach. While two reviewers praised the project's comprehensive literature review and three reviewers felt the team had provided an adequate and clear approach, most reviewers questioned the project's level of detail. These reviewers stated the project should have more information about simulations and controls; validation efforts are not included; researchers did not compare their results to previous studies; information about optimization is lacking; and EnergyPlus might not be sufficient to meet the project goals.

All reviewers but one indicated the project could have some impact, and three reviewers made positive remarks about the project's alignment with BTO goals and the project's potential impact overall. One reviewer felt the project impact would be limited because similar and more comprehensive analyses have already been completed.

The reviewers found the project's progress was good and noted the project has accomplished a comprehensive literature review, evaluated several building energy modeling tools, and selected a tool in a short period of time. One reviewer felt the validity of the modeling approach and the AIS performance assumptions needed to be justified. Two reviewers commented on the lack of clarity regarding how optimization would be carried out.

Most of the reviewers felt collaboration was sufficient and stated that the project is a scoping project, while two reviewers indicated there should be some type of further collaboration. Most of the reviewers felt the project is on track to meet its goals. However, one reviewer stated the remaining tasks are not described in enough detail, and that the project's planned optimization analysis is insufficient.

Weighted Average: 2.90   # of Reviewers: 6
Approach: 2.80   Impact: 3.20   Progress: 3.20   Collaboration/Coordination: 2.70   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.80** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This reviewer believes that performing a comprehensive literature review of active insulation systems is important and the team produced a lot of information about previous attempts to create a dynamic insulation system. The approach to reach particular designs is clear.
- Switchable insulation systems may be attractive, but bypassing the enclosure to achieve higher thermal exchange can be performed with other systems, such as economizers.
- This project is a fairly straightforward scoping study on the energy savings potential of active insulation systems (AIS). It explores a fairly wide range of AIS implementations and control strategies. The simulations were run over eight different climate zones and three building types; this is thorough but maybe a bit over-extensive if the goal was just to identify whether AIS could lead to significant energy savings.
- This project is a scoping study based solely on simulation analysis with limited details on the assumptions made to assess the performance of AIS technology. The details of the simulation and the control should be clearly outlined to better understand the results of the analysis.
- The team has produced a well-detailed approach and reviewed the open literature very thoroughly. The team has a sound plan which has already been put to work.
- This is a short term/scoping project, so it goes directly into energy modeling and limits the scope of the project. However: 1) The project is missing validation efforts. How do they know the algorithms are working properly? This is challenging because there is no lab or field data, but there are some ways to do this. Validation could be performed using analytical solutions, steady state, comparison with software with simpler approaches (low vs. high values), or detailed analysis of how surface temperature, as well as indoor air temperature, changes. 2) PIs mention previous studies but did not make any comparison with their results. For example, Moncef Krarti has done similar work and no comparison or lessons learned appeared to have been shared or analyzed. How were previous studies used to help current work? 3) Not much information was provided about optimization beyond slide 10. What parameters and variables will be used in the optimization? Is the software optimizing for design or sizing, or for operations? These two are different. How is it doing it? Python scripts? GENOPT?
- The authors reviewed a number of building energy modeling packages and ultimately ended up on EnergyPlus. They are using this modeling package to scope potential. One reviewer expressed concern about how Energy Plus solves the relevant equations, and that potentially being a problem. So the question ultimately is, while EnergyPlus may be the best current option, is it even good enough? However, if the goal is to get a scoping study done in 1 year, creating a better building energy modeling platform probably isn't an option.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- It is difficult to estimate the entire impact of the project. However, the team is likely to learn several prospective strategies that may contribute to save energy in large scale.
- The goal is to identify the energy saving potential for active insulation systems. The study suggests significant savings are possible, and suggests further development to make these technologies a reality.

- The impact of the project is expected to be limited since several authors have already performed this analysis and included more climatic conditions, realistic active insulation and building envelope systems, and optimized controls, as noted in the literature review.
- This project aligns well with program goals. Furthermore, improved models and simulation to assess new technologies and their potential are, and will be, always in demand.
- Assuming project goals are met, this project will produce an initial estimate of the potential energy savings active insulation system can obtain. DOE should continue funding this type of work.
- A scoping study like this is great. Developing active insulation with integrated thermal storage for building would undoubtedly be a very difficult endeavor. This scoping study is a cost-effective way to determine whether this high-risk research direction would be worth it.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- In a short time, the team managed to produce a literature review that documents a few mechanisms to produce dynamic insulation systems, including ranges of thermal conductivities that could be interesting for use. The team also evaluated several building energy software tools that could be used to evaluate the performance of such systems. Additionally, they identified a few research gaps that need to be evaluated.
- Have made a lot of progress for a relatively short project.
- Although the simulation results look reasonable and in line with reported results in the literature for the same climate, the validity of the modeling approach and the AIS performance assumptions need to be justified. It is not clear the E+ numerical model has been checked against more detailed models for accuracy and robustness (or ideally performance data for some reported AIS). This should be done particularly because a step function of AIS response is assumed. It is not clear if the AIS response for each wall is decoupled from the others (it would be useful to show which wall was more active in the case study considered in the simulation analysis). Moreover, it is not clear if the optimization analysis would consider the entire year and not just representative days.
- Team seems to have made significant progress to date based on presented timetable.
- The project has identified E+ EMS as the way to simulate active insulation system. It already has done parametric analysis on multiple cities and different locations in the wall. It is not clear what progress has been done on optimization, as the team only mentioned evolutionary algorithms.
- This project is about halfway through a 1-year duration. The authors have done a reasonably good amount of work in scoping the potential of active insulation systems in this period of time.

D. Collaboration and Coordination

This project was rated **2.70** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Since it is a new project, team has not implemented much collaboration, relying primarily on ORNL researchers.
- Stakeholder engagement sufficient; presentation and discussion with researchers.

- Being a scoping study, there is limited collaboration outside the lab researchers. It would be useful to seek input from the industry (the insulation sector in particular) about the viability of such products and the required criteria to be commercially viable.
- Team seems to work well together.
- There seems to be missing link between grid, optimization, and building efforts. All team members are from ORNL, but presentation did not convey that.
- The investigators are doing an appropriate amount of collaboration and coordination given the nature of this project. This is just a scoping project to determine the potential of active insulation systems. Consequently, the stakeholders are mainly researchers and funding agencies. The project could eventually be of interest for industry and utilities and the investigators have plans to incorporate them as appropriate.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Team plans to complete simulations and determine best candidates for further consideration. There is an understanding of some of the important work that needs to be developed here. This reviewer would like to highlight the need to consider durability issues.
- Future work seems reasonable. Important results already obtained.
- As noted earlier, the remaining tasks are not described in detail, including the modeling validation, the response of AIS (stepped versus gradual change). Also missing is an optimization analysis to identify the best control settings for each building walls not just for one day but for the entire year depending on the objective function (not clear if the thermal comfort would be a constraint or included in the objective function).
- A well detailed plan was presented for the remaining project work and future work based on approved funding.
- Project seems to be proceeding as defined in slide 20.
- This project is about halfway through a 1-year duration. The authors have already done a reasonably good amount of work and can likely complete a scoping study by the end of the project duration.

F. Additional Comments and Recommendations

1. Project Strengths

- Clear thinking about how to conduct the investigation. Solid team of researchers involved in the project. Interesting preliminary results that show some promise.
- Illustrates and illuminates the concept of active insulation systems by considering several implementation and control strategies. Modeling approach straightforward and clearly described, assumption stated. Key elements that lead to energy savings identified.
- The potential strength of the project is to add and possibly confirm through yet another simulation analysis the results of the existing literature on the potential of AIS.
- Team expertise, its leadership, and resources.

- Team with strong background on building envelopes. Important topic with high impact. The team has already selected software (E+) and method to simulate dynamic properties (EMS).
- Conducting this work as a scoping study is appropriate. Creating an actual active insulation system with integrated thermal storage in the building envelope will be very difficult to do. So conducting this study is very appropriate because the main question is, "If it works, will it matter?" This scoping study is appropriate to help determine the best future directions for research investment.

2. Project Weaknesses

- The complexity of AIS systems. Comparison with simpler approaches, such as high insulation and economizer techniques, should be considered. The lack of involvement of manufacturers that would be interested in such a system.
- There could be more focus on the attributes (thermal conductivity change, values) of particular active insulation systems that would drive increased energy savings, and then activities that could help drive development of those systems for building applications.
- The main weakness is the lack of detail on the analysis approach and the assumptions made. A clear description of the optimization analysis and of the response of AIS to be evaluated during the remaining project work is also needed.
- Producing models without experimental validation may be a problem.
- The literature review is extensive, but it seems no analysis was done to learn from earlier results. There is no effort on validation. Plans to perform any optimization are not clear.
- Nothing jumps out at me. However, one of the other reviewers brought up concerns about the manner in which EnergyPlus models solves the relevant equations. This could naturally be important to decide upon whether or not to believe the modeling results. On the flip side, the investigators did seem take a rational decision process in landing on their choice of EnergyPlus. So the question ultimately is, while EnergyPlus may be the best current option, is it even good enough?

3. Recommendations

- Consider benchmarking solutions with simpler high insulation and economizer; inviting insulation manufacturers to participate in the project; developing an EnergyPlus subroutine that could be used to investigate simpler systems; and look for opportunities to validate the model with actual simple active systems.
- Would like to see some effort to weigh energy savings against the cost and complexity of particular implementations. The most complex implementations result in the largest energy savings, but are those implementations realistic or cost effective?
- 1) Involve the industry to provide better direction of the project. 2) Discuss actual IAS (building envelope systems and not materials) that have been proposed and evaluated in the literature. 3) Validate the modeling approach. 4) Clearly define the assumptions made to control the various walls for energy building model considered in the case study and provide a sensitivity analysis to show that the internal gains could have significant impacts on the performance of AIS.
- Look into possible validation of models used to simulate potential technologies.
- Look at previous work and see how results compare and what things can be skipped using previous studies. Optimization should be clearly described.

- The results of this study suggest that for an active insulation system to have an impact, it must be coupled with thermal storage. It's unclear to me why you'd need to do all of this in the building envelope. It seems to me that:
  - Opening and closing windows is a good way to achieve tunable thermal transport through walls. Why do we need to dynamically vary the insulation in the entire wall? Is there a concern about not controlling humidity flow? (Although perhaps membranes could handle that.)
  - Why do we need to put thermal storage in the walls itself and to actively control heat flow in and out of the thermal storage. It seems to me that a using standalone thermal battery (e.g., an insulated box for of phase change material) would be much easier than integrating storage into the wall envelope. Furthermore, controlling heat flow into and out of a standalone thermal battery would be much easier too (i.e., essentially turning air flow through the battery on and off). This would allow you to charge and discharge the thermal storage at the optimal times.

Project #31312g: An Ultralow Thermal Conductivity Material

Presenter: Jaswinder Sharma, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewer comments were split regarding the approach to the ultralow thermal conductivity material project at Oak Ridge National Laboratory. Many of the reviewers found the team's approach to be practical and considerate with a step-by-step path towards a high conductivity material. One reviewer appreciated the team's use of hollow silica spheres as the base material for the insulation but noted the importance of solving the issue around particle aggregation. Some uncertainty remained around which model the project was using to predict the presented performance and whether each of the steps would achieve the stated reduction in thermal conductivity.

In general, reviewers were very positive about the potential impact of the project to contribute to DOE's goals of reducing energy use in new and existing buildings. One reviewer stated that "a low-cost, high R-value insulation would certainly have a strong impact on energy efficiency." That same reviewer noted their concern about whether this particular project would be able to produce the material at the cost or performance proposed. A different reviewer remarked that even if the project did not reach the intended goal, the knowledge gained during the research would contribute to achieving an ultralow thermal conductivity material in the future.

Overall, the team's progress was applauded, and the initial materials were described as "promising" with "impressive uniform hollow spheres." A reviewer commented positively on the team's progress with particle formation as well as low thermal conductivity particle linkers and polymer coatings. While reviewers approved of the project progress in the laboratory, they viewed the collaboration efforts outside of ORNL as lacking. Several reviewers provided the suggestion to engage with relevant industry manufacturers and installers earlier in the process. However, some reviewers disagreed with that evaluation and referenced the early stage of the technology as reason for not engaging further at this point in the project.

Weighted Average: 3.09   # of Reviewers: 7
Approach: 3.14   Impact: 3.43   Progress: 3.14   Collaboration/Coordination: 2.57   Remaining Work: 3.14

Program Response

The Building Technologies Office leverages the peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.14** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is an excellent approach with a step-by-step path towards the goal of very high R-value/inch.
- The team is considering several aspects that can significantly reduce the apparent thermal conductivity of the produced material.
- Particles and linkers are considered as working together.
- The approach seems a little scattered; it is not clear what model is being used to predict performance.
- This reviewer is not confident each of the steps shown on the staircase slide will be able to achieve the desired reduction in thermal conductivity.
- The thermal conductivity measurement approach is not described (for particles or slab); they show TPS, but not sure that TPS is appropriate for low k materials like this.
- While the analysis approach is reasonable, it is not systematic and sufficiently comprehensive to account for various factors in order to optimize the R-value. It is not clear how the R-value improvement levels from different tasks have been estimated and if there are any compounded effects that need to be considered in the analysis. A clear description of the approach should be provided.
- The approach was broken down into essential components. Each component was very well explained and detailed. The team members seem to know what is needed, the risks, and their mitigation.
- This project includes a systematic approach to reducing each thermal transport mechanism, with a continual constraint of low-cost production.
- The approach uses earth abundant materials, low cost drying, and minimal solvent consumption.
- The approach considers moisture and fire resistance, and is working on addressing particle aggregation.
- It seems like a practical way to get to at least R-8-12/inch. R-14/inch may be a stretch.
- I like the use of hollow silica spheres as a base material for insulation. This coupled with many of their other ideas should lead to a good insulation material.
- The particle aggregation issue will be an important issue for them to solve because much of their materials processing goals need to be done on nearly all of the particles (e.g., applying a coating to all of the particles as opposed to just the exterior surface of particle aggregate clusters). Their idea to use sonication is certainly a quick and easy method/approach. However, sonication is something to try after aggregation has already occurred. It would be better to avoid the aggregation in the first place. They also mention they want to "avoid sintering" on Slide 14. However, do they understand the origin of the aggregation process in the first place? Is this really a sintering issue (i.e., to me sintering arises from a high temperature)? Could aggregation be avoided by incorporating various surface chemistries?

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.43** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- If successful, the insulation product developed by the team has the potential to significantly reduce energy use in buildings.
- A low-cost, high R-value insulation would certainly have strong impact on energy efficiency.
- This reviewer has concerns about whether this particular material will be able to meet either the cost or thermal performance targets.
- The impacts of having insulating materials that are low-cost with high R-value per inch are significant for both new and retrofit applications. While the project is still in its early stage, the project team seem to be in the right direction to develop an insulating material with high R-value/in even though some challenges remain to ensure the durability and the low cost of the technology.
- The project is well-aligned with BTO's program goals.
- The success of the project would result in high-R materials that are still affordable.
- No comment.
- A very thermally insulating material would contribute significantly to reducing energy use in buildings. Even if this exact materials processing scheme doesn't reach their goal in three years, the use of hollow silica particles and the knowledge gained during this study will greatly contribute to achieving new/improved insulation materials.

C. Progress

Based on current project efforts, the project was rated **3.14** for the degree to which the project has met ***project-specific goals.***

- Impressively uniform hollow spheres with very low thermal conductivity were created. Thermal conductivity close to 0.02 W/m-K in the particle powder.
- Current progress looks good. Initial materials look promising.
- Approach down select made.
- Overall, the project is on schedule and the project team is aware of the various challenges to achieve the set goals as well as have some mitigation solutions to some road blocks including particle aggregation. The involvement of industry partners may need to be accelerated to at least provide some input on realistic production cost levels in order for the proposed technology to be competitive compared to the available insulating materials.
- Based on what was presented, significant progress has been made to date.
- The team has achieved good particle formation, progress on particle linkers with low thermal conductivity, and they have been able to add low conductivity polymer coatings.
- The team is still working on addressing particle aggregation, which remains as a major challenge.
- They already got to R-8/inch. It may be harder to get past R-12/in, especially with "heat transfer direction control".
- This project is just 6 months into a 3-year project. In this short period of time they have achieved reasonably good success.

D. Collaboration and Coordination

This project was rated **2.57** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project is in its early stages and collaboration and coordination is still nonexistent. Working with commercialization staff is helpful. This reviewer would recommend presenting to insulation manufacturer's science and technology staff for feedback.
- Collaboration is a little light at this point, but the technology is still fairly low TRL.
- While the collaboration within the research team members is excellent, it seems the industry partners have not been engaged as noted earlier. An effort should be made to involve more potential stakeholders in the project.
- To date, the team seems well-coordinated and collaboration is taking place.
- Industries have been contacted.
- Other experts have also been contacted.
- The team has had some contact with relevant industries, but needs more involvement from potential manufacturers and installers in at least an advisory role for providing feedback.
- They seem to be working with a good team. Are there others they can consult to overcome the aggregation problem? Perhaps, someone else has solved this already.
- This is a very early stage project and so engaging stakeholders at this point is not overly crucial. The investigators are making efforts in this regard though and so that is notable.

E. Remaining Project Work

This project was rated **3.14** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- Significant work still needs to be performed to get to the goal, but the team showed a path that can be consistent.
- The remaining work was defined but it is not clear what specifically will be done to enhance the R-value to achieve these proposed material modifications
- The plan for the future work is well-defined even though some concerns still remain on the proposed approach to achieve optimal R-value using solely hollow silica particles with cellulose linkers. Other materials and processes could be considered as part of the future plan.
- The project seems to be on track.
- The team is making progress and following a systematic approach to continue that progress.
- It seems doable to finish the project, though getting to R-14/inch may be tough.
- This project is just 6 months into a 3-year project. In this short period of time, they have achieved reasonably good success. They have a lot of work ahead of them, but they have 2.5 years to do so and the layout of the remaining work seems logical.

F. Additional Comments and Recommendations

1. Project Strengths

- It is well-organized work.
- They have a clear vision on how to achieve their goal.
- They have an understanding of the different heat transfer mechanisms.
- Very uniform hollow spheres present an interesting base material for achieving low thermal conductivity composites.
- The main strength is the application of low-cost and high R-value/in materials since insulating building envelope for retrofitting residential and commercial structures can become cost-effective and economically feasible.
- The strengths include the approach and the team's understanding of the challenges.
- The project maintains a continual focus on low-cost production approaches while systematically reducing each mechanism of thermal transport
- It is a good practical idea. They should consider starting with hollow silica particles rather than creating their own. They are making good progress; it is already at R-8/in.
- This reviewer likes the goal of using hollow silica particles as a base material for thermal insulation. Even if the exact materials processing in this particular project is ultimately unsuccessful at the end of three years, the knowledge gained with respect to making and working with hollow silica particles will be highly beneficial to the community. It can also lay the groundwork/foundation for future projects in building insulation.
- Combining the results of this project with the results of the silica and alumina particle insulation project out of LBNL (project 313108-313111) could lead to even better, excellent next-generation insulation materials.

2. Project Weaknesses

- There is uncertainty about the stability of some of the solutions. For example, it is unclear how to maintain low-k gases in the spheres.
- Moisture performance is not clearly defined.
- The justification for cost reduction relative to aerogels is not compelling.
- A lot of approaches to reducing thermal conductivity are mentioned but a description of the specific implementations is lacking.
- The main weakness of the project is the proposed approach to arrive at a material with high R-value/in with a systematic analysis using comprehensive models. Moreover, the slow engagement of industrial partners in the project is a concern.
- Moisture and fire-retardant issues may present problems for which the mitigation approach may or may not work.
- The particle aggregation problem is a major challenge.
- The team would benefit from greater engagement and feedback from relevant manufacturers.

- They still need to solve the aggregation problem. Also, they have to ensure the stability of the material (that it doesn't fall apart over time). Some of the remaining work seems ambitious to get to R-14/in.
- The investigators recognize the problems that the particle aggregation presents. This problem will need to be overcome in order to implement many of their planned approaches to reducing heat transfer.
- The investigators mention that in later years they will achieve "heat transfer direction control." It is not clear how they will achieve this by using spheres, which are by definition isotropic. Will they be using these spheres in some sort of larger scale composite material (e.g., alternating 2-dimensional layers of spheres – metal films – spheres – metal film – etc.)?
- The spheres are ~300 in size and the interstitial spaces between them even smaller. These length scales are shorter than infrared wavelengths and so near-field radiation effects could lead to unwanted boosts in thermal transport.

3. Recommendations

- The team should consider how to produce the spheres in large scale.
- They should consider incorporating absorbing and scattering material to the sphere surface.
- They should also consider adding an advisory board with insulation manufacturers included.
- They should more clearly state the approaches to increasing air volume, controlling heat transfer direction, maximizing phonon scattering interfaces, etc. The approach, as described, is not specific enough.
- They should try to better justify the approach considered to optimize the R-value. They could possibly document the expected increases of R-value expected for each proposed task.
- They should consider engaging more actively industrial partners in the project.
- They should ensure that the impacts of the various mitigation solutions on the production costs be considered and estimated.
- They should look very carefully at moisture and fire-retardant issues.
- They should focus on solving the particle aggregation problem. There may be opportunities to drive particle dispersion by using different surface treatments, which might require moving away OH surface chemistry approaches.
- There is no harm in trying to get to R-14/inch, but this also could be valuable research even if they don't get all the way there. It is potentially useful at R-8-10/in if they develop a low-cost method for creating a stable material.
- Slide 16 says at the bottom, "test and improve mechanical properties... test and improve moisture stability and fire-resistance. "It seems like they could focus on these and have something useful here, even if not R-14/inch.
- With respect to the silica particle aggregation problem…Are these particles made via wet chemistry or some other approach? If they are using wet chemistry approaches, one potential industry to look at for solutions is the slurry industry for chemical mechanical polishing (CMP) in the semiconductor field. The manufacturers of these CMP slurries achieve very high concentrations of silica particles in water-based solutions while retaining particle dispersion (i.e., no aggregates).

- Is it possible to use longer linkers than the ones shown on Slide 12? This should enlarge the interstitial space between the particles and could improve the overall R-value.
- What is inside the hollow spheres? Is it vacuum, air, water, or solvent? Can the contents of the space inside the sphere be improved at all?

Project #31354: Anisotropic Thermal Management for Building Envelopes

Presenter: Som Shrestha, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewer comments were divided on the anisotropic thermal management for building envelopes project with reviewers disagreeing on the study's approach. One reviewer expressed excitement for the project and detailed the parts in the approach that would lead to the team overcoming technical barriers. However, several reviewers identified challenges that the team would likely face including control requirements, long-term performance, and the overall cost of the technology. There was a great deal of uncertainty surrounding the project details as reviewers asked for clarification on the heat sink in particular. Also, a reviewer was concerned that the technology might not function as expected in a real-world scenario with full weather conditions and multiple seasons.

The project's contribution toward DOE goals was similarly questioned by the majority of reviewers. While many of the reviewers reiterated their concerns, one reviewer applauded the project stating that it would "become the foundation for future studies that pursue this research direction." The reviewer continued by explaining that by achieving sufficient thermal anisotropy, the technology should improve the building envelope resulting in energy savings. On the other hand, several reviewers were unsure whether the technology, if successfully developed, would achieve widescale adoption. A reviewer was uncertain how the thermally anisotropic composites (TACs) would differ from the application of ventilated cladding. The impact presented was also disputed as it was based solely on summer applications, which would result in a reduced whole building estimate.

In terms of the team's efforts to meet their goals, multiple reviewers noted the good progress made in the first six months of the project. Some of the completed work included a simulation tool, a bench experiment, and a chamber experiment that led to results showing reduced heat transfer to the interior of the building during the summer months. One reviewer mentioned that the presentation failed to discuss the challenges of using a TAC system compared to traditional building insulations, such as the controls needed, manufacturing costs, and installation costs.

Overall, reviewers were split on the team's collaboration efforts with comments ranging from outstanding to poor and in need of improvement. The team's technical expertise was repeatedly cited as a project strength and their outreach to key organizations was commended. However, reviewers recommended engaging further with external stakeholders and developing industry partnerships to provide feedback on installing and operating the TAC system.

Weighted Average: 2.69 # of Reviewers: 6
Approach: 2.33 Impact: 2.50 Progress: 3.17 Collaboration/Coordination: 2.83 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This reviewer failed to completely understand the concept presented by the team. A clear indication on what is the heat sink is necessary to evaluate the potential benefits of the project. Unless a heat sink is available to dump the heat that is redirected, this reviewer is not sure how the project reduces energy consumption.
- There was not enough detail or focus on the heat sink/source. What is a realistic available temperature difference? Where is the heat being rejected to? How does the energy cost compare to the energy savings to the overset cooling load from redirecting the heat to the heat sink?
- The number of design variables is unnecessarily large. The effect of many of these can be estimated analytically without the need to test.
- While the development of prototypes and the testing approach are well documented, some of the challenges including the control requirements, the long-term performance, and cost of TACs are not considered.
- The approach may work well under controlled laboratory conditions, but may not function as expected under full weather conditions on daily cycles over two or more different seasons.
- The approach is adequate ranging from numerical to lab and field work. However, it is not assessing how this could be used as a grid-interactive efficient building (GEB) technology or addressing how this is different (better) than a ventilated cladding.
- Slide 10 shows a temperature gain of just 0.2 C, which is within the uncertainty of most temp systems.
- The team's approach of FEM, bench-scale test, large-scale prototype tests, building modeling, field evaluation, etc. (Slide 7) seems good to me. This will allow them to explore this concept reasonably well, help them identify problems quickly, and help to create a reasonable prototype for field evaluation. This is an exciting project.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)*.**

- A suitable candidate for heat sink is needed to determine the impact. The team presented a situation during the summer when heat enters the building through the enclosure. How is the heat sink created? One option, for example, would be to preheat the water that is used by building occupants. However, the amount of energy that it can absorb is limited by the temperature difference between the external surface of the envelope and the inlet temperature of the water.
- It is quite possible that this reviewer did not fully understand the project and that such question has a simple answer.
- There is the potential to save energy, but the feasibility of broad adoption of this technology would appear to be low.
- There would be challenges with designing the system to be robust to seasonal temperature variation.
- If successful and all the challenges related to installation, operation, long-term performance, and especially costs are addressed, TACs as prefabricated wall panels could be effective in reducing both energy use and peak demand for heating and cooling buildings.

- The impact slide seems to be based on summer applications only. The 25% of peak demand is not integrated over a day. A peak demand reduction of 25% in envelope may translate to less than 5% in overall energy savings.
- It is not clear how the proposed Thermally Anisotropic Composites (TACs) can be innovative and a solution to reduce energy use in buildings or even be GEB. How is this different from a ventilated cladding? Ventilated cladding removes heat and moisture and TACs are more complicated with less benefits. If PIs intend to use the low-grade heat for internal use, it might become internal gain, which is opposite of the goal.
- Among all reviewed projects, this is the one with the least clear impacts for DOE goals.
- Achieving sufficient thermal anisotropy should in principal improve the building envelope and reduce energy use. This project appears to be a good first concept, simulation, and experimental implementation of this concept. It will reveal the potential of this concept, key hurdles, and other important opportunities/challenges for this research direction. This will in turn become the foundation for future studies that pursue this research direction.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met ***project-specific goals*.**

- A simulation tool was developed by the team and they obtained results showing the reduced heat transfer to the interior of the building during the summer. The tests were conducted to evaluate the performance of the envelope.
- Progress is good for the early stage of this project.
- While some testing of small prototypes has been carried out, the project does not discuss in details some of the challenges of the TAC systems compared to conventional highly insulated building envelopes including, but not limited to, the control needs and the overall cost for manufacturing and installing these systems.
- Based on Project Plan and Schedule slide and presentation discussions, the amount of work completed to date is right where it needs to be.
- They have made adequate progress so far.
- This project is about six months into a 36-month-long project. In this time period, they have already done basic simulations, a bench scale experiment, and large-scale chamber experimental results. This is very good for just six months.

D. Collaboration and Coordination

This project was rated **2.83** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This early stage project needs more time to involve external stakeholder.
- Stakeholder engagement is sufficient for the early stage of the project and technology.
- While the collaboration between various research members of the team is clear and well-documented, there is a lack of involvement of industrial partners in the project to provide feedback about the potential installation and operation of the TAC systems.

- The team is made up of well-known and very capable scientists in the corresponding areas of research. The group seems to work well together.
- They have a strong team technically speaking, but perhaps they need somebody with a more holistic view that looks into the bigger picture and ask how this could become GEB and better than a ventilated cladding.
- Even though this is a very early stage concept idea, they have already introduced this idea to key organizations (NYSERDA, CEC), a key company (Katerra), and plan to present at a Buildings conference in December 2019.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- Reasonable next steps have been identified.
- The remaining work seems mostly appropriate.
- Their focus on the HSS doesn't come until later in the project. This reviewer would like to see more of that work done upfront.
- While major future tasks have been outlined, there was no discussion of the main challenges of the TAC systems and their potential mitigation solutions. Moreover, the involvement of the industry partners and collaborators is rather limited throughout the project.
- The Project Plan and Schedule seems very appropriate.
- PIs need to modify remaining work to address the issues raised here and in the presentation. This review is not sure how this could become a successful technology.
- The project has about 2.5 years left on a 3-year timeline. The remaining planned work is reasonable.

F. Additional Comments and Recommendations

1. Project Strengths

- The team has solid modeling and experimental capabilities.
- This is a straightforward approach to redirecting unwanted heat away from the interior of the building
- A good amount of work has already been done.
- The main strength of the project consists of the potential impacts of TACs to reduce peak demand and energy use associated with heating and cooling buildings.
- Project strengths include the team, their Expertise, and the national laboratory resources.
- It is a strong technical team.
- They have strong numerical/lab/field work.
- This reviewer is very excited by this project and the research direction. The investigators have a broad array of expertise that will allow them to quickly implement their ideas, identify problems, solve problems, and progress toward a first prototype system that is field tested.

2. Project Weaknesses

- The team did not identify heat sinks for the project.
- An evaluation of prospective heat sinks must be included and the potential of their use needs to be part of the project.
- The risks related to moisture accumulation need proper evaluation.
- The project costs may ramp up fast for a small benefit.
- There is not enough focus on the practical aspects of the implementation. Can the heat be passively rejected? What impact does this have on performance? Is active rejection required? What are the performance implications? This mostly comes down to realistic assumptions about the heat sink/source (HSS). How does the heat rejection approach depend on seasonal conditions?
- The heat transfer aspects of putting conductive layers between insulation are fairly straightforward, but this is getting the bulk of the focus (at least in the early stage of the project).
- The main weakness is the lack of a clear approach to tackle the main challenges of TACs such as their high cost, durability, controllability, and maintenance needs.
- The concept may not function under full weather conditions.
- This is not a strong idea with respect to cost-effective solution.
- The project does not address how this could be better than a ventilated cladding or more XPS.
- This project is not GEB and has no moisture control.
- Among all reviewed project, this is the one with the least clear impact on energy savings, peak demand, or GEB.
- The manner in which the investigators heat sink the heat energy coming from the thermal anisotropy will be very important. How many water pipes do they need to circulate around the building envelope and at what pitch does this need to be done? On Slide 10, it looks like they need a pipe every few feet. This seems like it could be expensive to create in an actual building. Based on the PIs' slides, it seems likely that they will be looking into such details.
- A small concern about the PI's implementation of thermal anisotropy is that it relies on surrounding the building in metal foil. This will essentially turn a building into a giant faraday cage and will quench transmission of any wireless communications. This would be annoying to building occupants and could also work against the goals of the GEB initiative. That being said, an engineering solution to this could surely be worked out. Furthermore, if this project progresses to a stage where this is a concern, it will have been highly successful to have progressed so far.

3. Recommendations

- They should consider evaluating different options of heat sink to drive heat flow in the vertical (in the case illustrated).
- They should consider moisture retention issues by the metallic layers.
- They should consider the increase in thermal insulation resistance if low emittance surfaces are used.

- They should have more of a focus on realistic assumptions around the HSS and practical aspects of implementation.
- They should discuss the potential challenges of TACs systems including their expected costs to be competitive compared to other options (such as walls with ventilated facades with air circulating along the outer or inner channels within the walls).
- They should involve relevant industry representatives in the design and the development of prototypes.
- They should conduct experiments in outdoor testing facilities before too long to see if the concept would function well under full weather conditions.
- This project might need to go back to the drawing board. Is this really a good idea compared to what a typical cladding is or simply adding more XPS?
- Unless it is cheaper, controls moisture, or has GEB, this reviewer doesn't see how this project can really improve.
- No comment.

Project #31312e: Developing the Metrology for Accurately Assessing the R-Value of Super Insulation

Presenter: Andre Desjarlais, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewer comments on the Developing the Metrology for Accurately Assessing the R-Value of Super Insulation project were very positive with reviewers describing the approach as clear and consistent with current needs. Several reviewers noted the limitations of standard thermal measurement approaches, which require a large sample size, and explained how the project would address these barriers. The strategy to work directly with manufacturers to adjust existing testing equipment was mentioned multiple times. Reviewers appreciated this approach compared to the alternative of proposing a new set of apparatus to test thermal conductivity. However, one reviewer remarked that some of the tests that were planned by the team seem unnecessary as the results are somewhat self-evident.

The potential impact of the project was similarly well-received due to the clear need that this study would address in the research community. Reviewers commented that the new technique would not only significantly facilitate material development but would also provide a more accurate method to test very low thermal conductivity samples. One reviewer followed up and stated that by developing a method and National Institute of Standards and Technology (NIST) standard material, the team could help reduce variability in results. Overall, the project's alignment with DOE goals to create a material with a very high R-value per inch was celebrated.

While the project is still in its early stages, the team's progress as presented was equally acclaimed by reviewers, who complimented the group's preliminary testing. The reviewers noted the work the team completed in order to identify shortcomings in the current apparatus and then down-select from their initial test methods. It was recommended that the project include test samples with R-values that exceed 10 per inch since the industry is progressing towards very low thermal conductivity materials. In addition, a reviewer highlighted the challenge of making the surroundings for the test sample so that the results are consistent and accurate.

In terms of collaboration and coordination, reviewers found the project team was appropriately engaging in stakeholder engagement efforts. The team's partnership with NIST, as well as other key stakeholders like thermal instrumentation manufacturers, researchers, and ASTM, was commended for its inclusivity. Several reviewers also specifically mentioned the project consortium in relation to the team's collaboration plan.

Weighted Average: 3.34   # of Reviewers: 6
Approach: 3.33   Impact: 3.33   Progress: 3.33   Collaboration/Coordination: 3.50   Remaining Work: 3.17

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach is consistent with the goals.
- A lot of tests run/planned. Some of the results of the tests seem fairly obvious and the tests not really necessary.
- Overall, the approach is well defined and presented. In particular, the project team is recommended to work with the manufacturers to adjust the existing testing equipment rather than propose a new set of apparatus.
- Approach is clear and consistent with current needs.
- The project will address the shortcomings of standard thermal measurement approaches, which require large samples and have unclear uncertainties for high R/inch materials.
- The development of new methodologies will allow testing small volume materials, which are often fabricated in small quantities with high R/inch.
- The team is coordinating with manufacturers of testing equipment to ensure it will be commercially available, as well as NIST to support the adoption of new standards.
- While a bit more "mundane" than some of the other presentations in this category, there is a clear need for being able to test smaller quantities of nanomaterials and this research seems quite helpful to that end.
- Trying to adapt existing commercial approaches to do these measurements would lead to the fastest market adoption and wide availability to researchers and materials manufacturers.
- Using a technique that uses a non-planar heat source (i.e., instead using a line heat source or a point heat source) would best enable the ability to measure small samples. Would a modified transient hot wire method be suitable in this regard?
- Transient techniques can make measurements much faster than steady-state techniques (e.g., transient plane source vs heat flow measurement apparatus). However, these measure thermal diffusivity and so additional measurements of mass density and specific heat are needed to determine thermal conductivity.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- There is a clear need for testing methods for very low thermal conductivity materials. This fits well with continuing work to develop high thermal resistance insulation materials.
- The development of easy to use equipment and procedures for testing low thermal conductivity materials would have significant impacts to accelerate the development and the evaluation of high R-value insulating materials needed especially for retrofit applications. Some challenges remain for the project especially related to the accuracy level and the adoption of reference materials especially with the ever-increasing needs of materials with very high R-value per inch.
- Impact aligns well with program goals. Impact from developing the necessary metrology was well explained.

- The new techniques would greatly facilitate materials development by making it easier to test/characterize small batch samples.
- The new techniques would provide greater confidence in measurement of incremental improvements by reducing uncertainties. This reduced uncertainty can support continued materials development in the appropriate direction.
- It is not clear that modifying the existing ASTM standard will be good enough to make a difference.
- Everyone needs to test their materials. And this will help them test materials when they can only make smaller quantities.
- If this project's goals are met, it will be immensely helpful. Measuring thermal transport at the extremes (i.e., very thermally insulating, very thermally conductivity, very small samples, etc.) is very difficult to do correctly and I frequently encounter individuals generating incorrect results. Developing a NIST standard material as well as a consensus method to measure these highly thermally resistive materials will help eliminate the widely variable results I see reported in the literature (in which it's difficult to tell if the researchers have a magic material, some sort of secret sauce, or they simply performed measurements incorrectly).

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- On track to achieve goals.
- Work so far makes sense, not steps clear and well identified.
- Down-selection of test methods good.
- While the project is in early stage, a significant progress has made including some testing of insulating materials with different sizes and background materials to evaluate the measurement accuracy levels. Some challenges remain but the project team seem to be aware of possible mitigation solutions. The team should, however, try to identify and test samples with R-value per inch exceeding 10 since the industry is expected to develop materials with very high R-values per unit thickness.
- Progress to date seems to be significant based on what was presented and what the objectives of the project are.
- The team has made good progress on narrowing down the experimental parameters and variabilities for the current ASTM technique.
- The team is exploring the parameter space for the ISO standard.
- The team has brought in feedback from stakeholders, including testers, materials developers, and manufacturers.
- Making good progress, although general conclusion is that it is hard to make surrounds for the test sample. Really need the sample to be larger than the sensor in order to get accuracy.
- The researchers have identified how and why measurements using the heat flow measurement apparatus and transient plane source fail. This is an important and good start to this project. The difficulty naturally lies in how and if they can fix the shortcomings of these techniques in trying to measure these thermally insulating materials.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Engagement with NIST good.
- Consortium includes relevant researchers working on advanced insulation materials.
- Good collaboration between various team members from various labs. While noted, the presentation did not describe any significant collaboration with the manufacturers of testing equipment. This collaboration and feedback from the equipment manufacturers should be clearly stated and discussed.
- A project consortium was created, which seems to be made up of highly skilled personnel. Collaboration seems to be taking place as expected.
- The project team includes representation from NIST, and includes modelers, measurement experimentalists, and materials developers.
- The team is working with manufacturers of existing equipment to ensure there will be manufacturers to make any newly developed devices.
- Seems to have good collaboration with stakeholders as well as equipment manufacturers.
- They are maintaining discussion with NIST, ASTM, thermal instrumentation manufacturers, and researchers. These are all of the key stakeholders.

E. Remaining Project Work

This project was rated **3.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Next steps clearly identified, fit well with work accomplished to date.
- The tasks remaining are clearly defined and seem to be achievable based on the progress made so far. The main challenge is the expected accuracy levels that will achieved by improving the existing equipment especially when measuring high insulating materials (with R-value per inch exceeding 12 or 14).
- A very well detailed plan to deliver what was proposed was presented.
- The team has articulated plans to continue progress on all fronts.
- Seems like there is enough time and budget to complete the project.
- The remaining work on the project is reasonable to achieve with the ~2+ years they have left. There will be uncertainty in how they eventually overcome the inaccuracies associated with small samples that are highly thermally resistive.

F. Additional Comments and Recommendations

1. Project Strengths

- Straightforward approach to extending capabilities of existing method (heat flow meter) to lower thermal conductivity materials.

- Good coordination with NIST on defining new reference material for advanced insulation material characterization.
- Good focus on accelerating material discovery by reducing sample size.
- The strength of the project is the goal is well defined with a clear approach (improving existing equipment) and well-defined testing plan. The main challenges are identified even though the potential solutions are not certain to achieve the expected outcomes.
- Team members from ORNL and NIST. A deep understanding of the issues. Sound approach to achieve goals.
- The inclusion of all the stakeholders in the materials development process.
- The opportunity to accelerate and increase the confidence in testing of high R materials.
- This seems to be addressing a real need for a low-cost way to test smaller amounts of insulating nanomaterials.
- The project strength is that is addresses a very important need for the research community (i.e., a standard reference material and measurement technique for highly thermally resistive materials that are small). If they can get a commercial vendor to provide this, that will be extremely helpful.

2. Project Weaknesses

- Some of the testing seems redundant and unnecessary.
- The weakness of the project so far is the lack of testing samples (and references) with high R-value per unit thickness. Without testing these samples, the accuracy levels of the proposed apparatus and testing approach can be estimated and evaluated.
- None.
- While there were clear reasons and motivations for adapting from existing measurement techniques, it is not clear that they will be sufficient for the target applications.
- It seems like the conclusion is that you really just need a smaller sensor, because the material-surround interface introduces too much uncertainty. So maybe the main focus should pivot to how to get low-cost smaller sensors (i.e., the custom-made 1" HFM).
- Finding a high throughput measurement technique would be helpful. It's unclear to me if a steady state technique will have high enough sample throughput. That being said, I personally don't know if the measurement speed (e.g., a few hours for a steady-state technique) is the true bottleneck in this type of ultrahigh-thermally-resistive insulation work.

3. Recommendations

- Could better frame the requirement for a new reference material. What is the impact on measurement accuracy due to using existing reference for lower thermal conductivity materials?
- Involve more actively the equipment manufacturers in providing feedback and guidance throughout the project.
- Identify and test samples with high R value per unit thickness (i.e., R-value/inch higher than 12).

- Clearly define the calibration procedures and the estimation of the accuracy levels that are expected from the proposed apparatus.
- May want to get more NIST input.
- Continue to explore existing (or theorize/explore new) thermal characterization techniques, particularly if the current approaches do not inspire sufficient confidence in their applicability.
- Smaller size HFM sensor seems to be the most promising (ASTM test method) so it seems like most effort should be focused here.
- As mentioned earlier, using a technique that uses a point heat source or a line heat source would greatly help with measuring small samples. If the need is for small samples is the most important than this could be revisited. If, however, the need for a standard reference material, measurement method, and fastest commercialization are the true priority, then using the heat flow measurement apparatus or transient plane source may be the way to go.

Project #31312f: Evacuated Spheres for Closed-Cell Vacuum Insulation Systems

Presenter: Diana Hun, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Reviewer comments were split with regards to the Evacuated Spheres for Closed-Cell Vacuum Insulation Systems projects, which include (1) polymeric vacuum insulation spheres and (2) coated and evacuated insulation spheres. While the two individual projects were well-received by most of the reviewers, some expressed concern about the team's approach. One reviewer noted the challenge of maintaining vacuum in a polymeric closed cell for extended periods of time and a second reviewer questioned whether the team had a clear strategy to optimize the performance of the spheres. On the other hand, several reviewers complimented the team's concept, range of techniques, and two test methods—air assisted and mechanical chopping.

Overall, many reviewers approved of the potential impact the evacuated spheres project could have on DOE building energy efficiency goals. The contribution of the new technology, if successfully developed, was characterized as hugely impactful since a cost-effective, high R-value product would increase deployment of advanced insulation. Reviewers mentioned the great potential for the reduction in energy use and predicted that the closed cell vacuum insulation would be well accepted by the construction community. However, a sole reviewer described the impact as limited due to a lack of discussion around technology production costs. The reviewer continued and explained that if cost remained high, market adoption would be constrained, especially since the team did not demonstrate the proposed target R-value.

In terms of project progress, reviewers disagreed as to the extent to which the team had accomplished their project-specific goals. Based on the presentation, several reviewers commended the team's previous work and, in particular, their progress with the mechanical chopping method. Other reviewers remarked on the good progress but were uncertain whether the team's future goals would be attained in the time remaining. The challenge to ensure durability and stability for long-term performance was also noted.

The team's collaboration and coordination efforts were generally well regarded for the very early stage of the project. While reviewers indicated that the team identified potential future industrial partners, some other reviewers stated that the industry involved could be "actively strengthened." These reviewers suggested that increased industry partnership would provide valuable insights on cost and any production challenges.

Weighted Average: 2.99   # of Reviewers: 7
Approach: 3.00   Impact: 3.29   Progress: 2.86   Collaboration/Coordination: 2.86   Remaining Work: 2.86

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Very good concept of using low pressure gases without some of the drawbacks of vacuum panels. Two different methods to create evacuated spheres were investigated. Option 1 (air assisted) did not lead to good results. Option 2 (mechanical chopping) is under investigation.
- Good range of techniques for producing evacuated spheres.
- Questions about the ability to characterize gas pressure of spheres and sphere permeability.
- The project does not seem to have a clear approach to optimize the performance of the polymeric vacuum insulation spheres as well as coated and evacuated insulated spheres. Two methods are being tested including an air assisted method and a mechanical chopping method with different degree of success. It could better to initially perform a modeling analysis to determine the optimized values and combinations of parameters to adjust to reach the target R-value per inch.
- The possibility of matching the thermal performance of vacuum insulated panels is high, but at the same time it adds the benefit that the proposed technology would be less likely to be degraded by punctures.
- The team has already anticipated issues related to installation of the technology in buildings, which seem very sound.
- The two approaches presented: (1) polymeric vacuum insulation spheres (PVIS) and (2) Coated and evacuated insulation spheres (CEIS) have been thoroughly investigated by the proposing team. The approach was well explained during their presentation.
- The team is working to develop low cost vacuum insulation, and this project focuses on addressing key challenges, including: gas permittivity, shell conductivity, and binder conductivity.
- This research could potentially lead to something interesting, but by the researcher's own admission, what she is trying to accomplish here is hard and could also just not work.
- The idea of closed cell vacuum insulation is very appealing due to the practicality and usability of this with respect to traditional vacuum insulation panels.
- Maintaining vacuum in a polymeric closed cell for extended periods will be very difficult. Even mylar balloons show permeability (i.e., a helium mylar balloon will stop floating after ~1 week…granted permeability to helium is different than permeability to air). They do cite literature that appears to show that small enough permeability rates are “possible.”
- The coated and evacuated insulation spheres are an alternative interesting approach to achieve closed cell vacuum. These likely stand a better chance at achieving acceptable gas permeability. However, the process to coat the spheres will need to be faster and more practical and sputter coating will not likely reach the mark. They do mention dip coating and powder coating procedures. However, the ability to attain vacuum inside the cells for those approaches is not clear to me.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.29** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If successful, a composite material using the spheres may deliver low effective thermal conductivity. If capable, delivering an R-14/inch will have a great impact in energy use in buildings.
- Approach could lead to a high R-value insulation that is robust to damage during installation; could increase deployment of advanced insulation.
- The impact of the project seems limited since there is no discussion of the production costs of both the PVIS and CEIS. If the costs remain high (potentially higher than VIP), then the use and adoption of the proposed insulation options will be limited. Moreover, the R-value obtained to date is rather low compared to the proposed target.
- The project is highly likely to contribute to the program goal in that it seems to be on track in the development of a cost-effective technology having the ability to reduce building heat transfer through the envelope.
- If it works, the development of low-cost, scalable vacuum insulation would be hugely impactful.
- Could lead to something really interesting or contribute to our knowledge of how to manufacture small vacuum-insulated spheres, or at least some interesting manufacturing methods ("mechanical chopping"). Coating of spheres supplied by others seems potentially more promising, although still need to contend with issues around how to ensure the vacuum persists over time.
- An affordable closed cell vacuum insulation would likely be well accepted by the construction community and I anticipate it would be highly used and contribute greatly to energy savings in buildings.

C. Progress

Based on current project efforts, the project was rated **2.86** for the degree to which the project has met ***project-specific goals***.

- Team tried a series of options to produce evacuated spheres. While some of the attempts failed, they delivered lessons that can prove useful in the near future. This reviewer commends the team for using a progressive table of target parameters. Some of the FY19 were already achieved, but the thermal resistance, the key parameter, is still not achieved.
- In the second project (CEIS), the team also made progress towards the goal. Spheres were chosen and coatings were proposed and tested.
- Progress to date is good. Some question as to whether future goals are attainable based on current trajectory.
- While the team has made a noticeable progress in the development of both the PVIS and CEIS technologies, the progress is rather slow and do not match the expected results. Several challenges remain in order to ensure the proposed technologies can achieve the target R-values as well as durability and stability for long-term performance.
- Based on what was presented, the project seems to be progressing well. Slide of work planned/completed in FY19 and planned for FY20 and FY21 demonstrated excellent progress to date.
- The team has characterized the oxygen permeability of polymer spheres, with and without nano-clay additions.
- The team has developed alternative manufacturing approaches for the polymer spheres.
- The team has demonstrated coatings of the insulation spheres, but there has not yet been sufficient performance characterization to assess how well its actually working.

- Seems to have made good progress, particularly with "mechanical chopping" method and working with spheres procured from others.
- The project has certainly made progress in reaching their goals. However, given the amount of time that has elapsed it seems that they are behind schedule.

D. Collaboration and Coordination

This project was rated **2.86** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Assembled team is large. Projects are in early stage, so external collaborations are primarily being considered at this point. An insulation manufacturer could be a good partner.
- Current stakeholder engagement sufficient for TRL of the technology.
- There is a good coordination between the diverse research team members to address the challenges for the development and testing of both PVIS and CEIS prototypes. However, the involvement of the industry members is not strong and could be actively strengthened to get valuable insights on the production challenges and costs for the proposed technologies.
- Project seems to be well coordinated.
- The team has had preliminary discussions with manufacturing partners and is working with the ORNL modeling group to coordinate model and material parameters.
- There is a large team on this project that seems to be working well together. Seems to also be good coordination with industry partners or others who would ultimately manufacture the material.
- This is a very early stage project. They have identified potential future industrial partners assuming that they can retain vacuum in the closed cells. Maintaining vacuum in the closed cells for long durations will be a critical hurdle and so it is not necessary for them to already be working with industrial partners. They are also presenting this work at a building conference and I anticipate it will generate excitement there.

E. Remaining Project Work

This project was rated **2.86** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining work for both projects is consistent with their current stages. Many challenges are still ahead for the teams.
- Future steps are logical.
- Some uncertainty on the steps to achieve FY19 targets that haven't been met yet.
- While the remaining work tasks are generally well outlined, the challenges that could be encountered and the mitigation solutions are not well defined. The remaining work to achieve the target performance (of over of R-14/in) seem significant based on the current progress and results achieved so far (R-5 for PVIS without binder).
- Well-detailed explanation as to what remains to be done was presented. Team seems to be on track to deliver what was proposed.
- The team will continue to work to reduce permeability of the polymer spheres.

- The team will characterize and continue to develop coated insulation spheres for insulation applications, with insulation targets.
- Seems to be on target to finish the project, although outcome is unclear. There is at least a path to achieve goal (page 13, page 21).
- The project has certainly made progress in reaching their goals. However, given the amount of work that remains it seems unlikely that they will reach their goals in the short period of remaining time.

F. Additional Comments and Recommendations

1. Project Strengths

- Concept is innovative and can be disruptive.
- Novel approach to achieving something akin to a vacuum insulated panel without the concerns about installation damage.
- Variety of approaches to synthesizing evacuated spheres.
- The main strength is the potential to have an alternative insulation option of VIP with significantly higher robustness and hopefully similar and lower costs.
- The fact that the technology is less likely to be degraded by punctures and the proposed mode of installation (i.e., via board and/or spray-applied components).
- The fundamental approach aims to produce low-cost evacuated particles that can be assembled into insulation materials, which could be hugely impactful.
- This is basic research and is contributing to our understanding of how to manufacture vacuum-insulating microspheres.
- The goal of achieving closed cell vacuum insulation is very exciting and would likely be very well received by the building community. The investigators recognize that this project is challenging both to (1) create the vacuum and (2) maintain the vacuum for an acceptable period of time. To this extent they have proposed a wide variety of approaches (PVIS and CEIS, with varying ways of creating the material in both cases) to reach their goals.

2. Project Weaknesses

- There are a lot of unknowns.
- Matrix's (binder) high thermal conductivity may deny most of the benefits of the vacuum filled spheres.
- Preserving vacuum in the spheres over time may prove difficult.
- Plan (or maybe description) of sphere characterization lacking, particularly with regard to measuring the internal pressure and permeability. Are these inferred from thermal conductivity or can they be measured directly?
- The weakness of the project is that there is no systematic approach to develop an optimal design for the evacuated spheres. So far, various technologies and manufacturing methods are being tested with only incremental improvements.
- Methods to be used for maintaining the vacuum within the spheres were not clear.

- Issue of price. Will the technology be affordable for home/building owners? What would the payback be?
- The oxygen permeability is a big problem for the polymer spheres, even with nano-clay addition. Given that sphere formation is also a challenge for the polymer spheres, it is unclear whether this approach should continue to be pursued
- This is hard and may not work. Unclear how well the spheres will keep vacuum. Unclear how to get the spheres to adhere into a useable material (nano-clay?).
- I am skeptical of polymers being able to maintain high enough vacuum levels over long enough periods for this to be useful. The inorganic materials will likely be more effective at this (but could also lead to more complicated processing and increased costs).

3. Recommendations

- Consider using proxies made of other low thermal conductivity materials to test the concept and the matrix. For example, could one use spheres of Aerogel and deliver a consistent low R-value in a matrix?
- More clearly document the feasible path to attain >=R14/in based on FY19; this is not clear from the presentation.
- Define a systematic approach (possibly based on modeling methodology) to develop evacuated spheres with the desired high R-values.
- Engage industrial partners more actively in the project and assess the costs of the proposed technologies along testing their performance.
- Consider possible thermal bridging outside the spheres. Look at the dependence of R value on the size of the spheres. Explore ways to quantify the efficiency of the coatings.
- Make a critical assessment of whether there is a viable path to addressing the permeability of the polymer spheres, and if not, focus efforts instead on the insulation spheres.
- Project seems to be doing the right things for an early stage R&D project. I like that you are both trying to manufacture the spheres and working with spheres from others. Seems like the purchased spheres (CEIS) may have more promise, so consider focusing more effort there.
- To me the most critical thing for the investigators to do at this point is to measure the vacuum levels in their closed cells (and it's unclear to me how one does go about measuring the pressure inside a 50 micron sphere). If they can show that they can achieve reasonable vacuum levels, then I'd say that this project should definitely get continued funding for FY 20 and 21 that they appear to be requesting.

Project #31450: Low-Cost Composite Phase Change Material

Presenter: Kyle Gluesenkamp, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Multiple reviewers agreed that the project has a good approach, with one noting how characterization and modeling will guide material design, while another highlighted the approach of using molecular dynamics (MD) simulations and XDR as a function of cycling. Another noted that the team has already surveyed available phase change materials (PCMs) and determined candidates to further study and one reviewer questioned if there is a more efficient way to pick design alternatives. One reviewer cautioned that a problem with salt hydrate PCMs is supercooling, and two reviewers recommended focusing more on phase separation and supercooling. One reviewer thought that the description of the approach to develop the low cost PCMs is unclear. Another reviewer found that the connection between the molecular modeling and material design should be more explicit.

All reviewers agreed that if this project can achieve its goals, it will have a significant impact. They noted the impact of low-cost PCMs is significant for enhancing the thermal performance of buildings, including integration within building envelope systems, as well as heating, ventilation, air conditioning, and cooling (HVAC) systems. The PCMs will provide thermal alternatives to electric storage that could be significantly cheaper and seamlessly integrated within the building systems. A few reviewers pointed to significant energy use reduction of the technology. Others highlighted the cost barrier in industry and mentioned that this technology could change the PCM industry if cost goals are met. One reviewer was impressed that this project could be less expensive than Tesla's and LG's technologies with comparable life spans.

The majority of reviewers found that progress to-date is reasonable for the time period, as the project is still in its early stages. However, one reviewer commented that little progress has been made so far in these early stages. A couple of reviewers remarked that the outcomes and purpose of MD simulation analysis are not clearly defined but a few reviewers were pleased that the team already had test results on composites. One reviewer commented that preliminary degradation studies look problematic but the majority of reviewers commented that the remaining work for the project seems reasonable within in the timeframe remaining. However, two reviewers pointed out that remaining tasks should be more clearly described and defined.

The majority of reviewers agreed that the team has solid coordination and collaboration. Multiple reviewers highlighted the multidisciplinary team with expertise that aligns with the important areas of the project, such as HVAC and thermal storage companies and graphite suppliers. One reviewer commented that the team has good early engagement with industry, while others recommended that the involvement of industry partners should be strengthened. One reviewer applauded the team's well-known track record of working well together. However, another reviewer commented that it is unclear how the building energy modeling component of the project is represented in the project team's expertise.

A few reviewers highlighted the concept of combining graphite with hydrated salts. However, another warned that it is unclear that graphite can address all of the shortcomings of salt hydrates (incongruent melting, large supercooling, low thermal conductivity, corrosion, etc.). One reviewer suggested the project team consider adding other salt hydrates as candidates, as the different combinations with graphite may offer alternative solutions.

One reviewer applauded this project for taking a much more scientific approach to creating better PCM composites than other comparable projects. One reviewer approved of the strong capabilities to test many samples at a time. One reviewer recommended the team look into active ways to avoid segregation in addition to the passive ones already being investigated. One reviewer suggested adding cycles as a parameter to make comparisons between different PCMs. Another reviewer noted the team should concentrate on the chemistry of the PCM and have the final product evaluated in several places with different climates.

Weighted Average: 3.08 # of Reviewers: 6
Approach: 2.67 Impact: 3.50 Progress: 3.17 Collaboration/Coordination: 3.17 Remaining Work: 3.17

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Using the HVAC system to charge salt hydrate phase change materials is compelling. While a large number of researchers is trying to incorporate the material to the envelope, separating them may prove more successful since each system may deliver their specific function: the envelope functions as the barrier while the separate PCM serves as storage. Addressing the incongruent melting and the large supercooling with the addition of graphite may lead to potential solutions.
- Good description of how characterization and modeling will guide material design.
- Rapid characterization development will speed material design evaluation and help screen alternatives. Is there a more efficient way to pick design alternatives?
- It is clear that the project is still its early stages with limited progress milestones. The description of the approach to develop the low cost PCMs is rather sketchy. The approach presentation rather compares the level of investments between electric storage and thermal storage as well as some applications such integration with the HVAC systems, very little has been outlined to define how the low-cost PCMs will be developed, optimized, and tested.
- Well thought out approach. Too many acronyms that are not necessarily known by reviewers were used. This makes the interpretation of any information much more difficult.
- Good approach: already surveyed available PCMs and found candidates PCMs that will study more in details with different composites using compressed expanded natural graphite (CENG. PIs will do detail analysis on different composites that could achieve goals.
- It seems methodology is well defined, and all stages flow naturally.
- I like the authors approach to solving the phase separation problem by using molecular dynamics simulations and XRD as a function of cycling.
- However, another huge problem with salt hydrate phase change materials is supercooling. I did not see any work/path to addressing this (although perhaps the investigators have a plan that they didn't discuss during the presentation). The supercooling of these materials can often be many tens of degrees Celsius. This can make it extremely difficult to refreeze them after they have melted and can render the material near useless.
- The investigators seem to have focused some of their early attention on improving thermal conductivity. While improving thermal conductivity helps and may need attention later, this is not the primary problem. More important is to address phase separation and supercooling because these problems can incapacitate the material. Low thermal conductivity just slows thermal charging/discharging time but can be addressed via phase change material packaging (i.e., thinner layers as opposed to big blocks).

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact of developing such PCM may be very significant in energy use. Reducing costs is one of the major needs in PCM incorporation in buildings. While salt hydrates have been good inexpensive candidates, they have drawbacks that the team is trying to address.

- A viable phase change material could have large impact on energy efficiency and thermal energy storage in general.
- If successful, the impact of low-cost PCMs is significant for enhancing the thermal performance of buildings including integration within building envelope systems as well as HVAC systems. The PCMs would be provide thermal alternatives to electric storage that could be significantly cheaper and seamlessly integrated within the building systems. However, it is not clear if the project would deliver in the targeted performance and cost levels.
- If the project were to be successful, ORNL would have developed a system less expensive than Tesla's and LG's with comparable life span. If the concept is able to be integrated with building technologies, the impact could be significant.
- One of the main barriers for PCM is COST. If they can achieve their goals (and at the same time increase their thermal conductivity), this could change the PCM industry.
- However, there are still challenges ahead due to durability too that the team plans to address.
- This project's use of (i) molecular dynamics, (ii) XRD vs. cycling and (iii) low flow forced convection + high throughput T-history will help unlock a better fundamental understanding. This could in turn lead to meaningful improvements in salt hydrate phase change materials that might finally make them practical for use as phase change thermal storage in buildings.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met ***project-specific goals***.

- Team developed some concepts using graphite. Samples have been created and IP protection is being pursued. Team developed a series of tools to evaluate the performance of the system. Results of cycling of the samples were presented with some improvement identified for some combinations. Simulations have been conducted using molecular dynamics to understand phase segregation.
- Progress to date seems good. Some test results on composites already. Degradation results presented; not much shown on calorimetry results.
- MD simulation results shown but preliminary conclusions not clear.
- As noted earlier, the project is its early stages and thus little progress has been made so far. Some of the outcomes and the purposes of some noted completed tasks are not clearly defined such as MD simulation analysis. More details should be provided to better assess the challenges that would need to be addressed in the remaining tasks outlined for the project.
- Significant progress has been made to date. This assessment is based on what was presented.
- All going very well, already testing composites, etc.
- This project is only 6 months into a 3-year project. They have achieved a reasonable amount of progress in this time period.

D. Collaboration and Coordination

This project was rated **3.17** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Team collaboration is in place with different organizations. Potential industry partners are being pursued, but none is already participating.
- Large team from multiple organizations.
- Good early engagement with industry.
- The team involves members from several institutions with clear tasks and the groups seems to be well coordinates even though the progress for each group is not well characterized. The involvement of the industry partners while noted need to better strengthen since it still in the exploration phase with little contribution to the project.
- The team covers, with the expertise of its members, the important areas of the project. This team has a well-known track record of working together well.
- Team already reached out to different HVAC and energy storage companies and has a strong team. The only not very clear part was the building energy modeling part.
- The project is talking with a variety of thermal storage companies, HVAC companies, and graphite suppliers. They are also publishing their work via patents, journal papers, and conferences.

E. Remaining Project Work

This project was rated **3.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Next steps are clear.
- Remaining tasks could use more description, but the general steps seem correct to achieve the desired goals.
- The remaining tasks while listed are not well described and defined. In particular, the expected challenges and potential mitigation solutions are not discussed.
- The Project Plan and Schedule, together with what has been completed today, seems very reasonable, and one that will take the team to the timely completion of this project.
- It is still early on, but work looks very promising.
- This project still has 2.5 years left on a 3-year timeline. The remaining amount of work seems reasonable.

F. Additional Comments and Recommendations

1. Project Strengths

- Multidisciplinary team.
- Clear understanding on how to approach the problem.
- Good results in a short period of time.

- Adding a relatively inexpensive additive (graphite) to overcome the limitations salt hydrates, which are already fairly promising from a cost and melting temperature perspective.
- Large project team with different expertise.
- Combining simulations and rapid experimentation to discover best candidate material systems.
- The main strength of the project is the potential benefits of the low-cost PCMs if successfully developed, tested, demonstrated, and commercialized for building applications (i.e., integration in building envelopes and HVAC systems).
- Expertise. The concept of combining graphite with hydrated salts. The expertise of members of the team.
- Team already identified potential PCMs with low cost as well as a low-cost solution (using compressed expanded natural graphite (CENG)).
- Team has a solid plan and already testing different composites.
- Experimental plan is strong with capabilities to test many samples at a time.
- If successful, this could be a game changer for PCMs.
- This project is taking a much more scientific approach to creating better phase change material composites. Most phase change material composite work that I see appears to be “shake and bake” wherein the researchers put in filler material X at varying volume fractions into phase change material Y. I like this project’s use of (i) XRD to probe degradation rates, (ii) MD simulations to better understand phase separation, and (iii) high throughput T-H tests using low flow forced convection.

2. Project Weaknesses

- Working with a single salt hydrate.
- Lack of industry participation.
- Not very clear on graphite deals with the listed shortcoming of salt hydrates (incongruent melting, large supercooling, low thermal conductivity, corrosion). Would find it hard to believe that graphite is able to address all of these issues.
- Preliminary degradation studies look problematic (large degradation after just a few cycles).
- Not much justification for cost estimates (yet).
- The weakness of the project is a lack of clear development, testing, and analysis approaches for the proposed low-cost PCMs. Some of the tasks lack specific clear goals and expected outcomes and challenges as well as potential mitigation solutions.
- Nature may impose unwanted issues with PCM segregation.
- I did not get a strong impression on the building energy modeling, how are they going to find the optimal PCM properties?
- Team has plans to address some issues, but not all have been addressed, such as durability.

- As mentioned earlier, the supercooling in these materials can be a significant problem. The investigators should have a plan to address this. It is possible they have a plan in this regard, but just didn't describe it during their presentation.
- Is this supercooling problem why they didn't show a T-history curve of salt hydrate on Slide 12? They showed octadecane here, which is basically paraffin. Paraffin does not supercool because it freezes in an amorphous structure (salt hydrates supercool because they must form a crystalline nuclei to freeze and this can require cooling significantly below the freezing point).

3. Recommendations

- Consider adding other salt hydrates as candidates. The different combinations with graphite may offer alternative solutions.
- Consider inviting industrial partners that already work with PCMs.
- Consider active ways to avoid segregation, in addition to the passive ones that are being investigated.
- Consider adding cycles as a parameter to make comparisons between different PCMs.
- The connection between the molecular modeling and material design should be made more explicit. How will the simulation inform material design and selection? What do they hope to learn from the simulations?
- Be clearer about the plan to overcome all of the technical issues with salt hydrates. It seems like the addition of graphite can only be part of the solution.
- Well defined the remaining tasks and their expected results and expected challenges to be addressed.
- Engage the industry representatives early in the project especially for the techno-economic analyses that are planned to be carried including the manufacturing challenges and costs.
- The testing approach of the properties of the low-cost PCMs should be clearly defined and compared to the existing materials.
- Concentrate on the chemistry of the PCM. Have the final product evaluated in several places with different climates.
- Use building energy simulation to guide the selection of materials properties and quantify the benefits.
- There are already commercial companies that are attempted to make, manufacture and sell salt hydrates as phase change materials. I assume the investigators are talking to these companies.
- Some common ways to deal with phase separation are (i) the use of small phase change material packets, (ii) water impermeable packaging, (iii) the addition of gelation agents to slow migration. Some common ways to deal with supercooling is the addition of nucleating agents. While these are standard ways of approaching these problems, I'm unsure if any of these approaches have been "good enough" (i.e., if they were, then perhaps salt hydrate phase change thermal storage would be much more widespread).

Project #31312d: Models to Evaluate and Guide the Development of Low Thermal Conductivity Materials for Building Envelopes

Presenter: Som Shrestha, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

A few reviewers commented positively and noted that this is needed in industry and will aid in the development of new materials and address a knowledge gap on subcontinuum thermal transport in amorphous materials and research on interfacial thermal resistance. However, multiple reviewers expressed concern about the inherent difficulty in modeling subcontinuum thermal transport. Many reviewers noted that while ambitious, the project approach is very general and not sufficiently focused. They agreed that it is unclear what the model will capture, what materials will be considered, accuracy levels desired, the input parameters required, limitations of the models, and which morphology possibilities will be available. One reviewer commented that the team will likely need to rely on empirical modeling due to the difficulty of properly incorporating nano-scale heat transfer effects through physics-based models, while another pointed out that the number of effects and variables the project is attempting to capture in a unified model are too broad. A reviewer suggested that defining the scope only on the characterization of materials may be more beneficial than building the model, as the model will not provide significant results if it cannot be calibrated.

Reviewers provided multiple recommendations to the project team, and one noted that the project focuses on foam-like materials and asked if the model could be applied to fibrous systems. Another suggested that in addition to steady state, the team should look into possible non-steady state capabilities of the model. One reviewer commented on the importance of providing well-defined instructions on how to use the model and clearly outlining if and how the models can be flexible to be used to develop and assess properties of other materials with no empirical data. Another reviewer encouraged the team to focus on sensitivity to key design variables and uncertainties rather than the accuracy of the final conductivity prediction. One reviewer recommended considering motion of molecules when dealing with interface heat transfer.

Multiple reviewers commented that the project could be hugely valuable in the design and development of new insulation materials. Many reviewers agreed that the primary strength of this project is the development of reference models that can be valuable to improve the design optimization of highly insulating materials for building envelope systems. One reviewer noted that developing models does not directly deliver energy savings, but that models are needed to create new insulation systems that may deliver energy savings. One reviewer pointed out that if the project can characterize the materials to calibrate the model, it will be quite useful. A reviewer critiqued that the project presentation did not provide impact information. Two reviewers expressed concern that they were unclear how useful the model will be, questioning the validity of a quantitative model for materials development, as well as the flexibility of the model.

Multiple reviewers noted that the team has made progress building pieces of the model and running simulations, but two reviewers suggested that better definition of the project scope is required. One reviewer remarked that the project plans to incorporate nano-scale effects will take longer than planned, so the project timeline should be adjusted accordingly. A couple of reviewers noted that challenges remain to completing model calibration and sensitivity analysis. One reviewer flagged the limited data available for the model as a potential issue.

Many reviewers agreed that the project team has extensive collaboration through a strong advisory board of thermal transport researchers and the materials development field. One reviewer commented that the project team is engaging a good portion of the research community who would be the users of the modeling tool. Another reviewer flagged that it appeared most of the collaborators are members of universities and/or research labs. This reviewer recommended seeking input from industry stakeholders that may provide valuable feedback of the required capabilities of the models as well as possibly provide additional data.

A couple reviewers were concerned about completing the project within the current timeframe. Many of the reviewers observed that project work is logically planned and progressing well. A few reviewers raised concerns regarding materials characterization for model calibration, noting that it will prove challenging, especially within the timeframe planned. One reviewer cautioned that this project will be an incremental step forward, not a significant advancement in the state-of-the-art insulation materials.

Weighted Average: 2.73   # of Reviewers: 7
Approach: 2.57   Impact: 2.86   Progress: 2.57   Collaboration/Coordination: 2.86   Remaining Work: 2.86

Program Response

The Building Technologies Office leverages the peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **2.57** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Models to evaluate the thermal performance of insulation, particularly novel ones, are always in need, so the work has promise. The multiple scales that need to be addressed pose some interesting challenges. The team proposes to bridge the work developed by semiconductor research into the heat transfer realm. They also would like to apply findings from molecular dynamics to develop such models.
- Focus seems to be on the solid/solid interface phenomena and gas interactions with matrix.
- The modeling goals are very ambitious, but the approach does not appear to be sufficiently focused. The number of effects and variables that they are trying to capture in a unified model are too broad. They were not clear about which morphology possibilities would be available in the model. They need to more plainly state what the model will and will not attempt to capture.
- The presentation was not clear about the scope of the models and tools to be developed as part of the project. For instance, it is not clear what materials will be considered, accuracy levels desired, the input parameters required, and the limitations of the models.
- As presented, it seems that the approach is very general and vague at this time. It seems, but this may not be the case. This assessment is only based on the material presented and how questions were responded during the presentation.
- The development of high R/inch insulation requires subcontinuum thermal transport, and a model to aid in material selection and design will aid in the development of new materials.
- The Proposed modeling tool will capture all modes of heat transfer, including subcontinuum transport, interface resistance, gas conduction, and radiation.
- The research on subcontinuum thermal transport in amorphous materials is limited, and this effort will aim to filling in the research.
- The research on interfacial thermal resistance is also limited for amorphous materials and polymers. The project will address this by performing molecular dynamics simulations and experiments to identify types of interfaces with high thermal resistance, which is a key element to inhibiting thermal transport.
- It is not clear how much accuracy can be achieved in a computational model.
- It seems like you are taking on a very large task with a lot of unknowns. As stated in the presentation, you weren't originally intending to actually do the molecular/material characterization but realized that you needed to in order to build the models. It seems to me that it might be better to define the scope only on the characterization of materials and hold off on building the model. The model won't be much good if you don't have anything to calibrate to.
- The advisory board will help mitigate many of the problems that this project is likely to run into. It will be difficult to properly incorporate nanoscale heat transfer effects through physics-based models. This is due to the fact that nanoscale heat transfer is highly dependent on how the material is processed as opposed to just the materials themselves. They will likely need to rely on empirical modeling here.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.86** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- While the development of models does not deliver energy savings, it is needed to work on new insulation systems that may deliver such savings.
- The existence of such model will direct insulation developers on the significant parameters that allow to reach better insulation properties.
- The project could have high impact on the design of new insulation materials. It would be particularly valuable if it could suggest new pathways for thermal conductivity reduction (rather than incremental change to approaches tried in the past).
- The impacts seem to depend on the available data required to develop the models or the parameters needed for the models. It is not clear how flexible the tools/models would be in order be used to assess future materials. For instance, how the models can be used to evaluate dynamic and tunable materials.
- No impact information was provided by the presented and it was not included on the downloaded power point.
- It is not entirely clear that a quantitative model will be that useful: is the materials development approach being driven by conceptual knowledge or quantitative knowledge? It is not clear that a quantitative model is more useful.
- While the accuracy of the final predictions of a model are not particularly important, the greatest impact will come from being able to predict which variables are more impactful than other variables, which allows materials engineers to assess the tradeoffs between different design variables. If the model can achieve this level of predictive accuracy, it will be highly beneficial.
- It is not clear that at this juncture, a quantitative model is the primary barrier to materials development. Instead, measurement or low-cost manufacture may be the primary barriers. However, a model that can predict the relative impact of these variables may support addressing the other barriers.
- Per previous response, it seems hard to build a useful model if you don't have materials to calibrate it to. So, I'd focus on the standard materials characterization first.
- But if the project goals are successful, this would be quite a useful model.
- If the described model is in fact developed and can successfully predict thermal resistance, it will be hugely valuable as a means to direct the experimental/developmental efforts in the development of new insulation materials.

C. Progress

Based on current project efforts, the project was rated **2.57** for the degree to which the project has met ***project-specific goals***.

- Work is under development and it is difficult to identify how successful it has been this early. A path for development of the models was offered by the team. Inclusion of existing research was presented.
- Team presented a generated geometry of porous materials with size and thickness distribution.

- Molecular dynamics simulations were conducted predicting the thermal conductivity in the range of what is seen through experiments.
- Team also presented a series of effective thermal conductivity models of porous media as a function of its porosity.
- Team presented options to calculate the thermal radiation within the insulation.
- They have made some progress on defining the scope of what they plan to model but more scope definition is required. They need to set realistic expectations on what can be achieved over the term of this project.
- The development of the models for certain insulating materials has been completed and consider bulk heat transfer, morphology, ITR, and STT. Even though the models are mostly based on empirical analysis using experimental data. Some challenges do still exist to complete main key tasks for the project including the calibration of the models and sensitivity analysis to assess the key parameters that affect thermal properties of insulating materials.
- Progress information is very vague. It is difficult to know if what is listed as progress has already been done, or is being done, or will be done. It seems that at this point the team is only working with Polysterene.
- The team has built out several pieces of the model and is currently gathering and integrating feedback from the advisory board.
- The team has built molecular dynamics simulations for interface resistance and has demonstrated a good match to experimental data.
- The project seems to have a good team and is making good progress. However, again, I am concerned about size of scope. If you can achieve the materials characterization and model development, in the timeframe and budget, you will have something very valuable for the industry. But there are still a lot of characterizations and variables to evaluate (per slide 9).
- This project is only about half-way through year 1 and they have successfully done MD simulations non-porous bulk polystyrene. While that is progress, I anticipate that they will encounter significant problems once they start trying to incorporate nanoscale effects. Their FY19-20 work will likely take longer than a single year and it will be important to start some of that during this year 1.

D. Collaboration and Coordination

This project was rated **2.86** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- An extensive team of researchers, including an advisory board, was assembled.
- The advisory board is strong and well qualified. They have engaged a good portion of the research community who would be the users of this modeling tool.
- It seems most, if not all of the collaborators are members of universities and/or research labs. There are no members of the team with connections with the industry that may provide valuable feedback of the required capabilities of the models as well as possibly additional data. In the future, it is recommended to seek input from other stakeholders (i.e., insulation industries that typically have significant research and development capabilities).
- If it is difficult to see how much progress the team has done, it may be that in part collaboration and coordination are lacking.

- The team has an advisory board that includes both thermal transport researchers and insulation materials developers, and they are incorporating their feedback in response to their model development.
- The team is comprised of and coordinates well with relevant stakeholders. Other stakeholders in the room expressed the need for the model that is being developed.
- The stakeholders for this project are other researchers and the materials development field. By incorporating an advisory board, they are successfully engaging these individuals.

E. Remaining Project Work

This project was rated **2.86** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Project work that remains to be executed is consistent with its current stage. Model calibration will prove to be challenging.
- All remaining work would still only be an incremental step forward. I don't see this tool, as realized, leading to significant advancement in the state-of-the-art insulation materials.
- Generally, despite the challenges, the project is progressing well. The team seems to be in the right path to complete the project. Again, some involvement of practitioners and industry representatives may be valuable for this project.
- Somewhat detailed plan was presented.
- Due to the challenges with quantitative accuracy in subcontinuum models, there should be an explicit focus (at least as a backup plan) on being able to do sensitivity analysis on key parameters – determining the dominant variables and the key uncertainties. Even if the model cannot accurately predict overall thermal conductivity values, it could still have significant value if it can accurately predict trends and relative impacts.
- I think the work is logically planned. I'm just not sure you'll be able to get it all done with the budget/time, depending upon how much effort is required for the materials characterization.
- The year 2 and year 3 work could easily take longer than those dedicated time periods. In addition, a number of compromises in modeling quality will need to be made in order to achieve a true nanoscale-to-macroscale simulation. They will need to push to start those parts of the project earlier and possibly even start some of the year 2 work in year 1.

F. Additional Comments and Recommendations

1. Project Strengths

- It tackles an important and challenging problem of predicting and tuning the performance of novel insulation materials.
- Extensive team of researchers can provide insight to make progress towards developing the model.
- Understanding of the different modes of heat transfer exists.
- Ambitious effort to model insulation materials.
- Strong advisory board.

- Could lead to the identification of new pathways to thermal conductivity reduction (if based on 1st principles).
- The main strength is that the potential development of reference models that can be valuable to improve the design optimization of highly insulating materials for building envelope systems.
- Resources of National laboratories.
- The primary strength of the project is the opportunity to provide a theoretical foundation for assessing the relative impact of different design variables, to aid materials developers in assessing the tradeoffs between different design variables.
- Ultimately if successful, it could greatly speed up the process of materials research by enabling researchers to use the modeling tool to do initial analysis as to what might make sense, rather than having to create every potential material to test.
- In my opinion, the primary value of this project will come from its use as a design tool for sensitivity analysis. It will be very difficult to achieve quantitative predictive ability. However, it can provide materials designers and manufacturers a guide for understanding where they should focus their energies and efforts (i.e., where they can potentially get the biggest bang for their buck). For example, the model may tell them that they should they are highly sensitive to interfacial thermal resistance and they should focus on ways to improve that (i.e., increase acoustic impedance mismatch, introduce surface disorder/contaminants, etc.).
- The advisory board will help ensure that they produce a useful tool and capture important parameters.

2. Project Weaknesses

- There are challenges on how to validate such model.
- Complex interactions may exist, and model may have difficulties accounting for them.
- Material characterization needs to be a priority. Other projects may deal with it.
- Does not appropriately communicate the complexity of the modeling task. Multiscale models that bridge the range from the nanoscale to the macroscale are notoriously difficult to make work.
- Scope not adequately defined. What are the model restrictions no materials, morphology options, etc.? As currently posed, the model wouldn't be able to model anything and everything.
- The main weakness of the project is that rely heavily on empirical data to develop the models limiting the applications and the scope of the project. In particular, the models may only be suitable for materials with known experimental data.
- There is so much to be learned by the team.
- The primary weakness is the inherent difficulty in modeling subcontinuum thermal transport in a way that will provide accuracy beyond the order of magnitude estimates seen in the experimental literature.
- Need material characterization to make the model work. There is still much characterization to do before you can build all the variables into the model.
- I don’t believe that this project will achieve quantitative predictive ability of heat transfer in insulation materials using physics-based models. The empirical models might yield better results. In the case of physics-based models, researchers have long tried to create models that predict nanoscale heat transfer well. While

they have had some success, this success is largely limited to very "clean" systems such as 99.9999999% pure crystalline silicon processed in a clean room with electron beam lithography. Replicating this success in comparatively very "dirty" systems like building insulation will likely be unsuccessful.

- This difficulty lies in the fact that subcontinuum heat transfer and interfacial thermal resistance is hugely dependent on the nature in which the sample is prepared (i.e., materials processing considerations as opposed to the materials themselves). Subcontinuum heat transfer depends on surface roughness, impurity concentration, impurity types – point defects, line defects, grain boundaries. Interface thermal resistance depends on surface contaminants, surface roughness, atomic mixing at the interface, etc. Knowing these factors is very difficult for crystalline materials and will even more difficult for porous amorphous materials. It's likely that people simply won't know these values.
- In addition to the above difficulties. There simply isn't much literature on interfacial thermal resistance at amorphous-amorphous interfaces. There is some data on amorphous-crystalline interfaces, but that is also quite limited.

3. Recommendations

- Use engineered insulation systems to validate the model. Create artificial fake insulation systems in the laboratory and test the capabilities of the model to capture the phenomena.
- Involve insulation manufacturers in the team.
- Focus seems to be in foam-like systems. Could the model be applied to fibrous systems?
- Start with small steps. Define a particular morphology (i.e., evacuated spheres in a matrix) with a limited number of parameters. Get that working and then expand the scope of what can be modeled.
- Need to better discuss the models and the tools that you plan to develop, the form, and the needed input and desired output of the models/tools.
- Clearly outline if and how the models can be flexible to be used to develop and assess properties of other materials with no empirical data.
- In addition to steady state, look into possible non-steady state capabilities of the proposed model. Use a material that is well known for calibration purposes. Evaluate all the sensitivities of the model. That is, to which parameters is the model sensible to. If possible, consider motion of molecules when dealing with interface heat transfer.
- Focus on the sensitivity to the key design variables and uncertainties rather than the accuracy of the final conductivity prediction. Getting the trends right seems to be more important than getting the conductivity right.
- Again, focus on standard materials definition and characterization. If you achieve that, then the next step can be creating the model once you have something to calibrate against.
- Since this model will likely end up being a design tool for sensitivity analysis, it will very important to provide well defined instructions on how to properly use it. It will need to allow users to enter in the various values for different parameters (e.g., interfacial thermal resistance), but it should also inform users of what "typical values" of these parameters are).

Project #31395: Ultra High R/inch VIP with Developmental Core Material and Self-Healing Films to Improve Durability of VIPs

Presenter: Kaushik Biswas, Oak Ridge National Laboratory
DOE Manager: Sven Mumme

Brief Summary of Reviewer Comments

Overall, reviewers approved of the approach to the two Oak Ridge National Laboratory (ORNL) projects: (1) Ultra High R per inch Vacuum Insulated Panel (VIP) with Developmental Core Material and (2) Self-Healing Films to Improve Durability of VIPs. The projects were described as well-thought-out, methodical, and consistent with both project-level and program-level goals. One reviewer highlighted the importance of long-term performance studies and applauded the team's emphasis on manufacturing and scaling up the technology. The puncture tolerance and durability of VIPs were two challenges that several reviewers mentioned would be addressed during the duration of the projects. A reviewer continued and stated that, if successful, the development of self-healing VIPs films could lead to a "much larger wide-scale adoption of VIP panels."

With regards to project impact, reviewers agreed that the studies had the potential to significantly contribute to reducing energy use in buildings. The application of the technology's use in retrofitting buildings was stressed as particularly beneficial in terms of energy savings. The majority of reviewers emphasized the impact that the projects could have on VIPs as a building envelope technology. The opportunity to increase the performance and market adoption was described as "transformative in the area of insulation."

In terms of the team's progress, reviewers applauded the projects' preliminary work and their planned future activities. Some of the specific progress included the development of a low-cost polymer fiber core, a retrofit demonstration on the R25 boards, and testing of self-healing method using epoxy chemistries. In addition, reviewers reiterated the importance of addressing the remaining challenges related to long-term performance, cost effectiveness, and durability of both project materials.

Reviewer comments on the team's collaboration and coordination efforts were overwhelmingly positive with five of the reviewers rating the section as "Outstanding." Several reviewers referenced the added value of partnering with industry including material manufactures of both VIPs and traditional building insulation. However, it was recommended by two reviewers that the team accelerate their collaboration surrounding the self-healing films project.

Weighted Average: 3.38   # of Reviewers: 7
Approach: 3.29   Impact: 3.43   Progress: 3.29   Collaboration/Coordination: 3.71   Remaining Work: 3.14

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.29** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Team's approach is consistent with the goals of the project. Goals are aggressive to achieve much higher R/inch.
- Approach to both projects well thought out and methodical.
- Long-term performance studies important.
- Nice approach to initial testing of self-healing films; good emphasis on manufacturing and scale-up.
- The approach for both projects is well defined and documented based on results and lessons learned from previous projects. The testing results are promising for the insulation materials even though challenges remain to address the durability, long-term performance, and production cost.
- The team has precisely presented the history of this project and its accomplishments. Based on this, the current path represents a sound and proven approach.
- This project aims to improve vacuum insulated panels (VIPs) on three fronts: improving their thermal performance, improving their long-term performance and permeability, and increasing their durability to puncture.
- The long-term performance and puncture tolerance of VIPs are key limiting factors in their usage and adoption.
- Both new VIP technology and self-healing films seem like promising technology.
- The use of tri-lobe fibers as a VIP core material seems to be a good approach to increase R-values as this can scatter radiation, increase thermal interface resistance, and lead to potential thermal transport anisotropy.
- I like the idea of self-healing VIP films. It would seem to me that this could lead to a much larger wide-scale adoption of VIP panels.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.43** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- While there can be issues with the use of VIPs, if successful, the project may have a significant impact in energy use in buildings. When thickness is limited, VIPs can deliver thermal performance when no other material may be able to.
- Vacuum insulated panels have great potential to improve energy efficiency. Both products seek to address the shortcomings of these materials to increase commercial viability.
- If successful, both projects can provide high R-value materials and self-healing coatings for VIPs to make insulating building envelope cost effective retrofit measure and thus improve the energy efficiency for the existing building stock. The progress of the two projects is satisfactory and promising.
- Project aligns well with program goals. A development of the proposed final product would be transformative in the area of insulation.

- VIPs provide a variety of energy savings opportunities, with a particular benefit for retrofits. By making VIP more viable, this project could have significant benefits.
- Seem to be working on useful R&D that is still early stage, but with an eye towards commercialization and what is needed in the market.
- I think the potential impact of self-healing films for the VIP barrier has the potential to have a huge impact due to the potential for market acceptance (i.e., addressing durability and concerns for puncture/poor installation). Achieving higher R-values and lower cost is important as well, but in my opinion the longevity and poor installation of VIPs is the more important issue (i.e., I think the impact of the self-healing films is potentially more than the higher R-value).

C. Progress

Based on current project efforts, the project was rated **3.29** for the degree to which the project has met ***project-specific goals***.

- On both projects, progress has been consistent.
- Retrofit demonstration of R25 boards in use in a low-slope roof.
- New core developed.
- Aging tests show deterioration at higher temperatures. Even at temperatures as low as 24 C, the deterioration was above 20%.
- Low-cost polymer fiber core was developed.
- Self-healing films are necessary to prevent full deterioration of thermal performance when VIP is punctured.
- Good progress on meeting goals.
- The results of the testing are promising and show good progress towards achieving the proposed performance targets for both the high insulation materials and the self-healing coatings for VIPs. However, the project team need to address the challenges related to the long-term performance and durability for both materials. Moreover, the production costs for the insulating materials remain high and may not competitive compared to the conventional options. More detailed analysis should be considered to estimate the target cost for the self-healing coating for VIPs.
- Based on what was presented and accomplished to date and compared to the Project Plan and Schedule, progress to date is as expected.
- The team has explored a variety of approaches to improve the performance of VIPs, including opacifiers, fiber processing, and fiber size, demonstrating feasibility of R80/inch.
- The team tested aging in an installed site, which was outfitted by panels that were manufactured in a continuous process.
- The team completed a preliminary cost analysis, beating their project targets.
- The team demonstrated the feasibility of self-healing using epoxy chemistries, demonstrating good performance of the healing film, but longer time testing is needed.
- This is really two projects, and both seem to be moving along nicely.

- The project appears to be making good progress in reaching their goals (albeit much of the work in this project is outside of my expertise and so I may not be a good judge of where the biggest hurdles are).

D. Collaboration and Coordination

This project was rated **3.71** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Different teams were assembled to deliver the two projects. External input from two manufacturers will prove to be valuable to the team.
- The ongoing collaboration with Firestone a strong asset of this program.
- The involvement and the collaboration of the industry is well documented especially with the production of composite insulation boards at Firestone. Moreover, professional contractors have used the insulating boards to retrofit a roof. Similar industry involvement for the self-healing coating product should be accelerated.
- It seems that the team has a good record of working well together. Partners seem appropriate.
- The project team includes material manufacturers of both VIPs and traditional building insulation.
- The team identified potential partners for self-healing films.
- Great to see real-world test of the new VIP technology! Good industry partnerships.
- There seems to be less collaboration around the self-healing films at this point, but once it gets a bit further in the lab, it would be good to test the films with a variety of manufacturer's VIPs...
- The investigators are talking to the right people (i.e., VIP manufacturers).

E. Remaining Project Work

This project was rated **3.14** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining work in both projects is ambitious, but doable.
- Steps to understand observed thermal performance of High R/inch VIP make sense.
- Remaining work for self-healing films mostly around manufacturing: all goals seem reasonable and attainable.
- Both projects seem to be complete (at least in terms of spending all DOE funds). Some potential future work has been proposed to refine the performance of both products and improve their production as well as lowering their manufacturing costs. These tasks are more suitable to be supported and funded by the industry rather than by DOE.
- Project seems to be progressing well and the remaining work is expected to follow the same path.
- Most of the planned remaining work is logical and reasonable given the current status and goals of the project, including optimizing production parameters and testing stability and robustness.
- There is a need to further explore the tolerance to defect size and puncture removal for the healing films.
- Seem on track to complete the projects.

- The project appears to be have made good progress in reaching their goals and so reaching their remaining goals seems doable (albeit much of the work in this project is outside of my expertise and so I may not be a good judge of where the biggest hurdles are).

F. Additional Comments and Recommendations

1. Project Strengths

- Comprehensive project to both manufacture and prevent gains of pressure of VIPs.
- Empirical and numerical approaches are used to deliver results.
- Experience with VIPs in other developments can be leveraged.
- Concern about maintaining performance after puncturing the VIP is relevant.
- Identifies and addresses critical roadblocks to the successful deployment of VIPs such as barrier film puncture and permeability.
- Industrial collaboration strong and ongoing.
- Long-term degradation studies important.
- The strength of both projects is that promising performance of the products has been demonstrated through laboratory testing and even field monitoring (insulation boards). Thus, products are close to be ready for production refinement and ultimately commercialization.
- Team. Partners. Expertise. Work completed to date.
- There is a comprehensive approach to improving VIPs, with a clear awareness of the various barriers.
- I like the fact that you have a product with the VIPs that you can test in the real world, that is intended to be a "slot-in" for poly-iso boards.
- The self-healing films is a great idea given the fact that on construction sites, you cannot expect the workers to take the care one would in a lab, and sheets will get punctured.
- Please see comments interspersed in above questions.

2. Project Weaknesses

- Polymeric fibers traditionally deliver a lower thermal resistance than glass or mineral wool fibers. Why are they being considered in the project? Is there a special characteristic of these fibers that make them a suitable candidate? Maybe the team could consider a comparison.
- Stability of the thermal performance at higher temperatures is of concern.
- None.
- The main weakness of the project is lack of sufficient testing to document durability and the long-term performance of the products especially the self-healing coating. Moreover, the production costs for both products may still represent a significant challenge for their market adoption.
- Cost of the product may be an issue. Life expectancy of the product may be an issue as well. How long can the expected pressure inside the VIP be kept?

- None.
- The VIP boards sound quite heavy, which could be a real barrier to commercialization. Also, the fact that attachments (nails) must be limited to the 1" foam strips will make it hard for the building industry to adopt. Even though so much of housing is 16-on-center, there are various angles, eaves, roofs, and various custom places. So, you might end up with high insulation VIP in the main part of a wall, but then all the edges and corners must be field-applied foam with a much lower R-value (or much thicker application?).
- Self-healing films is a great idea. Tests are still early stage. Must test removal of nails, too. Think puncture-resistant tires. Figure workers in the field will do everything you don't want them to do, and design/engineer for it. If we get a really robust self-healing coating out of this, it could have broad applicability, not just for VIPs.
- Please see comments interspersed in above questions.

3. Recommendations

- VIPs are vapor barriers. What sort of recommendation could be made in regard to the placement of VIPs in the wall assembly?
- Consider other fibers to contrast with the polymer fibers being used.
- None.
- Seek support of industry partners for future improvement and production optimization of the insulating boards. A more active industry involvement for improving the performance of self-healing coatings should be also sought.
- Refine the manufacturing of both products to reduce their costs.
- Needles are being used to puncture the panels. May want to try a larger diameter (e.g., nail) puncturing tool. Test the technology under several different climates.
- The self-healing film work should include an investigation and consideration of the variety of puncture scenarios that might occur in a practical use situation.
- Continue working closely with manufacturers to ensure that the R&D directions are aligned with how the products would reasonably be used in the field (i.e., weight of boards, puncture testing).
- The investigators have shown reasonably good self-healing when the films are punctured, and the nail/screw/fastener stays in the material. It should also be investigated whether the healing will still work once the nail/screw/fastener is removed because this will happen in the real world.

Project #35530-35531: Core Windows Research & Development

Presenter: Eleanor Lee and Charlie Curcija, Lawrence Berkeley National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Overall, reviewers praised the triple pane insulating glass unit (IGU) approach. Reviewers agreed that the Core Windows Research & Development work is based on a solid background of existing research and utilization of current technology for thin glass beyond televisions. Reviewers noted that the approach to characterize and evaluate energy saving window technologies is incredibly comprehensive and analytical. One reviewer highlighted that the largest hurdle may be thin glass manufacturing and handling.

Reviewers generally agreed that this project provides tools, methods, and analysis of advanced window technologies to guide materials/product developers and window manufacturers to optimum performance products, although it is not focused on new window technologies. Based on initial assumptions, the impact of this project as modelled is tremendous, and two reviewers singled out the importance of the Foundational Design Research Aid (FDRA) project as crucial and something most technical subjects lack, adding that the project has merit and should be continued. Another reviewer expressed uncertainty over the impact of the FDRA project.

Most of the reviewers did not find any concerns with the project's progress to date. Reviewers mentioned that the team has achieved good early results in all four areas, with the triple pane IGU having made most progress and the educational videos at the earliest stage, and it has been many years of focused development and continuous improvement of window materials, technologies, evaluation, and testing techniques and tools. On the other hand, reviewers were somewhat split as to the extent to which the FDRA project has demonstrated contribution to the project-specific goals.

In general, reviewers agreed that the team is working on collaborative projects. Regarding the FDRA project, some reviewers suggested additional collaboration with organizations such as additional universities with window projects, existing ARPA-E projects (such as SHIELD), NFRC, AAMA, WDMA, and IWFA. There is excellent diversity of stakeholders to reach out to and identify. One reviewer suggested diversifying collaborators on the educational/training videos to include manufacturers, R&D, and engineering functions.

Overall, many reviewers praised the forward-looking analysis and the future work planned for all projects. Reviewers commented that everything appears to be in line, and noted that the researchers should continue to support updating and education of product developers in understanding basic window performance technologies and features.

Weighted Average: 3.46 # of Reviewers: 6
Approach: 3.50 Impact: 3.67 Progress: 3.17 Collaboration/Coordination: 3.50 Remaining Work: 3.33

Program Response

The project team recognized reviewer feedback and is working to address comments suggesting collaborations with additional organizations. Specifically, the team is reaching out to stakeholders including existing and past ARPA-E SHIELD teams and will incorporate input from any additional collaborators as appropriate.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The multi-component organization of this 'project' only allows an average rating.
- The triple pane insulating glass unit (IGU) is an existing concept; the model comparison with vacuum insulated glazing (VIG) is done well and is useful.
- Modulated Spectrophotometer principles can result in new analytical capabilities and possibly in-field measurement techniques.
- The BSDF modeling (relative to complex fenestration systems) was not well-defined for the presentation. This is an important task due to limited industrial capabilities.
- If made appropriately, training videos can be quite beneficial for different audiences.
- The approach is very encompassing, yet focused.
- This work is based on a solid background of existing work and utilization of current technology for thin glass beyond televisions.
- No comment.
- The highly collaborative approach is favorable.
- The approach to net zero energy is more likely when including both thin triples and VIG in the same study.
- Updating adaptable modeling for public use will allow for a wider variety of new research and development.
- Validated standards will build confidence in consumers.
- The largest hurdle may be thin glass manufacturing and handling.
- It is incredibly comprehensive and analytical approach to characterize and evaluate energy saving window technologies.
- There is a special focus on low-cost high-R value glazing.
- It includes optical, thermal models, tools, and systems evaluations.
- The triple pane IGU approach is fair. However, several key issues need to be addressed for it to be successful.
- Their VIG modeling and support is outstanding. It will help industry to adopt the technology and also organization like National Fenestration Rating Council (NFRC) will be able to rate the product.
- The windows core lab infrastructure and support work is outstanding. The project supports programs like NFRC and EnergyStar and also to analyze newer technologies and products like frit glass and attachments.
- The Foundational Design Research and Aid Innovators and Research approach is poor. Based on the presentation, the material is already available on the web and easily accessible by consumers, innovators, and researchers.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.67** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact is primarily measurement and analytical tools. Although it is not focused on new window technologies, the methods can help propagate the use of new technologies.
- Based on initial assumptions, the impact of this project, as modelled, is tremendous.
- This will move the bar to the goals of the Building Technologies Office (BTO) roadmap.
- No comment.
- High-R window adoption is the impact.
- This reviewer would like to highlight the importance of the Foundational Design Research project: This project is crucial and something most technical subjects lack. For those new to the subject, the learning curve for window technology is tough due to a lack of consistent data. Most learning comes from technical glass guides from window/glass manufacturers which come with only specifics about their products and likely bias about what is most efficient. A one-stop-shop from a respectable institution like Lawrence Berkeley National Laboratory (LBNL) would be game changing for young scientists. This industry specifically is made up of mid-late career scientists and, therefore, educating a younger generation about windows and the future needs will generate a larger retention rate of young scientists in the industry. This also has a large potential to stimulate a wider variety of technologies being adapted to fit window applications. This could be given as a start-up lesson for all Department of Energy (DOE) window projects. It could also be used to educate the general consumer who is overwhelmed by ratings and options. The currently available books with all of this information are outdated and less likely to be accessed in an adapting internet-based learning world.
- This project provides tools, methods, and analysis of advanced window technologies to guide materials/product developers and window manufacturers to optimum performance products.
- The technology uses known methods for manufacturing of VIG with some variations.
- Using whiskers instead of pillars is a good concept and will assist in addressing stress issues seen in pillar technology.
- A flexible seal has been tried in previous research. It still needs to be proven for larger real glazing sample sizes used in windows.
- If the thin glass within triple pane IGU is temperable and low-E coat-able then it will help achieve the project objectives.
- The VIG support and analytics impact will be outstanding as it will help ratings, energy programs, and manufacturers to determine performance of the product and help in design.
- The Lab Core Program impact is also outstanding as it supports all key stakeholders and consumers.
- Foundational Design Research to Aid Innovators and Researchers impact will be poor, as the material presented is already available on the web, published books, etc.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met ***project-specific goals***.

- They have good early results in all four areas, with the 3x IGU having made most progress and the educational videos at the earliest stage.
- There is not enough information for an outstanding. It is still early.
- There are no concerns either.
- No comment.
- All projects appear to be on track with no major concerns.
- It would be good to see an improved prototype video for the Fundamental Design Research Project.
- It has been many years of focused development and continuous improvement of window materials, technologies, evaluation, and testing techniques and tools.
- Thin glass triple pane has shown modest contribution to the project-specific goals. The project should work towards making the thin glass temperable and low-E coat-able.
- VIG analysis has demonstrated excellent contribution to the project-specific goals.
- Lab core project has demonstrated excellent contribution to the project-specific goals.
- FDR to Aid Innovators and Researchers has demonstrated little or no contribution to the project-specific goals. The material demonstrated will be of little help to innovators or researchers. The team needs to work on providing information on barriers faced by newer technologies so that innovators and researchers can work on solutions.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Diversifying collaborators on the educational/training videos to include manufacturers R&D and engineering functions should be considered.
- There is excellent diversity of stakeholders to reach out to and identify.
- For Wang's presentation, there were no manufacturers/builders identified.
- No comment.
- Thin triple/ VIG/complex fenestration systems projects are highly collaborative with a favorable feedback loop platform.
- Modeling/Lab infrastructure project could promote more user awareness of updates coming soon and how to access the GitHub code. Optical measurements standards could include spectro-manufacturer education to promote implementation.

- The FDR project's initial partnerships are okay, but more feedback may be heard from additional universities with window projects (first year graduate students). Working with existing APRA-E projects (like SHIELD) could provide feedback on videos from those who have recently learned window fundamentals.
- LBNL core windows research is internationally acclaimed, and has excellent collaborative relationships with technical institutes, industry organizations, universities, product developers, window manufacturers, etc.
- The thin triple pane window project has good collaboration and coordination among project team members. The team can work with more stake holders to determine areas for technology improvement.
- VIG analytic and support has outstanding collaboration and coordination among project team and all stakeholders.
- Lab core program has outstanding collaboration and coordination among project team and all stakeholders.
- Foundational Design Research to Aid Innovators and Researchers has poor collaboration and they need to coordinate and collaborate with institutions like NFRC, AAMA, WDMA, IWFA, etc. to get their inputs. Also, they could get more input regarding the material developments which will be helpful to innovators and researchers.

E. Remaining Project Work

This project was rated **3.33** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The forward plans are good for all projects.
- BSDF modeling project has defined a nice path forward. They should demonstrate matrix calculations correlation with real systems.
- At this point, everything appears to be in line.
- No comment.
- For the FDR project, with only a few months remaining until the Go/No-Go, feedback from stakeholders must be collected as soon as possible to remind DOE of the impact potential. Higher quality videos/animations will contribute to success.
- Fenestration systems is a new project with a detailed future work plan.
- High-R windows and facilities is a new project on seemingly established technology. The forward-looking analysis seems well-thought-out.
- After a long gestation period, the work should proceed rapidly on high-R value windows and advanced characterization tools and techniques.
- The researchers should continue to support updating and education of product developers in understanding basic window performance technologies and features.
- The project team should work on the thin glass to make it temperable and Low-E coat-able.
- VIG analytic and support project work is on schedule to meet the project goal.
- Lab core project work in on schedule to meet the project goal.

- Foundational Design Research to Aid Innovators and Researchers project has had a poor start, but the project is at an early stage and can change strategies based on comments received during review. It is unclear whether it will be able to achieve the stated project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- They are multiple capability development projects that are relevant to window efficiency assessments.
- They are consistent with LBNL core strategy.
- There is very strong industry involvement from manufacturers at various levels to equipment manufacturers
- No comment.
- The FDR project has a high reward potential/investment in future window science.
- The fenestration systems project is working on the development of ISO standards. It is measuring a few representative samples vs. 100s.
- The high-R windows & facilities project has a diverse approach through prototyping/measurement improvements and modeling.
- The key strengths include excellent LBNL staff and a unique focus on windows technologies.
- Thin triple pane windows have market advantage due to weight and their highly insulating property, provided it is temperable and low-E coat-able.
- The VIG analytics and support project has outstanding expertise and collaboration with stakeholders.
- The lab core program and support project has outstanding expertise and collaboration with stakeholders and has already provided good results, especially in analyzing window attachments.
- Foundational Design Research to Aid Innovators and Researchers project has expertise but lacks strategy and direction.

2. Project Weaknesses

- There is a reliance on existing capabilities versus emphasis on innovation.
- There are too many projects under one umbrella.
- It is unclear whether the projects are being too short sided by only focusing on the glass. There may be an opportunity for frame innovation as a result of 3 panes of glass.
- Additionally, it is uncertain what the comparison would be between two thick and two thin panes and a triple pane.
- This idea was patented several years ago, it is uncertain whether they are thinking enough ahead for a big enough change.
- No comment.
- For the fenestration project, there are few tools able to validate measurements.

- For the thin triples project, the consumer adoption and education about benefits could be weaknesses
- The FDR project has the following weaknesses: outreach to researchers / product (education material) awareness & marketing.
- It is difficult to maintain funding level for this excellent work.
- The thin pane needs to be temperable and low-E coat-able.
- VIG analytics should be able to analyze more pillar shapes and construction details.
- Lab core program and support currently has no weaknesses.
- Foundational Design Research to Aid Innovators and Researchers project lacks strategy and direction. They need to provide information which will be useful to innovators and researchers such as barriers faced in newer and transformable technologies.

3. Recommendations

- On 3x IGU, LBNL can take a leading independent role in identifying the major issues that this approach will face. Industry (from SBIR to major companies) will then have clear targets and roadmaps.
- The researchers should not stop at just the glass. Including the frame and the window sill in the solution set should be considered.
- The project is divided in several parts which span a wide array of topics. As such, it is difficult to evaluate as a whole. Each section of the project will be reviewed in the order in which they were presented at the meeting.
- Part I (C. Curcija): The objective of this part of the project is to help getting highly insulating windows out of niche markets. The group has a clear understanding of the technological challenges and of the needs of the markets and of the stakeholders. However, the scope of the work and the overall project came across as disorganized. This lack of focus may have been only apparent. The projects span from triple panes to frames to VIG spacers, and giving a cohesive representation of these activities can be challenging. Yet, a bit more focused presentation would have helped the evaluation. Problems are being tackled which are extremely relevant. The potential impact is remarkable. The group is functioning well and stays close to the stakeholders. For the remaining part of the project, they should prioritize research projects and focus on those with the highest priority.
- Part II (windows core laboratory infrastructure): This is another project with a wide variety of goals. Yet, the presentation gave a much more focused impression. The objectives of each sub-project were clearly outlined, and the same applies to the progress report. The sub-projects are likely to have quite some impact on the field and be welcomed by the stakeholders, especially the industrial ones. The goals for the remained of the project will be met. These folks know what they are doing.
- Part III (Daylighting – Taoning Wang): The scope of this project is much smaller than that of the others, and therefore it is easier to gauge. The group is producing data using a scanning goniophotometer and working to extend the work to classes of materials using numerical simulations. The end goal is to produce a database for practitioners. As such, the project does make a lot of sense. The progress has been more than reasonable, the team is capable, and everything checks out. There are some issues with stakeholder engagement. The International Energy Agency and Fraunhofer ISE are good starting points, but engineering and architectural firms, and possibly some manufacturers, should be involved. A lot of work lies ahead of the group including characterization of a sufficient number of systems. The validation of the simulations will take time and patience. Convincing the stakeholders of the validity and importance of the approach will also take some time. However, feedback from the stakeholders will greatly benefit the project. For example, one of the reviewers

was worried that the approach may not be realistic/reflect all nuisances of real systems. The approach seemed a bit naive at times. Having more stakeholders involved, especially commercial ones, will help validate the assumptions made by the team and get closer to the real world. The approach is valid and worth pursuing.

- Part IV (Aiding inventors, Fernandes/Kohler): This is the project that this reviewer enjoyed the most. It was also the most simple so maybe that is the reason. At any rate, as an academic researcher, this reviewer has lost count of the frogs that I have kissed because of my ignorance of cost and durability. On the other hand, there are also many engineers in industry that are not-so-aware of some basic concepts. The project will alleviate these issues. It has merit and it should be continued. The project should be advertised heavily once it comes online. As for the format, there was some back-and-forth between web pages and videos. This reviewer would prefer not to use videos, yet they could be a good idea. Producing videos without a person should be considered for several reasons. The main reason is that a person is distracting, see arguments brought forth by the Khan academy. Also, if one uses a researcher for the video, the risk is that the person will not be a good actor. Conversely, if one uses an actor for the video, his/her lack of competence will become apparent. Either way, the result will be cheesy. A good compromise could be the format shown in the following link: http://toutestquantique.fr/en/laser/. The researchers could also look up other videos on the same website. The team should include in the website a list of "blue sky" issues, including the following questions: what would we like to have in an ideal world? and What are the most pressing issues of current technologies? A wish list might stimulate new inventions.
- The thin triples project should consider a detailed TEA and market research to validate customer needs and willingness to upgrade.
- The FDR project should consider outreach to researchers / product (education material) awareness and marketing.
- The team needs to develop integrated solutions for windows in buildings.
- The list includes dynamic high-R value windows and frames integrated with lighting, HVAC, DC grid, PV, and energy storage.
- The team should also consider advanced internet of things controls.
- The team should demonstrate thin glass that is temperable and low-E coat-able.
- The Foundational Design Research to Aid Innovators and Researchers project needs a major change in strategy and direction to achieve the goals. It needs to provide information that would be meaningful for innovators and researchers such as information about barriers faced in newer and transformable technologies. They need to have more stakeholder inputs.

Project #31320: Windows Attachments

Presenter: Charlie Curcija, Lawrence Berkeley National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Reviewers were enthusiastic about this project in all respects. Overall, they praised the project's approach of involving multiple laboratories and industry partners, as well as creating and employing sound methods, facilities, simulation, and field testing. The reviewers also noted that developing certifications for window attachment products could have a significant impact on program goals. It was noted that ratings will help consumers, product developers, and architects make purchase, production, and design decisions.

Overall, reviewers rated the project highly for progress towards the project-specific goals. They added that there has been very good progress in testing and simulation of attachment products and that all project phases have been executed in a timely manner. Reviewers also rated the project collaboration efforts highly and commended the wide range of participants and the effective way they worked together. In general, the reviewers were confident the remaining work will be accomplished as presented in the project plans, and commented positively on the quality of the project plans.

Weighted Average: 3.70 # of Reviewers: 4
Approach: 3.75 Impact: 3.50 Progress: 3.75 Collaboration/Coordination: 3.75 Remaining Work: 3.75

Program Response

Per reviewer feedback, the project team will consider a broader variety of shading devices selected for field testing in future project work. They will also explore approaches for better communicating ratings and tested performance information to consumers moving forward.

A. Approach

This project was rated **3.75** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Multiple labs and multiple industry partners are very key.
- Team and approach are diverse.
- Test homes in good locations.
- Derived data likely to be accurate and understandable to average consumer.
- A well-proven approach in Phase I is being carried out in Phases 2 and 3. There has been a development of methods and algorithms for window attachments followed by facilities preparation and field trials.
- The team has a well-planned-out approach of simulation and field validation testing for both interior and exterior shade.
- There is good industry participation for obtaining real market products and installation practice.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- While a Btu savings is called out, the over-arching concern is that these are people-driven products.
- The impact could be huge, due to the ease of use and cost of attachments vs. new windows.
- Adding a certification brings confidence and educated decisions from consumers.
- Optimization of window attachment technologies for maximum energy savings under a variety of climate and use conditions.
- The project provides tools for architects, as well as product developers, for the best window attachments solutions.
- The project will provide unbiased validation of the product performance and energy savings potential.
- This project should help the adoption of rating programs to assist consumers to make informed choice.
- Simulations will help in the ratings of product, and assist designing and developing more, better energy-efficient attachments in marketplace. It could also generate competition among market players.

C. Progress

Based on current project efforts, the project was rated **3.75** for the degree to which the project has met ***project-specific goals***.

- Progress to date appears successful.
- Largely on track with no indication of significant road blocks.
- Phase I completed.

- Phase II in progress and on schedule.
- Phase III being designed.
- The team has made very good progress in testing and simulation of attachment products.
- Team is focused and well-coordinated

D. Collaboration and Coordination

This project was rated **3.75** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Very comprehensive group from industry and various labs.
- Substantial stakeholder engagement shown.
- Excellent collaboration with LBNL, ORNL, PNNL, outside laboratories, industry organizations, AERC, Manufacturers (e.g., Hunter Douglas), etc.
- There is very good collaboration between National Laboratories, industry, and rating organization.
- Sharing of knowledge between team members and stakeholders is good.

E. Remaining Project Work

This project was rated **3.75** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Solid plan in place with resources selected
- Still early in project with clear plan for the future shown. No large road-blocks identified.
- Detailed plan for remaining project work.
- Project is in early stage, however, the task planning is well thought out among team members

F. Additional Comments and Recommendations

1. Project Strengths

- Solid cross-section of stakeholders.
- Significant stakeholder engagement.
- “Quick-Fix” to average consumer for energy conservation.
- Customer education through rating will create more informed decisions.
- Project strengths are the excellent staffs of the National Labs and the specialized test facilities developed for this work.
- The analytical modeling of window attachment performance.
- Participation of national laboratories with each having strength in required fields for success.
- Industry and rating organization participation.

- Good scientific knowledge base.

2. Project Weaknesses

- The field testing seems a little weak on the variety of shading devices selected for field testing.
- Along with the size factor of the windows; seems to be of no concern.
- Consumer education about how the rating works could be a concern, although I know this may be outside of LBNL's control.
- Not enough information to assess weaknesses.
- Project is in early stages. The products are complex and have many variables. This will pose a challenge to the team to come up with high accuracy of validations.

3. Recommendations

- Has there been research on the amount of human engagement with these types of products? From my experience, there has been very little, and mostly for privacy reasons with fashion as a strong consideration. For these "savings" to be realized, humans will need to change their behavior substantially.
- More diverse climate field testing.
- Continue funding this activity.
- Should consider all attachment products types for evaluation.

Project #31316: Windows Core Program

Presenter: Robert Tenent, National Renewable Energy Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Reviewers commented positively on the validity of the project's approach, and praised the promising approach and cross-disciplinary experts involved. One reviewer specifically emphasized the importance of proven test strategies and techniques and the involvement of experts across disciplines. Another reviewer noted that the national lab's role in durability testing was still being established between test execution or test development. Other reviewers also pointed out that the national laboratory's most significant role should be focused on failure mode discovery and new test method development for emerging technologies.

Overall, reviewers commended the potential impact of this project and highlighted the importance of durability of windows in their market success. More specifically, reviewers emphasized the importance of solidifying the technical validity and standardization of emerging technologies as a means of enabling certification to help promote market adoption. The reviewers also agreed that the project can be expected to contribute to program goals, citing the importance of testing and validation to industry and organizations.

Reviewers noted the project seems to be on track, but qualified their statements by noting that the project is in very early stages. Reviewers praised the project's collaboration efforts, with one reviewer suggesting the project include the National Fenestration Rating Council. Reviewer praised the quality of the project plan and indicated they felt the project would progress towards its goals.

Weighted Average: 3.50   # of Reviewers: 5
Approach: 3.40   Impact: 3.80   Progress: 3.20   Collaboration/Coordination: 3.80   Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.40** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The strategy for NREL as the durability center of excellence is clear. Still establishing whether the core role of the lab in durability assessment is primarily testing or test development.
- Excellent foresight into research of the failure modes of new technologies that are currently being developed. This project will challenge the testing procedures of today for durability.
- The approach is promising since it appears to involve cross-discipline (research-manufacturing-marketing) experts who will help tune the standards. The continued use of workshops to identify industry need is key to staying on track.
- It is essential to have proven test strategies and techniques to support the evaluation of new EC and window technologies. It is important to have a broad spectrum of industry and government partners developing these.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Durability is a key attribute for market success. Having standards and the capability to conduct independent durability testing and certification for new technologies such as vacuum insulated glazing (VIG) and triple-glazed windows is an industrial necessity.
- As stated in the presentation, this work will help solidify the technical validity of emerging technologies, which is often a concern of organizations and companies looking to apply or integrate those technologies into their products.
- The need for standardization among these emerging technologies is apparent. Certifications leading to consumer trust will help promote market adoption. The project is a clear demonstration of why companies want to invest in this for large revenue bump after certifications.
- Independent testing of new technologies and windows to evaluate performance and durability will definitely impact investment in marketing and sales of these products.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- Few concrete results to date.
- Albeit early into the project, multiple partners have been engaged from a variety of arenas.
- Project appears on track but is very early on to make a fair judgement. Partnerships appear diverse, yet clearly in need of standards.
- Newly awarded project, no assessment of progress.

D. Collaboration and Coordination

This project was rated **3.80** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The industry-academic mix is strong. The next stage is to utilize this collaborative mix appropriately.
- Solid cross section of partners identified. Please reach out to the National Fenestration Rating Council (NFRC) so that they can have a representative involved.
- The continued use of workshops and the diversity of participants' knowledge, ranging from researchers to window manufacturers, is a great approach and keeps the industry heavily involved, leading to practical, fair, and effective certifications/standards.
- NREL has a good list of proposed key stakeholders. The University of Sydney will be very important for VIG testing. Supports a close working relationship with LBNL.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Work is in the planning stage, and the current plans appear appropriate.
- Still early in the 3-year plan, but appears to be on track. The project should reach out to the Insulated Glass Manufacturers Association (IGMA) and NFRC to work on transfer of protocols.
- The project is in its early stages with clear future plan. The use of existing partnerships and testing facilities at NREL will allow for continued support of emerging technologies while the standards are being refined.
- The project plan looks good for a newly awarded project.

F. Additional Comments and Recommendations

1. Project Strengths

- The partnerships; the initial partners' assessment; and the NREL mission and expertise, which align well with this project.
- The project acknowledges one of the challenges of an emerging technology that is key to deployment. The project does a nice job of building on the history of solar.
- The diversity of input across the window industry, ranging from researchers through manufacturers. The established trusted partnerships with organizations of various sizes.
- Reliable scientific tests and evaluations of new technologies. Vendors make many claims of performance and durability. Consumers need independent third-party testing to assess the validity of those claims.

2. Project Weaknesses

- The mission definition still needs to be clarified. In my opinion, NREL's most influential role can be research on failure modes, development of relevant test methods, and establishing test details and outcomes. Although NREL can run tests until significant market penetration by new technologies, the tests should be ultimately conducted by independent lower-cost labs.
- I have some concerns about involving a standards agency with a June 2019 draft plan due.

- It could be hard to get experts to reveal or share their testing practices.
- The project is under-resourced. It needs to add an expert on glass stress modeling and testing.

3. Recommendations

- Seek additional funding for this work. It is very fundamental.
- This is an important project which may be key for the development and commercialization of future technologies. The current stage of the project is rather exploratory in nature, and rightly so. We have only a vague idea of which technologies will enter the market, and an even more vague expectation of how new materials will age or react when stressed. In this respect, the meeting held at NREL in March 2019 was an important milestone and a boon for people working in the field. The findings and recommendations from that meeting will likely be the foundation of future testing methods. The objectives for the remainder of the project were stated very clearly, making apparent (in my view at least) that the team has thought a lot about the plan, knows where the field is most likely to go, and what the needs of the practitioners (academic, industrial, and commercial) are. My only suggestion is to keep the lines of communication open. I am under the impression that the momentum waned a bit after the meeting. While this is understandable (organizing the meeting, and digesting its outcomes, is time-consuming), the follow-up appears a bit lacking.
- Continue to listen to all industry sectors and perspectives and remain adaptable to consumer desires.
- Need to develop technology "acceleration factors" to more accurately relate NREL accelerated test performance to lifetimes in a variety of field environments.

Project #30008: Vacuum Glass for R10 Windows (SBIR)

Presenter: Michael Petit, V-Glass
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

The reviewers agreed the project approach is solid and could result in a novel window vacuum insulated glazing (VIG) manufacturing process. One reviewer specifically mentioned the ultrasonic welding technique as promising, and three reviewers specifically mentioned the whisker pillars. One reviewer also noted the flexible seal needs to be tested on larger sample sizes.

The reviewers agreed the project could contribute to BTO's energy reduction goals, given the size of the residential windows market and the importance of VIG to high-R windows. The reviewers noted that the project needs to demonstrate the window's market aesthetics will be acceptable; that the success of the welding system is critical and needs to be proven cost effective and that weld seals will be durable; and that thermal transmittance has not yet been tested. Given these challenges, the reviewers felt that while the project is progressing towards its goals, it still needs to demonstrate some of the key innovations.

The reviewers felt overall that the project's collaboration efforts are good and that team members have expertise. Two reviewers felt industrial or manufacturing companies could be involved more in the project while one reviewer questioned why the project is deemed as "too early" for venture capitalists to consider.

As for the remaining project work, the reviewers felt progress towards goals is being made and the project work is well-planned. However, they noted, as they did in their remarks about the project's impacts, that a number of manufacturing process issues have been identified and need to be addressed. Two reviewers noted the presenter was not the technical lead, and thus some questions about these issues were not answered.

Weighted Average: 3.12   # of Reviewers: 6
Approach: 3.20   Impact: 3.20   Progress: 2.80   Collaboration/Coordination: 3.30   Remaining Work: 3.30

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- There are several innovative concepts that, if demonstrated, could provide a cost-effective approach to VIGs. Demonstration is key, however.
- Very solid and well thought out.
- The approach is novel and uses ultrasonic edge sealing without ovens, metal foil edge seal, line contact whisker pillars and spacers, and plasma degassing. The project is still relatively new, with a few approach changes (welder).
- Good approach to make low-temperature rapid welds. Good to work with automation companies to make welding a high-quality process.
- Technology uses known methods for manufacturing VIG windows, with some variations.
- Using whiskers instead of pillars is a good concept and will help address stress issues that have been observed in pillar technology.
- Flexible seal has been tried in previous research. It still needs to be proven for larger glazing sample sizes. Currently the team has only demonstrated flexible seal in 1 ft by 1 ft samples, in which the linear stress is not very prominent.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The energy efficiency of the VIG should lead to high efficiency residential windows. Market acceptance of the windows' aesthetics will have to be established.
- Tremendous impact and very innovative approach.
- There is the potential for lowering the cost of VIG units, which would allow for market saturation above 10%. The project outcome is heavily dependent on the success of new large welding system.
- Low-cost VIG is an important step to very high R energy-saving windows.
- It is not yet clear if the technology is market ready, because the samples made are only 1 ft by 1 ft.
- Thermal transmittance of the physical sample produced is not yet tested to International Standards Organization (ISO) methodology to demonstrate the targeted R10 objective.
- Rapid tungsten inert gas (TIG) welding is a good concept. However, it needs to be proven to be cost effective for actual glazing sizes in installed windows, and to result in durable welds.

C. Progress

Based on current project efforts, the project was rated **2.80** for the degree to which the project has met ***project-specific goals***.

- Several of the innovations are yet to be tested and demonstrated. The project should have identified the major challenges and presented them by this stage of the project.
- Well done identifying what won't work and pivoting.
- Historic progress is significant, as shown in slide 19. Current progress is slowed by issues with the welder.
- The team explained the ultrasonic welding apparatus and technique needs to be improved. The team has demonstrated that whisker separators are feasible.
- The project is progressing well as per project deliverables. Several key fabrication issues for actual size glazing need to be resolved.

D. Collaboration and Coordination

This project was rated **3.30** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The partners are mainly technical organizations and not industrial or manufacturing companies. The latter could help the project team understand challenges and plan the project accordingly.
- Very solid team of various skill sets.
- The team has documented smaller glass company interest, with the potential for joint development with larger companies. The team mentioned the project is "too early stage" for venture capitalists. That is an interesting statement considering it was made almost at the top of the slide 19 progress graph. I would like to know what is missing or what red flags exist related to investor satisfaction.
- Very important to have automation company, LiSec, and the University of Sidney involved.
- The team members collaborate well and have the expertise to address issues. Participation of an active manufacturer is critical and very helpful for project success.

E. Remaining Project Work

This project was rated **3.30** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The presenter was not the technical lead. This did not allow an adequate discussion of future work. However, the plan seems appropriate. Many concepts have to be demonstrated, and they are on the list.
- Problems with the manufacturing process have been identified and the team is focusing on them.
- Project success depends heavily on the ability of the new welder to improve vacuum life.
- The most important work remains to be done. The durability and long life of low temperature ultrasonic welds must still be proven. The product must demonstrate it does not leak and can maintain high R in a VIG product.
- The project work is well planned.

F. Additional Comments and Recommendations

1. Project Strengths

- Novel, high energy-saving concept, including a foil edge that should keep the edges free of stress and remain cost efficient.

- The project focus on manufacturing costs will have a very big impact on a key hurdle to wider market deployment of VIG.

- Project strengths include the team (which is knowledgeable and diverse), the oven-free approach, the low costs, and the interest of small manufacturers in the product.

- The project's strengths are product's low-temperature glass to metal weld and its work to develop automated equipment and processes.

- The team is well-qualified and has the necessary expertise to address issues. The team is interacting with international experts and manufacturers are actively participating.

2. Project Weaknesses

- The team needs to demonstrate the stability of the ultrasound glass to metal bond. Glass corrosion can affect that bond. The team needs to detail plans for demonstrating quality regarding weld quality, the degassing concept, and the foil corner stress profile.

- May need additional funding for scale, testing, or manpower.

- It is difficult to comment on technical aspects of project because the presenter was on the business side and unable to field technical questions. If the new welding apparatus does not fix vacuum issues, the project lacks a Plan C.

- Visibility and non-uniform placement of whiskers may be a problem. The presenter could not elaborate on these.

- The fabrication technologies used (e.g., TIG welding, flexible seal) were not tested using real size window glazing. I am concerned how the team would address the thermal stress issues generated for glazing in an actual sized window. Currently the team has only developed a sample size window that is 1 ft by 1 ft.

3. Recommendations

- Engage manufacturing (insulated glass, window, and glass partners) to help clearly identify where the technology might fail, and then plan accordingly.

- Infuse additional investment and skill sets to expedite the product's development.

- This is quite an interesting technology. It has been more than 10 years in the making, but that is to be expected for such an innovative project. The team has a clear vision of the technical and cost hurdles that must be overcome to market the new technology and acts accordingly. The proposed ultrasonic welding is extremely promising, and the team is working hard to overcome the capacity issue it encountered. Successful completion of the project will yield an estimated 75% cost savings over oven-based materials, so the project's potential impact is very high. The team has a clear vision of the future requirements for their technology, most of which focus on increased throughput. On the other hand, I found stakeholder involvement somewhat lacking. Only one company appears to be willing to work with the proponents, and a second company has produced a letter of intent. In my view, a letter of intent is not a very encouraging development. However, I have limited experience with the commercial sector, so take my comment with a grain of salt. This is all a bit surprising, since the materials have been validated by the National Renewable Energy Laboratory (NREL). Is this because the VIG main market is China? If this is the case, V-Glass might have to look in China for strategic partnerships. Along the same lines, I was surprised the learn that venture capitalists consider the technology to be early stage. I suggest that V-Glass market its technology more aggressively; the proposed angel funding route is notoriously unreliable. As for the team, it is very qualified. One minor negative is that the person who gave the presentation was coming from the commercial side. As such, he could not answer some of the technical questions that were being asked. It would have been better to have the technical manager in the room. He or she could have answered those questions, which in turn would have helped us advise on future developments.

- Provide an outline of answers to basic questions about the product that could be used by any member of the presenting team. Develop convincing marketing material targeted at venture capitalists. Demonstrate line contact whisker movement, or the lack thereof, with thermal cycling of foil.
- The team should have a laser focus on weld quality to glass, and on automation issues. The team should work with NREL and the Lawrence Berkley National Laboratory to validate performance and vacuum quality.
- Since the final objective is to deliver R-!0 window, the team should demonstrate that VIG can be used in real size windows and be able to successfully pass the durability test. R-10 performance should be demonstrated using the National Fenestration Rating Council 100 test procedure.

Project #313113: Dynamic Reverse Plating

Presenter: Michael McGehee, University of Colorado
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Several reviewers were supportive of the Dynamic Reverse Plating project and noted that the approach was following good experimental concepts. One review was complimentary of the team's coordination with industry and other stakeholders. On the other hand, some reviewers expressed concerns about how some technical issues were being addressed. These reviewers felt there should be more of a focus on a systems approach; that the project might not be scalable; that the use of perchloric acid was not an optimal choice environmentally or economically; and that the project would not result in a significant improvement over existing electrochromic (EC) windows.

The reviewers were generally positive about the project's potential impact and contribution to program goals. Reviewers commented on the product's low solar heat gain and highlighted that it could achieve 20% energy savings with long term use. A reviewer also remarked that if the technology successfully works for large size samples, it would make an impact in the market. However, reviewers also noted the high amount of energy needed to manufacture the product and that the product may not perform better than existing EC windows.

Overall, the reviewers found the project to be on-track to meet project-specific goals. While several reviewers approved of the team's approach to future tasks, one reviewer felt some fundamental issues had not been properly assessed or planned. As for the project's collaborative efforts, one reviewer praised the project for its excellent collaboration with relevant stakeholders. Other reviewers noted that there was room for improvement with regards to participation from industry and coordination with stakeholders.

In terms of project goals, reviewers were split as to whether the project is on-track to meet its objectives. Some reviewers felt the project approach and plan are on-track, with one reviewer noting the project team manages developments related to materials well. Other reviewers felt that it was not clear how the proposed technology could be leveraged to make a large window, and that significant and challenging project work remains.

Weighted Average: 2.90   # of Reviewers: 6
Approach: 2.80   Impact: 3.20   Progress: 3.00   Collaboration/Coordination: 2.70   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.80** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Early stage innovative materials science approach to switchable window technology. Focus areas include electrode stability, switching uniformity, and electrolyte development. All seem to be following good experimental concepts.
- The project focuses only on the chemistry and could be enhanced by including a systems approach to include the power integration, switching, and control.
- I have concerns over the scalability and use of perchloric acid in this approach. The product clearly works well, but can it still be considered "green" and "cheap" with these additional activities added since the conception of the project?
- May provide a pathway to achieve privacy. Desirable for residential but not a requirement for energy saving. No significant improvement in contrast ratio over current electrochromic (EC) windows. Probably can achieve neutral color in dark state. It is hard to achieve uniform plating over large areas due to decrease in the infrared (IR) spectrum. The ultimate switching speed for large windows would not be much faster than existing EC windows.
- The team has looked at a new material and deposition method window electrochromic glazing. The team has good participation from industry and other stakeholders.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The metal layer will be effective in reflecting solar energy, thus allowing low solar heat gain.
- Potential savings due to its range and reflection of IR is very impressive.
- If successful and marketable, this product shows evidence of 20% energy savings with long term use. I have a concern about energy consumption, considering that 2V/sq. ft. is required to use the product.
- The challenge is to make highly uniform large area windows. The materials technology is capable of the required solar heat gain coefficient (SHGC) and visual transmittance (VT) performance. Including lithium in the electrolyte requires excellent moisture barriers. Creating a stable electrolyte system will be challenging. If the system were to perform optimally it would not achieve better energy performance than existing EC windows. It is hard to determine if there will be a cost advantage because the device failure modes or durability parameters are not known.
- The team faces significant challenges in demonstrating that the technology will work for larger size samples. If the technology works for larger size samples it would impact the market. The amount of electricity and time required to switch from clear and dark and back to clear needs to be determined.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Some fundamental issues, such as the effect of 5-volt switching on degradation or hysteresis due to irreversible metal sorption, do not seem to have been assessed or planned for future work.
- Very early work with solid lab performance.
- Progress is steady with good approaches to adapt to scientific challenges, such as voltage drop. The remaining half of the project will have a strong focus on scalability and practicality of materials used.
- This is a very early stage project, but not the first-time metal plating has been tried. The early stage goals have been met, but the next stage will be much more challenging.
- The team has been making progress and is on schedule, except for one missed milestone to produce a durable counter electrode.

D. Collaboration and Coordination

This project was rated **2.70** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- In spite of a good list of collaborators, they don’t seem to provide much input on requirements or technical issues, including the choices of materials.
- Did not see much other than company collaborative interest.
- The team mentioned a few "company collaborative interests" at the beginning of the presentation and nothing after that. I would be interested to know how these collaborative interests feel about the scalability of and switch to perchloric acid.
- The team indicated "interest" by some EC and window companies, but no partnerships or investment by them. An industry partner will be essential for next stages.
- The team has demonstrated excellent strategic collaboration or coordination with relevant stakeholders. It has acquired a participant that can adopt the technology and deliver it to the marketplace.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Good approach to resolving the product development issues. More issues exist, which need to be listed and addressed.
- Appears to be on track.
- Project pivots in reaction to developments related to materials aid in the likelihood of success. The project appears to be on track to meet project goals, but the cost and practicality of this product remains unclear.
- The project team needs to consider how to make an energy saving window. It is not clear how the proposed technology can be leveraged to make a large window.

- The team has significant and challenging project work remaining to build a triple-layer electrode and a prototype.

F. Additional Comments and Recommendations

1. Project Strengths

- Innovation, the metal reflective concept, and the team's technical expertise.
- Solid quantification of the product's performance. The project is using a very novel approach. The chemistry used is an excellent approach.
- Optical clarity, speed of switching, flexibility, and longevity of tested to date cycles.
- The product has high contrast, good SHGC, and is capable of providing privacy.
- The use of metal and electrodeposition is significant project strength. The process can reduce the cost of the insulating glass unit significantly. The team has very robust participation from key stakeholders. The team has significant expertise in the field.

2. Project Weaknesses

- The team lacks a true industrial voice and direction, as well as a full understanding of the technical and commercial challenges.
- With the understanding that this is a very early stage R&D, engage the window industry to understand the potential challenges such as common size, wiring, and the potential market. Also, think of the whole system to identify the power and controls needed.
- The product requires 2V/sq. ft. to operate. The product scalability and the long-term stability of perchloric acid is questionable.
- I suspect the product is very nonuniform over large areas. The electrolyte technology is not well defined. The presence of lithium requires good moisture barriers. The long-term durability of the plating technology is suspect.
- The project needs to address the key issue about durability and electric current; there are known barriers for this technology. One of the key team members from Stanford University has been inactive and funds have been transferred to Colorado-Boulder.

3. Recommendations

- Engage partners proactively. It is great to have a strong list, but they need to be actively helped to guide the project.
- Talk to a window manufacturer and a glass manufacturer.
- This is an early-stage research project that has some promise and may have an impact on the field. Like all these projects, it has overcome many hurdles, but many more lie ahead. I was therefore surprised to see that the presentation was given by a junior student instead of the principal investigator or the senior student that participated in the meeting in Colorado. In my opinion the quality of the presentation suffered a bit. Most importantly, the questions were not handled well because of the presenter's lack of experience. Presentation issues aside, in my opinion the project is extremely innovative but some key issues should be addressed. Most important is the current. The materials are now at 2 mA/cm^2. Hence, a $1m^2$ window will draw 20 A, which is a lot of current. There was also some lack of clarity regarding the electrode configuration and the electrolyte. Is

it indium tin oxide, nitrogen oxide, or perhaps both? I was also a bit surprised to see perchloric acid used as an electrolyte. The student was not aware that perchlorates are toxic and explosive. I suspect that perchloric acid is a temporary solution that will be replaced by another electrolyte in the future, after the other technical issues have been addressed. Moving forward, I suggest that the group focus on one solution (one electrode configuration, one electrolyte, etc.) and then try to address the current (Ampere) issue, as well as durability. I would like to see the product test through more cycles, and at different temperatures, for example. Longer-term, an alternative to platinum should be considered, and a more detailed cost analysis should be carried out. It was unclear how much the new technology would save and how the cost savings would be achieved.

- The team should gather feedback from industry partners and report on their assessment of the product's scalability and stability. A report on the cost of this product versus current dynamic windows is needed. The team should conduct a thorough investigation of perchloric acid stability and reactivity within this system, and create convincing slides for stakeholders.
- The team should concentrate on ways to reducing the electric current requirements for switching phases. The team should ensure the product's durability and long service life so that the technology is cost effective.

Emerging Technologies

Solid-State Lighting

Project #31151: AlInP-based LEDs for Efficient Red and Amber Emission

Presenter: Kirstin Alberi, National Renewable Energy Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

Most reviewers agreed that the approach of building on the known technology of a red LED is a reasonable and promising approach. Reviewers commented that if the project yields the expected results, it will achieve significant increases in efficiency with no barriers of adoption by LED manufacturers and the results so far have indicated very good progress towards the project goals. However, one reviewer noted that the project is purely experimental.

Two reviewers agreed that the project is expected to contribute to program goals. Specifically, reviewers commented that the project is well aligned with DOE's goal to fill the green gap and the project will have a transformative impact on the field of electric lighting in buildings. One reviewer commented that the approach should work if the single crystal synthesis is stable for this composition. Another reviewer expressed concern about the real-world impact on building energy savings.

All reviewers agreed that the project has shown good progress thus far. Two reviewers commented that the project is still in the early stages (five to six months into the project). One reviewer described the progress to date and emphasized optimization of the energetic barriers through control of the order parameter and demonstration that the team can obtain exceedingly high energetic barriers to inter-valley transfer in the new material.

In general, most reviewers agreed that the remaining project work is ambitious but reasonable and well-planned and collaborations are appropriate. Most of the reviewers agreed that the project currently has an adequate amount of collaboration with LED chip manufacturers, module and luminaire manufacturers, lighting designers and subject matter experts, and end users. One reviewer commented that this is the appropriate amount of collaboration, considering the funding level. Another reviewer highlighted that the team is collaborating with DOE Energy I-Corps in order to identify possible commercialization pathways.

Weighted Average: 3.17   # of Reviewers: 4
Approach: 3.25   Impact: 2.75   Progress: 3.50   Collaboration/Coordination: 3.00   Remaining Work: 3.50

Brief Summary of Reviewer Comments

Reviewer feedback was well-received by the project team, and although reviewers noted potential issues regarding the stability of the project's AlInP alloy composition and ability to meet the stated quantum efficiency targets, the team is confident in its ability to meet these aggressive targets based on the fundamental band-structure of the material. To that end, the team is continually improving the required material quality.

The PI also recognized reviewer comments on the potential impact on real-world lighting applications, and the team is engaging stakeholders across all levels of the LED lighting value chain to understand how improvements in red and amber LED efficiency can help address needs for near-, mid-, and long-term products in addition to meeting the efficiency and human health and comfort objectives articulated by the DOE. The team will report their findings on the potential impacts of this R&D as part of this project moving forward.

A. Approach

This project was rated **3.25** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is a novel approach building on the known technology of a red LED. The results so far have indicated very good progress towards the goals.
- The approach adopted seems promising. If the project yields the expected results, it will achieve significant increase in efficiency with no barriers of adoption by LED manufacturers. Filling the "green gap" is the objective. The approach is to utilize a new material with a higher direct-indirect crossover energy. This approach will result in five benefits, i.e., (1) potential for the highest luminous efficacy with no down conversion, (2) narrow FWHM, (3) long lifetime, (4) utilizing existing manufacturing methods since the to-be-developed product can be a drop-in replacement for existing LEDs, and (5) shorter anticipated development time compared to using completely new materials.
- The approach seems fine. However, it is purely experimental. DFT modeling could provide a lot of insight. It might be good to consider this in future studies.
- The approach is a reasonable approach, based on a scientific and fact-finding method.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.75** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project is well aligned with DOE's goal to fill the green gap.
- The expected increase in the efficacy to around 300 lumens per watt will have a transformative impact on the field of electric lighting in buildings. Such efficacy far exceeds the efficacy of natural daylight! The anticipated fast adoption by LED manufacturers should be followed by fast increase in the market share of this new technology.
- It seems like the approach should work if the single crystal synthesis is stable for this composition.
- I am concerned about the real-world impact on building energy savings. Unless the efficiency of color mixing lighting becomes significantly more efficient as compared with non-color mixing technology, there will be very little impact of this project on building energy savings.

C. Progress

Based on current project efforts, the project was rated **3.50** for the degree to which the project has met ***project-specific goals***.

- The progress so far has been promising and has more or less met the predetermined goals.
- It is about six months into this two-year project. Progress is commendable. Progress includes optimizing the energetic barriers through control of the order parameter and demonstration that the team can obtain exceedingly high energetic barriers to inter-valley transfer in the new material.
- The progress seems good. They have deposited some material already and it is demonstrating measurable promise.
- The early work on this project (about five months) shows good progress and is logically organized.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project staff have partnered with two external entities, which is appropriate considering the funding level.
- The question 7 drop down menu has an error. Option 3 is labeled 'poor', in addition to option 1. I chose option 3, intending it to denote 'good'.
- The team is participating with DOE Energy I-Corps in order to identify possible commercialization pathways. In this effort, they may be able to solicit feedback from LED chip manufacturers, luminaire manufacturers, subject matter experts, lighting designers, and end users. In addition, the team is currently working with one LED manufacturer (MicroLink Devices) to demonstrate the potential of this new technology. MicroLink is also contributing their metamorphic buffer layer technology to the development of the devices.
- The collaboration seems fine. There is uncertainty over what Professor Phil is contributing besides expertise.
- In this early stage of the project, the project team is in communication with external stakeholders as follows: LED chip manufacturers, module and luminaire manufacturers, lighting designers and subject matter experts, and end users. These are the correct set of external stakeholders with whom the team should work.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project team has an ambitious but reasonable plan for the remaining work.
- Planning for the remaining work is organized by each quarter for achieving the end goal by the end of the project.
- Prospects on the remaining part of the project look good.
- The project team has a well-planned set of steps and goals for the remainder of the project.

F. Additional Comments and Recommendations

1. Project Strengths

- The project builds on existing technology.
- The project partners bring required expertise in fabrication.
- The project addresses a known gap in LED technology.
- The biggest strength of this project is the approach of developing a new material that can be adopted very quickly by LED manufacturers. This should eliminate the long time it may take to figure out a new manufacturing process and eliminate the need for further funding to develop a new manufacturing method.
- The strength of the project is researchers that have a good handle on the deposition technique and chemistries.
- The project strengths include the background, experience, and qualifications of the five members of the project team. They have the right mix to successfully address this project.

2. Project Weaknesses

- There may not be sufficient funding to complete the project on schedule.
- No weaknesses were found.
- There is uncertainty if the quantum efficiencies of this material are going to improve drastically.
- The only definable weakness is that of no guaranteed success in the project. However, that is a weakness of all scientific projects. Even if the project is not successful, it contributes to the Body of Knowledge in this field.

3. Recommendations

- Although project staff did not indicate it, additional funding would probably help overcome obstacles that have not been anticipated at this stage.
- Other reviewers with a background in the relevant physics are able to provide more in-depth review of the physics involved in developing this new technology.
- One thing to consider is how you might simulate the material from first principles. This may be done to prove this was a worth-while experimental exercise. Overall, the project seems like a good idea. One suggestion is to move on to another composition once you have proved that this is a valid approach for this composition.
- The project is well thought out. At this stage of the project, there are no recommendations to improve the project.

Project #32102c: Application Specific Lighting

Presenter: Bruce Kinzey, Pacific Northwest National Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

All reviewers commented positively on the project's approach. Reviewers stated that the approach is an excellent starting point and is well thought out, well-planned, and should minimize risk of failure. However, one reviewer did comment that this project has the potential for a significant contribution, but there is much work to be completed.

Two reviewers agreed that the project will have a high impact and will contribute positively to BTO's goals. Another reviewer commented that the program goals leading to adoption of widespread use is encouraging, but the reviewer recommended that building owners and manager edification become a priority for these goals to be attained. One reviewer acknowledged that additional efforts addressing lighting energy reduction for animal production will be investigated.

Most of the reviewers agreed that the project is on track and showing great progress, particularly in identifying the disconnect between installation instructions from manufacturers and actual installation by end users. However, one reviewer expressed concern over the potential for the project to lag, especially with the horticultural effort which includes scientific research on spectrum, intensity, etc. that will drive market adoption.

Reviewers were divided on the project coordination and collaboration. Two reviewers agreed that the project shows good collaboration, and significant collaboration and coordination has taken place with partners and stakeholders including several public presentations of work on the project. Contrastingly, two reviewers recommended more industry representation and involvement with collaborators who have little to no background in lighting to avoid biased results.

Most of the reviewers agreed that the remaining work is well-planned and appropriate. The reviewers emphasized remaining work, including outreach to other universities who are not currently collaborators, studying changes in the Chicago night sky from street lighting conversion, working on Light Measurement & Automobile Crash Statistics with the Virginia Tech Transportation Institute, and proceeding with horticultural lighting analysis. One reviewer recommended considering whether this project will meet its objectives in the specified timeframe.

Weighted Average: 3.26 # of Reviewers: 4
Approach: 3.25 Impact: 3.75 Progress: 3.00 Collaboration/Coordination: 3.00 Remaining Work: 3.25

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.25** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project is new as of 10/1/2018, therefore it is still in the "startup" phase. This project has the potential for a significant contribution, but there is much work to be completed. The approaches for both outdoor and horticultural applications seem reasonable and basically demonstrate how current technology trajectories are not meeting goals.
- Observational research related to connected lighting installation problems is both a basic and necessary starting point to overcoming obstacles in order to bring connected lighting technology to widespread deployment. This approach is an excellent starting point. From these observations, testable hypotheses can be formed, as well as common language developed.
- The project shows good progress.
- The approach of this project is well thought out and planned and should minimize risk of failure.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.75** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If the project is successful and can inform the development of application-specific lighting, the impact will be significant and will contribute positively to the goals of BTO.
- The program goals leading to adoption of widespread use is encouraging. However, building owners and manager edification must become a priority point of contact for these goals to be attained. Manufacturers clearly have a stake in selling their products and are self-motivated.
- The project has a high impact.
- The project is focused on reducing energy consumption in buildings and outdoors through the adoption of energy efficient LED lighting products for general lighting, public lighting (outdoor lighting), and horticultural lighting. Additional efforts addressing lighting energy reduction for animal production will be investigated.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- The project is just starting. After reviewing the proposed schedule, it appears as if the project is somewhat on schedule. However, there appears to be opportunity for the project to lag, especially with the horticultural effort which includes scientific research on spectrum, intensity, etc. that will drive market adoption.
- Current progress is commendable, particularly in identifying the disconnect between installation instructions from manufacturers and actual installation by end users.
- The project shows good progress.
- With a little more than four months into the project, progress is on a very good track. Much factual information has been gathered and synthesized.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project has a number of partners which will be valuable to the outcomes of the project. More industry representation may be warranted.
- The choice of collaborative partners such as Parsons and Virginia Tech could lead to biased results. It is imperative to include collaborators who have little to no background in lighting for the adoption and installation of connected lighting systems.
- The project has good collaboration.
- Significant collaboration and coordination has taken place with partners and stakeholders including a number of public presentations of work on the project as follows: ANSI/IES Sky Glow Calculations Committee (Scope: Committee is tasked with developing recommended calculations, procedures, and tools for estimating contributions to nighttime sky glow from various end-uses of general illumination.), public presentations of DOE research (2018 IES Street and Area Lighting Conference (SALC), 2018 Artificial Light at Night (ALAN) Conference, 4th International Street Lighting + Smart Controls Conference, regular requested participation or input to municipal public hearings; small (e.g., Bend, OR) to large (e.g., Chicago, IL), feature article Lighting Design + Application (LD+A), Apr 2019), and collaboration with National Park Service on lighting efficiency, resiliency in hurricane-affected areas (report: Lighting and Power Upgrade Recommendations for U.S. National Park Service Caribbean Units, PNNL, City of Seattle, NPS Natural Sounds and Night Skies).

E. Remaining Project Work

This project was rated **3.25** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- While this project is only just starting, and this is the first review, there is a lot of work that needs to be completed. There should be a lot of consideration given to whether this project will meet its objectives in the timeframe given. This is especially true as several of the project team are involved in other, comprehensive projects as well.
- The remaining work plan is well thought out, particularly with reaching to other universities who are not currently collaborators.
- The project is expected to do well.
- Remaining work is well planned.
- Adler Planetarium is going to study changes in the Chicago night sky from street lighting conversion.
- There is future work on Light Measurement & Automobile Crash Statistics with the Virginia Tech Transportation Institute.
- Steps are in place to proceed with horticultural lighting analysis.

F. Additional Comments and Recommendations

1. Project Strengths

- The project's strength lies in its focus on application specific lighting, mostly on the horticultural side which doesn't seem to be a significant area of research. This will be a very critical area of research for the future of food systems.
- Strengths of the project include including observational research detailing the areas of improvement, summarizing the principles and practices to minimize configuration complexity, and getting the word out to stakeholders.
- The project has two important application areas.
- The project strengths include the expertise of the PNNL project team, as well as the experience of VTTI and the IES committees.

2. Project Weaknesses

- There is no clearly stated pathway that has been identified in the project to meet the stated goals. There are broad statements about decreasing output, eliminating up-light, using controls, tuning color, etc., but that is all to be investigated and is very hypothetically stated as opposed to outlining it well in the project approach.
- Weaknesses include the fact that stakeholders are themselves being used as pilot programs for adoption of next generation systems.
- There are no observed weaknesses.
- No significant project weaknesses were found. The team is experienced and well-organized to achieve its goals.

3. Recommendations

- Based on the project's analysis thus far, the team should state whether it has the ability to adequately meet the goals it sets forth for the project.
- Some recommendations include working with collaborators outside the areas of lighting, reaching out directly to building owners/managers, and continuing development of a common platform and language.
- There is good progress so far. Please continue the good work.
- Use the results of the project to demonstrate the importance of energy efficiency in reducing electrical energy generation needs and improving air quality.

Project #32102a: Connected Lighting

Presenter: Michael Poplawski, Pacific Northwest National Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

Both reviewers approved of the project approach while one reviewer specified that the overall approach is comprehensive and attempts to address major areas of technical constraint, uncertainties, and barriers. A reviewer expressed concern that the project is taking on too much and won't be able to adequately complete the scope or achieve all the outcomes in the little time (FY2021) left in the project's operation.

Both reviewers commented positively on the project's impact. One reviewer emphasized that the project will provide meaningful impact to industry to accelerate adoption of standards, recommended practices, and minimum performance requirements, if the project is successful. However, this reviewer also expressed concern that the project's progress may fall behind and recommended additional evaluation after a year of project implementation.

The two reviewers agreed that the project has adequate collaboration and coordination. One reviewer praised the excellent project collaboration and coordination while the other reviewer commended the level of collaboration and coordination with industry as on par with what should be expected to accelerate adoption.

One reviewer stated that the progress on remaining work has been excellent. However, the other reviewer highlighted that the breadth of the project will make the remaining project work very ambitious to meet. Both reviewers praised project strengths such as the project's comprehensive approach to evaluating and reducing barriers to the myriad issues connected lighting might face (and doing so with industry collaboration) and the projects high impact. One reviewer recommended including discussions on adoption by end users or how to overcome the issues related to implementation.

Weighted Average: 3.35 # of Reviewers: 2
Approach: 3.50 Impact: 3.00 Progress: 3.00 Collaboration/Coordination: 4.00 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The overall approach is comprehensive and attempts to address major areas of technical constraint, uncertainties, and barriers, etc. There is concern that the project is taking on too much and won't be able to adequately complete the scope or achieve all the outcomes in the little time (FY2021) left in the project's operation.
- The approach is good.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- If the project is successful as outlined, the project will provide meaningful impact to industry to accelerate adoption of (largely) standards, recommended practices, and minimum performance requirements.
- The project shows promising progress.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- The project just started in October 2018, so the progress to date is in line with what might be expected. Because the scope of the project is ambitious, there is concern that the project's progress may fall behind. However, that should be evaluated after a year's time of project implementation.
- Progress is good.

D. Collaboration and Coordination

This project was rated **4.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Based on the stated project partners, the level of collaboration and coordination with industry is on par with what should be expected to accelerate adoption.
- Collaboration and coordination are excellent.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The breadth of the project will make the remaining project work very ambitious to meet.
- There has been excellent progress.

F. Additional Comments and Recommendations

1. Project Strengths

- Strengths include its comprehensive approach to evaluating and reducing barriers to the myriad issues connected lighting might face, and doing so with industry collaboration.
- The project will have a high impact.

2. Project Weaknesses

- The project's weaknesses are the other side of the same coin, meeting all the necessary outcomes is ambitious.
- There are no observed weaknesses.

3. Recommendations

- While it will add more complexity and breadth to the project, there is really no discussion on adoption by end users or overcoming many of the issues related to implementation.
- The project has shown good progress. Keep up the momentum to the finish line.

Project #32102b: Emerging Lighting Science

Presenter: Robert Davis, Pacific Northwest National Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

Two reviewers approved of the approach, describing it as addressing the conflict between energy needs and human biological needs in a straightforward manner, while being very relevant and exploring many unknown territories. Reviewers also provided suggestions on how to improve the approach: one reviewer highlighted that the question related to non-visual effects doesn't seem as clearly articulated, and another noted that taking standards advanced by WELL seems fine, but it would help to develop surveys that get at the effects that are claimed. One reviewer suggested focusing on one item more than the others as the project progresses, since the project scope covers many areas.

Most of the reviewers agreed that the project is expected to contribute to program goals and stated that the work toward the energy reduction goals is very clear and there is good potential for impact from all the tasks. Two reviewers emphasized the importance of meeting the non-visual needs of building occupants as a great benefit to the public. Because of this, one reviewer noted that achieving the energy goal is now a bigger challenge than what was previously assumed.

All reviewers agreed that the project has shown good progress towards exposing the energy gap between DOE's goals and specifications that address human needs. One reviewer praised that in this limited amount of time, the project achieved impressive results given that it explores an unknown field with little help from existing literature. Another reviewer highlighted that the second stage (non-visual) will be critical for contributing to the debate about how much energy is worth spending on non-visual effects.

All reviewers agreed that the project involves many relevant stakeholders and good collaboration. One reviewer praised that the experimental testing is happening with the hospital in Emory, Georgia and in classrooms in Sacramento, California and using these rooms in their realistic setting not only serves the research but also reduces its cost to the bare minimum. One reviewer suggested including manufacturers and software developers as the technology progresses.

One reviewer recognized that the project will face challenges with a changing landscape of metrics, but the project staff has demonstrated a desire and ability to stay flexible in the complex environment. One reviewer suggested that future work should include a discussion of how data collected from the ongoing experimental testing may translate into new regulations regarding the qualitative aspect of lighting design, and how these new regulations may be enforced by code. Two reviewers expressed uncertainty about task 3, stating that much of task 3 will depend on the framing of the work sub-contracted this coming summer and task 3 is non-existent, or nothing has started yet on task 3.

Weighted Average: 3.34   # of Reviewers: 4
Approach: 3.25   Impact: 3.25   Progress: 3.50   Collaboration/Coordination: 3.50   Remaining Work: 3.25

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.25** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is an important and ambitious initiative reckoning with the impact of the non-visual effect of lighting and the trade-off that presents for increased energy efficiency from SSL. The approach seems strong in the determination to study new technologies and techniques in realistic settings, but the question related to non-visual effects doesn't seem as clearly articulated.
- Since there isn't a consensus on the metric or standards for circadian effects, that would seem to be an important element to test more explicitly in realistic settings. Taking standards advanced by WELL seems fine, but it would help to develop surveys that get at the effects that are claimed. It may not be possible to detect them in the complexity of real lighting settings but that itself will be a helpful result.
- The project is addressing the conflict between energy needs and human biological needs in a straightforward manner.
- The project adopts a scientific approach to investigate the connection between the current practice of lighting evaluation based on human visual needs only and the non-visual needs. The subject of this project is very relevant and exploring many unknown territories. Investigating the non-visual needs is necessary in order to design buildings that address circadian needs in a holistic approach and to prevent any harm or discomfort to the occupants that may be caused by the continuous push for lower light energy in buildings.
- There is a lot going on in this study. It might be acceptable to focus on one of the items more than the others as the project progresses. The investigators are commended for implementing simulations into their research. This is a timely approach given recent advances in ray tracing.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.25** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The work toward the energy reduction goals is very clear. It seems the primary advances will be in exploring the impact of full spectral analysis and control on visual functioning.
- This project is addressing an important conflict between meeting DOE's goal of reducing energy consumption in buildings and addressing human biological needs for light. The latter must take front seat, otherwise people will not want to occupy the buildings. As such, achieving the energy goal is now a bigger challenge than what was previously assumed. But this project is key in discovering the correct path forward.
- The goal as stated was to support DOE's goal to achieve 30% energy savings in 2030 relative to 2010. The fact that this may not be achievable is why question 3 is 'fair'. That is not intended to diminish the importance of this project, quite the contrary. It is precisely because of this uncertainty that this project must be completed.
- The BTO goal is to reduce energy use (per square foot) by 30% by the year 2030. This project will likely end up with a recommendation to increase light energy (lighting power allowances) in order to meet the non-visual needs of building occupants. However, there is still of great benefit to the public.
- There is good potential for impact from all the tasks. Task 2 needs some re-evaluation on the exact impact. Meaningful information about the diffuser material can be obtained from task 2, but the details need to be worked out within this first year.

C. Progress

Based on current project efforts, the project was rated **3.50** for the degree to which the project has met ***project-specific goals***.

- The progress on tasks 1, 2, and 4 seem on track. The sub-contracted work on task 3 should bring that task further along, but the second stage (estimate value of non-visual) will be critical for contributing to the debate about how much energy is worth spending on non-visual effects.
- The project has demonstrated good progress towards exposing the energy gap between DOE's goals and specifications that address human needs. The project has also shown good progress with evaluating lighting quality metrics, as well as determining a path towards realistic goal setting.
- The start date of the project was the 1st of October 2018 (new scope for ongoing work). In this limited amount of time, the project achieved impressive results given the fact it really explores the unknown with little help from the existing literature. They achieved significant progress in task 1 (Energy), task 2 (Visual), and task 4 (Realistic Settings). A detailed description of the progress in task 3 could not be found.
- The overall progress seems good.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team has arranged many collaborations, leveraging ongoing work in other contexts.
- For the analysis of non-visual, spectral effects, they might reach out to the team at Solemna that developed ALFA.
- The project has engaged most of the relevant stakeholders.
- Question 7 has an error in the choices. I chose option 3 for 'good', which is erroneously labeled 'poor'.
- The project collaborated and coordinated with the right stakeholders. The experimental testing is happening with the hospital in Emory, Georgia and in classrooms in Sacramento, California. Using these rooms in their realistic setting not only serves the research but also reduces its cost to the bare minimum.
- The collaboration seems good. It might be useful to get in contact with manufactures as the technology progresses. It might also be helpful to get in contact with software developers. If the software was developed in-house (at DOE labs), this might be easier said than done.

E. Remaining Project Work

This project was rated **3.25** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The organization of the research is clear and targeted, but much of task 3 will depend on the framing of the work sub-contracted this coming summer.
- The project will face challenges with a changing landscape of metrics used to determine human biological needs relating to light, as well as standards and other specifications that set the requirements. The project staff has demonstrated a desire and ability to stay flexible in the complex environment.

- As presented by the team leaders and according to the information in the slide presentation, future work is planned in advance. Future work is mainly collecting data form the ongoing experimental testing at Emory Healthcare and the classrooms in Sacramento, California. Future work also should include a discussion of how data collected from the ongoing experimental testing may translate into new regulations regarding the qualitative aspect of lighting design, and how these new regulations may be enforced by code.

- Tasks 1 and 4 are progressing excellently. Task 2 subtask Optical Materials needs some focusing on identifying the objective. Task 3 is non-existent, or nothing has started yet on task 3. More information is necessary to evaluate task 3.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strength is the multi-disciplinary, collaborative approach to an emerging topic that exists at the intersection of energy, visual performance, and circadian effects. Like many other energy technology issues, the hard question is about value of human health or well-being and the realistic settings seem to be the right venue to evaluate that.

- Project strengths include addressing the problem head on and engaging with the research community to understand the evolving human needs.

- Project strengths include the interdisciplinary team that is prepared to tackle the unknown territory the project explores, the adoption of an experimental approach so the results are based on first-hand experience at the test sites, and the strong connection to stakeholders, including the experts in lighting and the manufacturers.

- Task 1 has some tremendous strength. The goal of re-evaluating the spectrum and using simulations to understand what spectrum is transmitted to the observer is a necessary approach. Task 2 has some strength in trying to identify some quantitative descriptors. The use of an HDR raw camera seems like a nice approach.

2. Project Weaknesses

- The weakness surrounds the hard questions of fitting the non-visual effects of lighting into the existing metrics and practices that have developed around visual performance.

- The project is not engaging with the energy efficiency community, such as ASHRAE, to develop a broad consensus on the potential compromise needed between building energy use and the needs of its occupants, or alternatively to influence the way future buildings are designed, such as for better daylighting.

- It is not really a weakness, but it would be nice if the project developed its own critical opinion regarding the non-visual requirements in the WELL Building system, as well as the data collected from the Swedish Medical Behavioral Health Unit. It would be helpful to study the scientific reasoning behind the development of such requirements/recommendations.

- Task 3 is a weakness. No information was given in the PowerPoint. Task 2 subtask Optical Materials needs some focus on the goals and objective.

3. Recommendations

- Use the realistic settings to test some of the propositions about the effects of non-visual perception in complex, real-world settings.

- It would be nice to see the project staff get more engaged in what these results mean for future building design, perhaps even involving the architectural community.

- One recommendation is that the evaluation of the quality of light be based on the quality of natural light (daylight). In reference to page nine of the slide presentation (SPD distributions), the comparison is currently to another artificial source of light (typical) instead of being compared to the SPD of natural light.
- One recommendation is that you look at collaborating with the developers of the ray tracing software. A lot of improvement could be made quickly on the software. You could achieve more realistic rendering of light and objects. This is potentially a tool that could be used for research as you are using it but also by architects in design. Another suggestion is to modify task 2 for the optical materials and do not use the HDR camera to look directly at the light figure but at some target instead. It might be necessary to create a room where the walls are nearly perfect black bodies and then the light fixture is mounted above and shown on some object and the camera takes a picture of the object. I think the objective should also be from the observer's point of view.

Project #32110: Lighting and Grid Integration

Presenter: Michael Poplawski, Pacific Northwest National Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

The project approach is was approved by two reviewers. However, one reviewer suggested including some collaborators from the daylighting community as well, who have a slightly different view. Another reviewer commented that there was not enough discussion on the modeling and simulation approach.

Two reviewers agreed that the project is expected to contribute to program goals, and one reviewer noted that the project will have a high impact. One reviewer highlighted that the goal is to evaluate whether CLS can provide any useful services to the grid and the project seems well formulated to achieve that goal. However, one reviewer commented that the impact is not well understood, and it is a fundamental aspect of this research.

Most of the reviewers acknowledged that the project is still in the early stages of development, and has shown reasonable progress for this stage, mostly in fundamental background work. One reviewer praised that the project team has made good progress, however, another reviewer commented that there is much work still left to be completed.

The reviewers were divided on the project's level of coordination and collaboration. One reviewer praised the project for its outstanding collaboration and another reviewer highlighted that the project advisory group suggestions seem very appropriate. In contrast, one reviewer commented that the listed collaborators and partners are very low and only includes NYSERDA. They suggested including more participation from utilities, regional transmission organizations (RTOs)/independent system operators (ISOs), end users, and other stakeholders.

Looking forward, reviewers were varied on their outlook. One reviewer praised the project for its high expected success, while two reviewers agreed that there is a lot of work still left to be complete. One reviewer commented that the next stage will likely be decisive, as the key will be to formulate the simulation so it captures the dynamic potential of lighting systems. A final reviewer recommendation is to include the daylighting community to help incorporate potential environmental dynamics that might be amenable to grid interaction.

Weighted Average: 2.82   # of Reviewers: 3
Approach: 3.00   Impact: 3.00   Progress: 2.67   Collaboration/Coordination: 2.33   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- They are in the early stage of project, and the approach of bringing together the lighting community and the grid service community seems very good. The only suggestion would be to include some from the daylighting community as well, who have a slightly different view.
- The approach of using modeling/simulation and laboratory/test beds to validate is straightforward. There wasn't much discussion on the modeling/simulation approach.
- They have a good approach.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The goal is to evaluate whether CLS can provide any useful services to the grid and the project seems well formulated to achieve that goal.
- An open question this project is attempting to answer is how much impact can grid-enabled lighting provide in the way of grid services. As of now, the impact is not well understood and is a fundamental aspect of this research.
- This project will have a high impact.

C. Progress

Based on current project efforts, the project was rated **2.67** for the degree to which the project has met ***project-specific goals***.

- The project is in its first quarter, and progress seems reasonable for this stage.
- The project is a new project and is in the initial stages of development. Progress appears to largely be in fundamental background work. There is much work still left to be completed.
- They have made good progress.

D. Collaboration and Coordination

This project was rated **2.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project advisory group suggestions seem very appropriate.
- The listed collaborators and partners are very low and are only NYSERDA. It would be better to have seen much more participation from utilities, RTOs/ISOs, end users, and other stakeholders.
- The project has outstanding collaboration.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Most of the project work remains, so the next stage will likely be decisive. The key will be to formulate the simulation, so it captures the dynamic potential of lighting systems. It wasn't clear how much the building lighting simulation will be customized to do this but incorporating technologies like storage seem vital.
- Based on the stated work to date, and the overall project schedule, there appears to be a lot of work still left to be complete.
- The project has high expected success.

F. Additional Comments and Recommendations

1. Project Strengths

- The project has brought together a capable team to consider a question that lies between two fields and is well structured to answer the question that was posed.
- The fundamental question the project is attempting to answer (Is lighting a suitable technology for grid integration and what are the benefits of it as a technology to support grid services?) is largely outstanding. This is a fundamental knowledge gap that needs to be addressed in a world with advanced grid services.
- This project is very important.

2. Project Weaknesses

- It isn't entirely clear that the simulation will capture all of the dynamic aspects that will be important for the question.
- Weaknesses reflect the lack of broad-based partnerships - i.e., utilities, RTOs/ISOs, end users, etc. There is stakeholder engagement, but it is unclear what exactly the roles are in the project.
- There are no observed weaknesses.

3. Recommendations

- The team seems well organized and directed to the question. The only possible suggestion was to include some of the daylighting community to help incorporate potential environmental dynamics that might be amenable to grid interaction.
- No comment at this time.
- The project has made good progress. Please keep momentum to the finish line.

Project #32102d: Lighting Systems Challenge

Presenter: Ruth Taylor, Pacific Northwest National Laboratory
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

Most reviewers praised the project approach as serving the valuable purpose of getting information to system manufacturers from installers that are typically not available. The "Observational Research", with experts in the field observing the installation and operation of the light fixtures being tested in a lab setting and encouraging manufacturer's participation through a government-run competition is a good approach for market penetration. However, one reviewer warned that the choice of collaborative partners that have something to gain could lead to biased results.

Overall, reviewers expected the project to meet program goals, with the results of this project expected to address a significant barrier in the adoption, installation and maintenance of energy efficient lighting systems. One reviewer praised the project, stating that both programs, Outdoor and Horticultural, have potential major impacts on program goals, but the Outdoor program major impact appears more well-documented related to limiting sky glow while attaining energy savings. Another reviewer commented that the impact of this project is in the form of educational seminars, presentations offered, articles published, and the NGLS competition.

In general, reviewers agreed that the project has shown good progress to-date. The project has identified several improvement opportunities and communicated those to system manufacturers, reaching significant results in a short time. One reviewer highlighted that Outdoor Lighting is more mature than Horticultural Lighting, so the progress on metrics with Outdoor Lighting, as well as validating real world models with data is impressive, but initial progress on Horticultural Lighting is limited.

Two reviewers approved of the project collaboration with several stakeholders, including major manufacturers, an expert panel of advisors, researchers, two universities, IESNA, lighting designers, and electric sub-contractors. However, one reviewer expressed concern about limited collaboration and coordination efforts. For Outdoor Lighting, coordination efforts seem somewhat limited as this appears to be driven in a “top-down” management structure and progress for Horticultural Lighting related to developing collaboration is limited because this is a new program.

Overall, reviewers agreed that the project is on track to achieve its goals with a realistic plan and timeline. One reviewer provided recommendations on how the project team should address the remaining work. For Outdoor Lighting, examination of crash statistics related to improved visual acuity of replacement LED systems should be expanded to several municipalities to add to the weight of evidence. For Horticultural/Agricultural Lighting, much work needs to be done to assess metrics and measurement methods in real field evaluations. This reviewer suggested using lighting in a real-time feedback scenario, not only to grow plants, but to control growth.

Weighted Average: 3.32   # of Reviewers: 3
Approach: 3.67   Impact: 3.00   Progress: 3.00   Collaboration/Coordination: 3.33   Remaining Work: 3.33

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project serves the valuable purpose of getting information to system manufacturers from installers that are typically not available.
- The choice of collaborative partners that have something to gain could lead to biased results. It is imperative to include collaborators who have little to no background in lighting for the various protocols.
- The approach of this project is the "Observational Research", which translates to experts in the field observing the installation and operation of the light fixtures being tested in a lab setting. Surely, it allows experts to watch the work in progress and document real-time the process being investigated. Although it seems to be a huge commitment on behalf of the experts, it is the method to yield the most accurate results. Encouraging manufacturer's participation through a government-run competition should motivate manufacturers with large market share to get involved. That is a good approach for market penetration as well.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The results of this project will address a significant barrier in the adoption of energy efficient lighting systems, the installation and maintenance of those systems. Without improvements in this area, adoption is likely going to lower.
- Both programs, Outdoor and Horticultural, have potential major impacts on program goals. The Outdoor program major impact is perhaps more well-documented related to the limiting sky glow while attaining energy savings. The Horticultural area will likely be exploding due to proliferation of indoor growing scenarios related to weather changes, as well as specific crop development.
- Impact of this project is in the form of educational seminars and presentations offered and the articles published in 2018 and 2019. The impact of the NGLS competition is also significant in the way some manufacturers are using the competition results to further improve their products (LUTRON & EATON). The competition closes the loop of design, testing, redesign, further testing, etc., which is of a great help to the manufacturers who do not have access to such advanced labs or research funded by the BTO. The initial findings are of special value. One observation regarding the initial findings is the complexity and difficulty of verifying the performance (energy savings) of daylight sensors and occupancy sensors. As it appears from the pictures, the existing lab wouldn't offer the possibility of testing such sensors. They must be tested in an occupied space, such as an office space or a classroom. It is my experience that daylight sensors are incorrectly installed most of the time and end up disconnected simply because the maintenance crew is not able to get them to work properly. My understanding is this research project has this within its scope of work. It is a problem that needs a solution.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- The project has identified several improvement opportunities and communicated those to system manufacturers.

- Outdoor Lighting is a bit more mature than Horticultural Lighting. The progress on metrics with Outdoor Lighting, as well as validating real world models with data is impressive. Initial progress on Horticultural Lighting is limited.
- According to the presentation, this project is continuing work with a new scope. The project started 10/1/2018 and reached significant results in such a short time.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project staff has engaged the major manufacturers in the project and has collaborated with an expert panel of advisors throughout the project.
- For Outdoor Lighting, coordination efforts seem somewhat limited as this appears to be driven in a “top-down” management structure. With the collaborative effort with the National Park Service, goals of the project need to be clarified. Again, progress for Horticultural Lighting related to developing collaboration is limited for this new program.
- The project reflects a collaboration with the right stakeholders. The project involves researchers, two universities, IESNA, lighting designers, manufacturers, and electric sub-contractors.

E. Remaining Project Work

This project was rated **3.33** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project has a very realistic plan and timeline. With the continuing engagement of the manufacturers, success is likely.
- For Outdoor Lighting, examination of crash statistics related to improved visual acuity of replacement LED systems should be expanded to several municipalities to add to the weight of evidence. For Horticultural/Agricultural Lighting, much work needs to be done to assess metrics and measurement methods in real field evaluations. Using lighting in a live time feedback scenario, not only to grow plants, but to control growth, seems like an additional area to explore.
- Based on the progress achieved so far in such limited time, it appears the project is on track to achieve its goals by the planned end date of 9/30/2021.

F. Additional Comments and Recommendations

1. Project Strengths

- Strengths include approach by observing and recording, without interference, collaborators and advisors, and manufacturer engagement through feedback.
- For Outdoor Lighting, the development of tools and metrics to measure sky glow impacts is a major strength. For Horticultural Lighting, due to the short duration of the program, no strengths could be identified.
- The strength of this project is its realistic approach in the way it addresses all steps involved from manufacturer design of their products, to the installation and operation of the luminaires. The lab setting allows real-time observation of the installation process. Its collaboration with the involved stakeholders is commendable as well.

2. Project Weaknesses

- There are no weaknesses.
- For Outdoor Lighting, the development of metrics to measure sky glow should be independently analyzed. Lack of inclusion of major players in Horticultural Lighting is a potential detriment.
- The lab setting won't allow testing the performance of daylight sensors and occupancy sensors. The limited time of the presentation did not allow the opportunity of presenting more specific results from the people observing the approach. Such information would have been helpful to understand the impact of that part of the project.

3. Recommendations

- This project needs to be completed and the positive results made widely available.
- Some recommendations include working with collaborators outside the areas of lighting, reaching out directly to agricultural and outdoor facilities managers/municipalities, and continuing development of a common metrics and measurement methodology.
- One recommendation would be for deliverables of this research project to include a checklist of specific tasks to be executed by a building inspector to verify all luminaires and controls are installed according to the manufacturer's specifications. Commissioning of electric lighting systems may prove to be as important to building performance as commissioning of HVAC systems.

Project #31150: Tunneling-Enabled High-Efficiency High-Power Multi Junction LEDs

Presenter: Andrew Armstrong, Sandia National Laboratories
DOE Manager: Brian Walker

Brief Summary of Reviewer Comments

In general, the reviewers agreed that the project's approach contributed to overcoming barriers, technical challenges, and mitigating project risks. The reviewers applauded the approach as one that is likely to see application in lighting and largely fundamental scientific research on GaN LEDs which will benefit the broader SSL market. One reviewer highlighted that this project is still in the early stage, but the team is aware of immediate barriers and tactics for overcoming them.

Impacts were praised by one reviewer for the project's excellent impact potential while two reviewers described the project's specific goals and impact. It was noted that research is aimed at increasing the output of GaN LED at higher power densities, not by increasing current, but by increasing voltage.

Reviewers mostly agreed that the project is still in the early stages, but progress has been made, highlighting the team's demonstration of the electrical efficiency of the multi-layer approach in diodes and their good progress with actual IV curves. However, one reviewer pointed out that no timeline was included with the project presentation.

The reviewers all approved of the project's collaboration, with one reviewer commenting that the two partners in the team seem well prepared for the project and are collaborating with Lumileds, a respected LED manufacturer, on commercialization. Two reviewers suggested opportunities for additional collaboration and noted that more industry representation may be beneficial. Also, Ohio State University (OSU) has some new TEM equipment that might be useful for this project.

One reviewer stated that the remaining project work is logically organized, but that will depend on success in overcoming the obstacles that arise as additional layers are added to the assembly. Another reviewer suggested the project team look to scaling of manufacturing and temperature stability. Overall, the reviewers generally agreed that the project approach is a major strength, given that the approach is an interesting, technical approach that addresses opportunities for efficiency gain in the fundamental science of SSL technologies that drive the overall LED market.

Weighted Average: 2.97   # of Reviewers: 3
Approach: 3.00   Impact: 3.33   Progress: 2.67   Collaboration/Coordination: 3.00   Remaining Work: 2.67

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This is the early stage of the project, but the team seems aware of immediate barriers and tactics for overcoming them.
- The reviewer does not have technical competence to evaluate the approach with any depth, but based on presented material, the approach is largely fundamental scientific research on GaN LEDs which will benefit the broader SSL market.
- The project has an interesting approach that is likely to see application in lighting. It is an electrical engineering approach that relies on increasing voltage instead of current.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The research is clearly aimed at increasing the output of GaN LED at higher power densities, not by increasing current, but by increasing voltage.
- The reviewer does not have technical competence to evaluate the approach with any depth, but based on presented material, the potential impact is largely based on the commercial implementation of fundamental scientific research on GaN LEDs, which will benefit the broader SSL market.
- This project has excellent impact potential.

C. Progress

Based on current project efforts, the project was rated **2.67** for the degree to which the project has met ***project-specific goals***.

- The project is in the early stages, but the team has demonstrated the electrical efficiency of the multi-layer approach in diodes.
- The project is fairly new, and no timeline was included with the project presentation. There appears to be some progress on the first goal.
- The progress seems good. They are making good progress with actual IV curves.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The two partners in the team seem well prepared for the project and are collaborating with Lumileds, a respected LED manufacturer on commercialization.
- The project implements collaborations with industry and academia. Given that the reviewer is not an expert in this project's area, the Reviewer is not aware of additional collaboration opportunities. However, more industry representation may be beneficial if available.

- The collaboration seems fine. What is OSU doing exactly? Is all deposition being done at Sandia? OSU has some new TEM equipment that might be useful for this project.

E. Remaining Project Work

This project was rated **2.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project is in the first stage. The rest of the stages seem logically organized, but that will depend on success in overcoming the obstacles that arise as additional layers are added to the assembly.
- Given that the reviewer is not an expert in this area of research, the reviewer is unable to sufficiently evaluate whether this research will be able to meet its stated goals.
- It looks like they may supersede the program objectives, which is great. One suggestion is to look to scaling of manufacturing and temperature stability.

F. Additional Comments and Recommendations

1. Project Strengths

- One strength is the clear technical approach using tunnel junctions and multi-layer construction.
- A project strength is addressing opportunities for efficiency gain in the fundamental science of SSL technologies that drive the overall LED market.
- This is an interesting approach that relies on an electrical engineering approach.

2. Project Weaknesses

- A potential weakness is the complexity that will arise with more layers, materials, and manufacturing techniques.
- The project is largely inaccessible to general practitioners or lighting lay persons.
- There is uncertainty if the project is taking enough risk for $1 million. One suggestion is to look into scaling of the technology and looking at non-mesa designs.

3. Recommendations

- Keep going with this project.
- For future presentations, spending some time on the background of why GaN LEDs are important might be helpful for those not involved in this area of research.
- A suggestion looking forward would be to determine how many cascades you can stack. The electron-phonon scattering rate should be influenced by the field strength at high voltages. You should also look at thermal stability of the device. The field-emission current is sensitive to temperature along with the mobility. You need to confirm that the performance can be maintained at all temperatures. Take advantage of the TEM machines at OSU and have Hwang get some nice images. Look at non-mesa designs for the interconnect.

Emerging Technologies

Building Energy Modeling

Project #32488, #32482, #32589, #32590: Empirical Validation and Uncertainty Quantification of Energy Simulation

Presenters: Ralph Muehleisen, Argonne National Laboratory; Christian Kohler, Lawrence Berkeley National Laboratory; Pijae Im, Oak Ridge National Laboratory
DOE Manager: Amir Roth

Brief Summary of Reviewer Comments

The reviewers feel the project is well-planned and organized, and that it addresses an important issue related to building energy modeling (BEM) accuracy and adoption of BEM tools. Reviewers praised the project for its potential impact and contribution to program goals. Reviewers also highlighted the team's plan to address the potential for input errors. One reviewer specifically noted that the test facilities are well suited to the project. They also remarked that support for ASHRAE Standard 140 aligns with program goals.

Reviewers commended the substantial progress made towards the project goals. Reviewers also rated the project's collaboration efforts highly, citing the importance of collaboration with ASHRAE. Reviewers commented positively on the plans for remaining project work and expressed confidence that the project would be able to achieve its goals. However, one reviewer added that additional work on modeling outdoor environments would be beneficial.

Reviewers highlighted the empirical test data generated by the project as a strength of this effort, along with the use of the robust testing facilities. One reviewer stated that the value of the data demonstrates the need for more related testing efforts. Both reviewers recommended further research given the value of the work completed thus far, with one reviewer specifying that educational outreach would be useful for collecting user input regarding variables that are more meaningful versus those parameters that may fall within the margin of error.

Weighted Average: 3.70   # of Reviewers: 2
Approach: 3.50   Impact: 3.50   Progress: 4.00   Collaboration/Coordination: 4.00   Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- A lack of confidence in building energy modeling's (BEM) predictive accuracy has long been a barrier to increased uptake in modeling. Separating any potential BEM engine inaccuracies through carefully controlled empirical validation will help to separate issues with the actual engine from issues with accuracies due to input error. Lawrence Berkeley National Laboratory's (LBNL's) FLEXLAB and Oak Ridge National Laboratory's (ORNL's) Flexible Research Platforms (FRP) are well-suited to perform this validation. The teams have done a very good job of addressing specific challenges, such as generic versus actual rooftop unit (RTU) performance curves.

- The project approach is well-planned and organized to overcome barriers and mitigate risk.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Clear validation of the engine calculations will help to separate engine inaccuracies from input error. The ability to make "definitive quantitative statements about BEM engine accuracy" and to improve this accuracy will help to alleviate some BEM-skeptic concerns about the overall accuracy and generally increase confidence in and use of BEM. Dealing with input errors is still a major barrier as well, but isolating where predictive errors may occur is a big first step. Close involvement with ASHRAE Standard 140 is also very valuable.

- The empirical validation work in this project and its contribution to expanding test suites in ASHRAE Standard 140 will have high impact for both improving BEM tools and for demonstrating the accuracy of BEM tools. Both outcomes contribute in important ways to increasing owner and engineer confidence in BEM tool accuracy, which in turn can contribute to wider use of BEM tools to improve building design.

C. Progress

Based on current project efforts, the project was rated **4.00** for the degree to which the project has met ***project-specific goals***.

- Each of the presentations showed substantial progress on project-specific goals. For example, the ORNL FRP presentation validated heating and cooling loads for three-week winter and summer tests in a two-story ten-zone brick building. The tests showed low uncertainty suitable for ASHRAE Standard 140.

- Both the FLEXLAB and FRP LAB tests are well on track to meeting project goals.

D. Collaboration and Coordination

This project was rated **4.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The presentations showed very good collaboration between labs and close coordination with ASHRAE Standing Special Project Committee (SSPC) 140. A Technical Advisory Group (TAG) consisting of vendors, practitioners, and researchers to review plans and results provides additional valuable stakeholder engagement.

- The project team's regular, ongoing consultation with the ASHRAE SSPC 140 committee has been effective for coordinating with stakeholders.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This reviewer looks forward to seeing more work on the outdoor testing.
- The future work appears to be logically planned and will advance the work to meet the overall project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- Very strong empirical validation through facilities that are "sufficiently characterized, controlled, and instrumented to support 'validation-grade' experiments."
- As a BEM software vendor, development of this empirical test data is immensely valuable for validating our algorithms in the software. Test data at this level of detail and fidelity has been very hard to obtain in the past. But beyond algorithm validation, the test data provides an additional benefit that could improve application of the algorithms in real world design. BEM tools using Heat Balance engines for load and heating, ventilation, and air conditioning system calculations have the potential for providing higher accuracy than the older reduced-order methods. However, achieving this potential accuracy will only happen if appropriate model input data is used for phenomena that have a large effect on results, such as inside and outside surface convection, surface radiative properties, and interior mass, to name a few. The older reduced-order methods embedded these inputs in the algorithm as assumptions, and a user did not need choose and apply those detailed inputs. Mechanical, electrical, and plumbing engineers generally will not know what data should be used for these kinds of inputs. Virtually any result can be obtained based on the chosen inputs, ranging from results that are accurate and appropriate to results that are very inaccurate. As a result, engineers look to BEM software vendors to provide guidance and proper defaulting to channel them into successful use of the software for their applications. The empirical testing done to date has started to clarify what guidance BEM software vendors should provide. It has also exposed significant needs for future research to explore these issues further. Ultimately the empirical validation not only improves the tools and algorithms, it improves the application of the tools and algorithms. That second benefit may be just as impactful as the first.

2. Project Weaknesses

- How will actual users handle lack of RTU real information? Or should they generate their own?
- The project "weakness" grows out of its strength. The empirical test data produced so far is so useful that it demonstrates the value of going further with these kinds of tests to provide more complete guidance on how the algorithms should be applied. For example, the LBNL FLEXLAB tests uncovered the fact that natural convection from interior surfaces is the dominant convection mode for the low air change rates used in the test. But it is unclear at what air change rate the dominant convection changes to forced convection mode, nor is it clear how a room transitions from natural to forced convection at intermediate air change rates. As mentioned in the "strengths" section, this knowledge is critical for proper application of the algorithms so the great potential for accuracy of the Heat Balance algorithms can be realized in practice. In addition, I recall both the FLEXLAB and FRP tests demonstrated how troublesome ground heat transfer is in matching modeled results with measured results. Efforts were being made to isolate the test cell from ground effects in some cases. But this demonstrates one of the glaring challenges for load and energy modeling software. Nearly all building applications have some sort of ground contact through slab on grade or basements. Therefore, ground heat transfer affects real building performance. In large multi-story buildings,

the overall effect on total building performance may be smaller, but the effect on smaller buildings (the majority of building stock) can be significant. This is one more example of a future research topic that could have value to the industry. So, the main “weakness” I perceive is how much more useful work could be done to realize the full potential of this type of research.

3. Recommendations

- Increase educational outreach to users to encourage accurate user input, and flag which variables actually matter versus inputs that are within the margin of error.
- See "weakness" – that comment really wasn't about a deficiency in the project it was pointing out how much additional useful research could be done. Perhaps that comment belonged here as "improvement" comments.

Emerging Technologies

Grid-Interactive Efficient Buildings

Project #34657: End-Use Load Profiles for the U.S. Building Stock

Presenter: Eric Wilson, National Renewable Energy Laboratory
DOE Manager: Monica Neukomm

Brief Summary of Reviewer Comments

Overall, this project was well-received with multiple reviewers positively commenting on the approach. One reviewer described the study as "very exciting and important work" and inquired about the emerging data sources that the team was planning on utilizing with the metered data from the different regions. It was suggested that the team should purchase any new data that becomes available during the project duration and that data should be prioritized over more modeling. Another reviewer recommended that the team address the issues that arise due to lower-quality data and communicate any of those shortcomings in the results. This reviewer also expressed concern about overfitting the models to the existing data and suggested either reserving enough funding to validate the models or comparing the results to ongoing or new studies.

Reviewer comments were generally complimentary about the potential project impact with the one exception being a reviewer who questioned a single use-case. This reviewer was skeptical about the second use-case – load forecasting and resource planning – and noted that longer range forecasts are often "driven by economic growth, assumptions about environmental regulations, and fuel price forecasts." Half of the reviewers found the project impact to have great value to stakeholders including utilities, researchers, and industry. One reviewer highlighted how future users could evaluate different demand-management controls approaches such as pre-configurations for common strategies.

In addition to approval of the project's progress, reviewers also applauded the team's coordination and collaboration efforts. Reviewers remarked that the project was a great example of coordination between laboratories and mentioned the 65-member advisory group that contains relevant stakeholders from utilities, consultancies, and government organizations. Other recommendations included developing a guide detailing the intended audience and use for each load shape, establishing multiple use-cases for the available data, and the further collaboration with utilities through state and national organizations.

Weighted Average: 3.19 # of Reviewers: 4
Approach: 3.00 Impact: 3.00 Progress: 3.00 Collaboration/Coordination: 3.75 Remaining Work: 3.25

Program Response

The Building Technologies Office leverages the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project builds off prior work (ELCAP) and tests improved methods for data collection and analysis (lower cost metering, disaggregation, and conditional demand analysis). The project has part of the team involved with the original ELCAP work, blended with new members and approaches. It would be good to design from the beginning DOE modeling approaches and structure for extrapolation to a regional study

- This is very exciting and important work. The presentation describes the use of a hybrid approach for developing the load-shapes. It would be good to know the emerging data sources that will be combined with the metered data from the different regions.

- The approach makes a lot of sense. Collaboration across the labs (to leverage different lab strengths) and consulting the industry is good. Leveraging the existing residential and commercial building models makes sense too. As the project continues, if new data sources become available (for a price) and a decision needs to be made about more modeling versus more data, the team should pay for the data. The more ground truth, the better.

- This reviewer really likes the ambition of this project as it addresses a major, major gap.

- The description of the approach was very high level (i.e., there are a lot of details that were unclear). (Note: this is inherent in trying to summarize such a large project with many aspects in a 20-minute presentation). Also, it will be important to have strong Go/No-Go criteria to make sure that this product lives up to its full potential.

- Maximizing the value of this project for utility stakeholders will require providing easy access to all the ResStock and ComStock models so that utilities, practitioners, and researchers can use the information developed to evaluate the grid impact of different technologies and their ability to provide grid services.

- Inevitably, there will be areas where the project team finds fewer and lower-quality data to characterize load curves for different end uses, in different building types (particularly some commercial building types). It will be crucial for the project team to address this issue and effectively characterize and communicate the quality of the underlying data and results.

- Ideally, the project team would come up with a meaningful way to validate the outputs of the models beyond comparing the outputs to the underlying studies used to develop the models. This could be comparing results to ongoing/new studies or reserving a portion of prior studies for validation only. Otherwise, there is a real risk of overfitting the models to the existing data.

In addition, these points require more information:

- How the project team plans to present the variability in potential load shapes in the model outputs.

- The level of effort allocated for "Targeted data collection" to address the data gaps found. Presumably, there will be some prioritization based on magnitude and importance of the gaps to the overall assessment, as well as the ability of the supplemental data collection to appreciably address those gaps.

- NEEP's role in the project ($750k budget) (i.e., what new/novel data sets will they bring to the project).

- Finally, the RECS and CBECS buildings are selected to be broadly representative of the overall building stock. How confident is the project team that it will be so at a sufficient level of granularity to characterize accurately characterize hourly load shapes for a wide range of (in particular) commercial buildings in specific regions/states? How will uncertainties/errors in responses to CBECS and RECS affect the ability to develop meaningful hourly load forecasts?

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Little work has been done to update or replicate this work since the 1980's. This project is a good contribution to update the studies and to update use cases for how this data can be used.
- This was a little hard to discern from such a short presentation. It is not clear what resolution of data will be available across the U.S. – and in which cases this study is updating older values versus creating new ones from additional data sources. How will the new data enable better modeling of certain end uses or climate zones? The top use case data requirements table was quite helpful. It speaks to the myriad uses for this data, but it would be good to know which are being enhanced or better served by the new load shapes.
- This project will provide an impact on the stated #1 use-case: energy efficiency and demand response utility programs.
- This reviewer is much more skeptical about the impact to use-case #2: load forecasting and resource planning. Longer range (2-10 years) forecasts tend to be driven by economic growth, assumptions about environmental regulations, and fuel price forecasts. Additionally, utilities are pretty accurate with shorter range (1-year ahead) forecasts. Having spoken to many load forecasting veterans, they believe bottom-up forecasting will multiply underlying errors in the models. A study that quantifies the relationship between bottom-up forecasts and load diversity would be beneficial to see. This would reveal how load diversity (i.e., a certain number of buildings) creates a smoothing effect that renders bottom-up forecasts inferior to forecasts that rely on historical data matched to season / day of week / weather forecast.
- Developing reasonably accurate ways to assess how technologies actually affect hourly load shapes for different end uses and buildings' demand management potentials would have great value for electric utilities, their consultants, and researchers.
- Ideally, the project would also enable users of the tools resulting from the project to readily explore different demand-management controls approaches (including pre-configurations for common strategies).

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- The team presented their progress with no significant barriers.
- This project has just started. The schedule on slide 21 makes it look like there has been some delay in getting the work going, but that's often the case with these types of projects. The challenge is going to be in getting timely delivery of the data.
- Good.
- The project appears to have a promising start.

D. Collaboration and Coordination

This project was rated **3.75** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- It is good to see a broad group involved. The team should continue to build use cases for data up front rather than after data collected. The establishment of multiple use cases for data would be good to see including the following:
- Capturing the capacity benefit of energy efficiency;
- 5-minute energy profile (as energy markets move from hourly to 5-minute dispatch);
- Sub minute/second profiles (for stability and response to disturbances);
- Capture load profile differences of existing building stock versus high performance new construction versus new high performance all electric buildings.
- When use cases are developed, a guide for who would use the load shapes and how they would use them should be made. The use for non-wires is different than resource planning or program design and would also differ by group (grid planning vs resource planning vs operations vs DSM).
- It looks like the project team is coordinating with the right folks. Its 65-member advisory group contains many prominent utilities, consultancies, and government organizations. This group will likely be helpful in securing the data to develop the load shapes and make appropriate technical choices for their modeling.
- This project is a great example of lab coordination. Keep it up! And keep testing your assumptions with utilities too!
- I would encourage the project team to integrate even further with utilities (e.g., via EPRI and CEE).

E. Remaining Project Work

This project was rated **3.25** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project plan presented seems appropriate.
- The team has done a very nice job identifying the tasks for this project. The work on use cases, data gap taxonomy, and occupancy modeling is a good start. More information about the model calibration and additions to the load profile library would have been helpful. What form will the final savings profiles and load shapes take? Will they be available on their own or only through ResStock and ComStock? And will the profiles be at sufficient resolution that they can be used by the state and regional planning agencies?
- None.
- There are a lot of details to be worked out in this project, and this will be a major project management and integration challenge with so many people and several labs involved. It might have been better to split into 2–3 smaller, more manageable projects that are re-scoped as needed based on prior project findings.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include engagement with a strong team in PNW on the topic and with those who produced the last version of a study to this depth (ELCAP). The team reviewed the prior work and improved upon it. The team is building use cases and plans to utilize information upfront (with ELCAP it was mostly done after the project). This is a good way for DOE to leverage and improve a regional investment.
- The expertise of the team, the large number of stakeholders with access to robust data sets, and the use cases are project strengths. This reviewer especially likes the prioritization of use cases and documentation of the high-level input needs for the models. This reviewer looks forward to having the new load shapes available.
- The team is testing the models against real data. The project is combining expertise from the labs. The team is collaborating with utilities.
- This project addresses a crucial need (i.e., develop high-quality estimated hourly load shapes by end use for different building types, in different locations, for a ~representative sample of buildings).

2. Project Weaknesses

- The team needs to ensure strong use case development to ensure data is useful to others. The team needs to ensure the regional data can be extrapolated to build national load profiles.
- It looks like the team is attempting to cover a large geographic region with both ResStock and ComStock, but it's not clear that the data will be generalizable to all climate zones and uses.
- There is relatively little real data when compared with the stated deliverable: a national comprehensive data set.
- It is uncertain that bottom-up forecasting is superior to top-down forecasts at scale.
- The approach.

3. Recommendations

- It would be helpful to get minute and second data on a set of buildings to get the data grid planners use for stability analysis to help inform them how the building stock responses to faults and disturbances will change as their loads change (greater non-linear and power electronic loads, low energy/high performance, all electric, etc.).
- The team should provide use cases and example applications of how to use the data to show how it's used differently for DSM program design, distribution planning, grid operations, non-wires, etc.
- The team should have presented more information on the weaknesses and strengths of the model as it is now. The focus on higher resolution data rather than annual consumption is encouraging.
- The team should run a stochastic analysis to quantify the effect of load diversity at scale. In other words, if forecasting load for X number of buildings, at what number X is top-down forecasting superior to bottom-up load forecasting? This should be a pretty quick exercise.
- The project should be broken into several smaller projects to make it manageable.
- There should be tight DOE oversight and utility/consultant feedback to make sure that it realizes its full potential.

- The team should ensure full access to all models coming out of the project so this $9 million DOE investment can be leveraged to the greatest extent possible.
- The project team should be very open and upfront about the data limitations (i.e., what end uses are relatively well characterized, and which are not) by building type and geographic location (the team may plan to do this, but it should be emphasized).

Commercial Buildings Integration

Energy Performance & Tools

Project #22291e: Commercial Buildings Stock Analysis

Presenter: Michael Deru, National Renewable Energy Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Overall, reviewers strongly approved of this project's approach to designing and developing ComStock, the commercial equivalent of ResStock. Multiple reviewers stated that while the tool would not directly contribute to technical challenges or energy savings, it would serve an important research and development (R&D) purpose. The approach was also described as practical and logical due to the fact that it was modeled after ResStock. As an area of potential improvement, one reviewer noted that it would be beneficial if utilities or other organizations could upload local information to segment the data for their unique service area. With regards to the usefulness of the project, one reviewer recommended enabling the new tool to reference ResStock so as to represent the total building stock.

In terms of project impact, reviewers considered the project to be a "phenomenal tool for research" and "critical to increasing [the penetration of] renewable generation." Another reviewer highlighted the tool's ability to support decision-makers within governments, utilities, and other organizations on a range of policy and funding choices. Similarly, a separate reviewer commented that the tool would help provide consistent data and methods to compare technologies and their contribution to program goals. However, the indirect nature of the project's impact had one reviewer uncertain as to how to assess its potential.

Across the board, reviewers had positive impressions of both the project's progress and its collaboration and coordination activities. Several reviewers commented that the project was on-track for completion and advancing as planned. One reviewer mentioned that the team has already had significant interest from the private sector, which they said, "makes a strong case for this project." The majority of reviewers approved of the team's stakeholder engagement and noted that the relevant collaborators were contacted, and a variety of perspectives considered. However, one reviewer recommended that the project team also reach out to other organizations for partnership, listing a number of potential national and local groups. As for the remaining work, reviewers agreed that the team was well-positioned to complete the project and meet their stated goals.

Weighted Average: 3.32   # of Reviewers: 6
Approach: 3.50   Impact: 3.17   Progress: 3.17   Collaboration/Coordination: 3.17   Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project will most likely not directly contribute to overcoming barriers or technical challenges. That said, if successful, it will serve an important purpose by providing policy makers and utilities with a screening tool that will assist in prioritizing funding and making high level decisions.
- This project builds on the success of ResStock to create a commercial version of the product. The project utilizes other existing data such as CBECS and augments it with energy modeling for greater breadth. It can also be modified to consider changes in grid, etc.
- Using ResStock as a model is the logical approach.
- This tool fills a niche which is missing from other data sources. The combination of granular geographical data and detailed energy modelling can create a really powerful research tool. That being said, there should be a way for utility or other entity to upload a geospatial data file in order to segment the data to their particular service territory.
- This seems like a very practical and achievable approach.
- Inclusion of hourly details of the building along with highly granular building stock information is a great approach for transparency.

B. Impact

Assuming that the **project-specific goals** are met, this project was rated **3.17** for the degree to which the project is **expected to** contribute to **program goal(s)**.

- The impact of this project could be important but will be indirect in nature making it difficult to assess its potential impact.
- This project is not intended to result in immediate energy savings, but to serve as basis for research and development. It is established to provide consistent data and methods for identifying the most impactful technologies for energy savings and contributing to Department of Energy goals.
- The modeling capability being developed in this project is critical to increasing renewable generation penetration – provides basis for modeling the impact of control technologies, which is necessary to justify the demand response program development and investment required to integrate variable renewables.
- This seems like a phenomenal tool for research. To see, on a granular level, what the impact of different measures would be on a national scale fills a void that could help with research efforts significantly. However, again, if one could segment it to show only the buildings in a utility's (or another entity's) service territory that would significantly add to the tools impact.
- This reviewer is still wrapping their head around all the potential use cases for this tool – and may not have given it quite enough thought yet, so this review might be a little short-sighted.
- The data that will become available is sorely needed to support a range of policy and funding program decisions by governments, utilities, etc.
- This project will provide data analytics and use of those analytics to multiple agencies and/or companies for their energy efficiency work. This will have a trickledown effect.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met **project-specific goals**.

- The project has made good progress towards it goals and is just coming up on some important milestones and decision points.
- The project is progressing and advancing as planned. Significant interest from utilities and private sector has already been demonstrated.
- All appears on track.
- Progress seems fine.
- Seems to be progressing well.
- Modeling challenges are the key to this project's success, and it seems that the team has tackled most of the known problems in modeling. They are on track for completion.

D. Collaboration and Coordination

This project was rated **3.17** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This team has done a great job reaching out to a very relevant group of collaborators.
- They have strong stakeholder engagement – a variety of perspectives have been considered. The interest expressed from utilities and private sector make a strong case for this project.
- They have done what is appropriate for this project. It's not expected that the team would need a lot of external stakeholder engagement for developing this kind of model since they weren't designing completely from scratch.
- No omissions here – think you guys are doing great.
- Collaboration could benefit from partnership with organizations like Electrical Power Research Institute (EPRI) to promote to utilities and International City/County Management Association, National League of Cities, National Association of Counties, National Association of Local Councils, and Council of State Governments to promote to state and local governments.
- Since the team is internal to one organization the coordination and collaboration challenges are at a minimum.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the **project-specific goals**.

- This is a very logical and well-developed plan.
- The remaining project work seems straightforward and well-understood by the time. The project is positioned to meet its goals.
- The schedule for completion seems doable.
- The remaining work looks good.

- Remaining project work is consistent with project goals.
- No comments.

F. Additional Comments and Recommendation

1. Project Strengths

- There is a need for this type of screening tool. The only similar tool today is Johnson Controls' Lean Energy Auditor, however, that tool does not get down to the ECM level.
- They are building on the successful RES Stock model.
- Project is well planned and operating on schedule.
- They have significant non-Department of Energy funding from Los Angeles Department of Water & Power (LADWP). They have made major progress on the project with LADWP and the team can now apply lessons learned to this project. Utilities are among the best customers for this product.
- This fills a huge gap in basic understanding of how buildings perform on an hourly basis – that is, creating a basic capability to model hourly load impacts of changes in building codes and upgrades to existing building stock.
- This seems like a great tool for designing utility incentive programs. It will fill a void that we've been trying to fill for a while, on our own (i.e., to size the different end uses of our portfolio, is it more beneficial to focus on lighting in retail or refrigeration in supermarkets, etc.)
- It seems well organized and productive. The data that will become available is sorely needed to support a range of policy and funding program decisions by governments, utilities, etc.
- Project strengths include access to data, technology, talent, and funds. The project also has an internal staff from one organization.

2. Project Weaknesses

- This will never be a decision-making tool for building owners because it does not consider cost and uses statistical analysis rather than the specifics of an owner's facility or portfolio. Because of this, this reviewer does not agree with the comment that industry (outside government, utilities, and perhaps ESCOs) is "chomping at the bit" to get this tool.
- It's not clear whether when users would reference this tool vs. CBECS as the dataset to apply energy conservation measures to. Would market confusion remain as users are referencing different datasets to understand energy savings potential?
- Don't see any huge weaknesses. Like any general model that classifies the units of analysis into a relatively small number of groups, the tool may not be very accurate on an individual basis, but for estimating potential for reducing consumption and moving load around on a regional or even circuit level, this will be very valuable.
- Energy modelling is notoriously inaccurate when compared to reality. It does a good job of comparing a building in state 1 versus state 2, but not when comparing state 1 to reality. Therefore, are we magnifying inaccuracies when we extrapolate this data across an entire service territory? This doesn't appear to be a problem.
- A project weakness is the potential for lack of market adoption/knowledge about the data service.

- No comments.

3. Recommendations

- No recommendations.
- Tool would be most useful if it could reference ResStock and be combinable with ResStock to represent energy use for total building stock. This reviewer would additionally like to see the ability to apply energy conservation measures to combined dataset to see total building savings potential.
- They have it wired and don't need additional input from me.
- It’s recommended to include the capability to segment the data based on geospatial data of some sort.
- It’s recommended to work with EPRI to promote to utilities and ICMA, National League of Cities, National Association of Counties, National Association of Local Councils, Council of State Governments to promote to state and local governments.
- It’s recommended to break down the ComStock data per climate zone instead of measuring it by state.

Project #25150: Building Energy Asset Score

Presenter: Nora Wang, Pacific Northwest National Laboratory
DOE Manager: Harry Bergmann

Brief Summary of Reviewer Comments

In general, the Building Energy Asset Score (Asset Score) project was highly regarded with reviewers in agreement about the team's strong approach to developing the new DOE tool. One reviewer praised the Asset Score and said it is "on-track to become an effective tool for informing investments and real estate transactions for the commercial and multi-family building sector." Several reviewers highlighted the easy-to-use interface and the balance between simplicity and customization of the tool to provide energy efficiency recommendations for potential retrofit opportunities. However, one reviewer expressed concern that the team should perform a large-scale comparison of asset and operational scores in order to identify discrepancies.

Most reviewers commended the project's potential contribution to DOE goals and provided a long list of relevant end-users including building owners, investors, utilities, regulators, and other decision makers. Reviewers found the interoperability of Asset Score to function with other tools to be one of the project's major strengths. While reviewers displayed great support for the project, they also asserted that the team needs to further its efforts to achieve an impactful level of market penetration. Due to this concern, reviewers stressed the importance of outreach moving forward.

In terms of progress and remaining work, the majority of reviewer comments were positive and noted the likelihood that the team would accomplish the project-specific goals. One reviewer mentioned the rollout to key stakeholders as an important indicator of success but continued by recommending additional engagement with other organizations that might not be as familiar with energy efficiency, such as financial groups. Multiple reviewers complimented the confidence level feature, the team's focus on integration with other tools, and their future work to expand use types.

Reviewer comments on stakeholder engagement were slightly mixed with reviewers in disagreement over the team's current progress. One reviewer noted their amazement that state and local governments have already specified Asset Score Audit Template as the compliance pathway for audit ordinances. Another reviewer applauded the project's coordination with utilities and municipalities. While the team's collaboration efforts were generally well received, reviewers recommended strategies to increase market adoption for the Asset Score tool. Similarly, reviewers were critical regarding the lack of inclusion of the real estate industry and suggested that the team help building owners recognize the value of the tool.

Weighted Average: 3.29   # of Reviewers: 6
Approach: 3.50   Impact: 3.33   Progress: 3.33   Collaboration/Coordination: 3.00   Remaining Work: 3.17

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The intent and approach of the project is desperately needed in the industry and is valuable to many stakeholders. There are obvious reasons for local governments hosting ordinances, as well as for ratepayer program use cases.
- Perhaps the most valuable part of the approach is the simplified inputs and the audit template which is closely related to the Asset Score. A minor suggestion in the Asset Score interface would be to consider a "page out of the book" of Building Energy Optimization Tool (BEopt). That tool has very simple option selectors roughly from a "1-10" (not in every case) for users to select a range of "low" or "high" efficiency inputs when creating the initial model. This not only gives one default value, but a range of common default values when a certain parameter is not known.
- Another aspect not covered in the presentation was the input prioritization map, by climate zone – which was an initial slide/resource when Asset Score launched. It very much helps the users understand the sensitivities of what they must collect versus what may be not as significant when collecting data for Asset Score preview/full. This also helps policy makers put certain emphasis on required fields for audit ordinances.
- The measure recommendations portion is a significant help. Perhaps with the emergence of electronic Technical Reference Manuals (eTRMs), or in resources like DSIRE were to become more granular, there could be a lookup function to select corresponding energy program measures. This could be an overly burdensome connection to maintain, but it would be worth looking into. San Francisco and potentially other audit ordinances require users to also report incentives that would be applicable. Another part of measure recommendation would be to consider how Asset Score would be able to handle grid-interactive efficient buildings (GEBs). For example, audit ordinances may start collaborating with load serving entities (LSEs). If an LSE had a need to curtail/load shape in certain hours of the day on certain circuits, perhaps the recommended measures could have an avoided energy curve, or a pre- and post-retrofit load curve as an output to the report.
- Lastly, with the popularity and need for decarbonization, perhaps electrification measures, or simple solar power/storage could be measures that run as well.
- The Asset Score tool is on track to become an effective tool for informing investments and real estate transactions for the commercial and multi-family building sector.
- The project is doing an outstanding job of addressing the following barriers:
    - Widely variable means of evaluating buildings relevant to the performance of building systems.
    - Asset Score approach: Asset Score has developed a consistent methodology for disaggregating the building operational parameters from the building energy-using systems, providing a consistent framework through which interested parties (real estate agencies, property managers, etc.) can evaluate the building assets relevant to energy efficiency.
    - Difficulty understanding complex energy model outputs: The 1- 10 score provides a simple, easily understood metric (similar to miles per gallon) that is easily understood across a wide audience. The uncertainty element currently under development will also help to provide additional context relevant to the level of detail provided.

- Provide energy efficiency retrofit alternatives in an easy-to-use interface: The tool does a good job setting forth recommendations for potential retrofit opportunities relevant to energy efficiency improvements.

- The project is making good progress on addressing the following barriers:
    - Residential multi-family – System configurations vary for residential multifamily and are difficult to model. Updating the Asset Score model to include these uses develops a critical market.
    - Interoperability with audit tools – Integration with the audit template, SEED, and Building Sync will help expand the usability and increase the number of projects that provide useful data for an Asset Score.
- Further work is needed to address the following barriers:
    - Convince the market that the Asset Score rating is meaningful:
    - When people use vehicle miles per gallon (MPG) estimates to make a purchase decision, they do so understanding that a higher MPG rating will lead to higher operational performance when compared to a lower MPG rating (in spite of operational differences). There does not yet appear to be any analysis that clearly shows a linkage between a high asset score and higher performing operations across a broad dataset of buildings. In order for the Asset Score to be taken seriously in the market, some kind of study demonstrating that this is the case would be necessary.
    - Market engagement: This tool could provide transformative impact on the real estate industry and could be very helpful for property managers (particularly for cases where the property manager is responsible for utilities – such as universities, etc.). However, further efforts need to be made to encourage the use of this tool by relevant entities.
    - Two-way integration with Energy Star Portfolio Manager (ESPM): ESPM is a recognized tool widely used by existing building projects across the U.S. Market penetration of the Asset Score tool would be significantly enhanced if information linking to the Asset Score tool and a direct transfer of data from ESPM were available. Two-way interoperability with ESPM could also allow large-scale studies evaluating building efficiency measures that yield the greatest operational savings.
    - Data security/web access: This reviewer was not able to access Asset Score from Chrome due to https: security issues. Chrome indicated there was malware and certificate issues with the site. The sites should be regularly checked for accessibility from multiple browsers and should not lose users due to this kind of error.
- Asset Score is a well-thought out and strong contribution to the suite of building energy tools.
- It’s uncertain how much stakeholder buy-in is already with the tool: have any big investors or other investor tools (i.e., CalPERS, GRESB, etc.?) indicated that they will use Asset Score. This seems like a crucial step toward mainstreaming.
- It is likely that the asset score would be most effective when added to existing commercial benchmarking policies versus as used as a voluntary tool by the private market. It's unclear to this reviewer what proactive support has been provided to these cities (other than NYC) to ensure that they feel confident in adding the Asset Score as a required part of current policies. Likely, continuing to highlight real world commercial building examples that have benefited from the use of the Asset Score tool would boost local government confidence.

- They have a very well-qualified team and seem to be doing all the right things from the perspective of data caressing.
- This reviewer's major reservation is a certain lack of humility about the potential of asset assessment. If it gets very granular in input data needs (or extrapolations from known data like vintage and location, e.g., HVAC system subtype) the requirements will discourage adoption. Conversely, too few and/or too poorly controlled inputs will escalate potential for errors that discredit the approach. This shows up in a couple of ways:
    - There is a huge need for a large-scale "beta" roll-out in which both asset and operational scores are compared, and there are systematic ground-truth observations to find the most common and most important sources of discrepancies. Some will be operational, and others will go all the way back to the discrepancy between "as designed" and "as built," as shown most clearly in the case of Federal buildings with elevated floors and under-floor air distribution.
    - Until there is a very mature set of tools, it's strongly advised to present results with humility. The implied precision of the E*PM (slide 8) seems unrealistic. Taking a leaf from slide 9, how can the team present the Asset Score as a distribution (cloud with intensity variation, or bell-curve) to honestly portray the underlying variability in the accuracy of the asset score applied to a real building? This seems to be tangentially addressed in slide 19, as "confidence level," but it's not just about user inputs versus defaults, but which inputs add more value, and which add less.
    - Ventilation can be a huge source of discrepancies in this kind of inferred characteristics simulation. Your system can infer whether there is likely to be a system that meets 90.1 and 62.1, but how will it "know" if it is properly functional? This can lead to large discrepancy between asset and operational scores.
    - As an example, consider slides 13 and 14. The team must have input or strong basis for inference to divide between "short distribution" vs. "central systems". Most office buildings (and lower grade schools) don't use much hot water, but many still have central boilers with pumped distribution – and long branches to convenience pantries, etc. For them, low-flow fixtures guarantee that energy consumption will not decrease, but no user will see hot water wait times too long. See work by G. Klein and many others (Hot Water Forum). It's not that the energy use is so high (a few % of building total) as it is an issue of keeping results credible.
    - Is the team able to anticipate "induced" or "implicit" costs of upgrades? As a terrible example, replacing a steam system might require expensive asbestos remediation. Adding that to project cost can trigger local requirement to bring other systems to current building safety codes. This varies locally.
        - There is some concern about "mission-creep," (slide 9) in the effort to continue adding "use types" and systems. Maybe a case can be made (for example) for the large number of "chain" truck stops, which combine relatively high energy consumption with relatively low labor costs (clerks and custodial dominate these costs). But, there are limits. Some widely distributed use types are "low-intensity" and "small consumers". Do they need a special case (e.g., single-family residences converted to retail in smaller towns)?
- Asset Score is impactful in a few important ways. First, is finding a way to establish a commercial asset metric across a wide range of building types and uses. That was a big challenge and the Asset Score tool strikes the right balance between simplification and customization.
- Second, the potential for this tool to serve as a data conduit between audits and energy disclosure data through to Asset Score and Building Energy Modeling (BEM) inputs does great service to both the Building Energy Data and BEM subgroups' goals.

- Finally, the Asset Score tool helps make BEM much more accessible by simplifying the process of setting up energy models. The OpenStudio Model (OSM) files produced by the tool are really good “seeds” for other analysis and in many cases need very few adjustments to serve as a “model of record” for buildings.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The sub-program is defining the state-of-the-art as a de facto standard in the audit world. It does this by standardizing the scoring, inputs, and outputs. It also is unique in that it nicely operates with other DOE subprograms such as SEED, ESPM, BuildingSync, and BEDES.
- The tool clearly supports policy makers. However, it is still to be determined how the industry would adopt Asset Score outside of such ordinances. We are currently evaluating the comparison of the measure recommendations from Asset Score versus a traditional audit. It would be interesting to see if part of the future work included a companion Building Component Library (BCL) measure to help auto-calibrate the Asset Score with ESPM or some other time series consumption data. As a screening tool for large portfolio owners, it stands on its own. But to extend the OSM / BuildingSync output with Option D or other BEM efforts, this may be something to consider.
- If the Asset Score meets the goals of 5% commercial space, it would be fantastic. If more tie-ins to permitting or other large-scale analysis were to occur, this would be helpful. Also, if Asset Score could be integrated into the Building Performance Database (BPD) or Energy Data Vault, it would be impressive.
- The Asset Score has been developed as an interoperable tool on which the private sector can build specialized services. It is also making use of the standards and data exchange specifications that have been developed for interoperability (though it does not itself include the development of such standards). The product can be used by planners, owners/investors, utilities, regulators, and others to make better informed strategic decisions.
- However, further efforts are necessary to achieve the level of market penetration for the tool to have a significant impact on building energy performance.
    - The web interface needs to be free from any errors across multiple browsers
    - Further interface and two-way data interoperability for ESPM would lead to significant additional market impact.
- Also, it is recommended that the tool be further configured to allow energy simulation developers the option to port building-data from the detailed energy simulation model to the Initial Asset Score for the project, and further integrated with BuildingSync.
- Asset Score and the work plan outlined for intermediate milestones appear likely to contribute to program goals.
- The commercial real estate marketplace lacks a metric that gets used to describe energy performance across the scale. EnergyStar and LEED are widely used to describe high performers, but poor ratings on ESPM are often described as being due to a tenant's specific energy uses. The Asset Score could enable discussion of a building's energy assets, making it clearer to investors and potential tenants.
- Clearly, this is a great applied data science effort; integrating a very large number of disparate data sources to given “hub” and output. There is concern that this is internally driven (what labs can do very well), rather than driven by well-supported market need or even strong signs that the market will need/want it. The impact desired (slide 16) will not happen unless the important market actors want to “own” the work. Outreach will

be essential – as demonstrated by the successes of EnergyStar and U.S. Green Building Council (USGBC). This is a criticism of the imposed scope of the project, not of the team that is executing the prescribed tasks. Wang and her team are very credible.

- The program will advance the state-of-the-art building evaluation tools. It's not clear how its impact will compare with other tool suites built on EnergyPlus or other engines completing in the market.
- A major reservation is the lack of documented involvement of the commercial buildings industry itself, through the Building Owners and Managers Association (BOMA) or large developers and owners of commercial real estate. For that matter, where is input from the service providers (e.g., auditors and ESCOs) in project guidance? It's not just cities.
- The complexity, cost, and inconsistent quality of BEM is a barrier in the commercial market for convincing owners and efficiency program administrators to focus on effective energy efficiency strategies. Asset Score is an excellent resource and simplified modeling platform in and of itself. But, it also has the potential to serve as a simplified starting point into larger workflows that can be largely automated through OpenStudio. That sort of workflow could start to be effective at the programmatic level rather than needing to rely on hundreds of individual modelers each with their own methods. Therefore, Asset Score and the work put into it has great potential for moving building efficiency towards the BTO goals.

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- Asset Score can be seen as a "capstone" project in that it ties together may other tools and drives the need for those other tools to be stable and perform well. Examples include BuildingSync, SEED, and the audit template. Having seen Asset Score from its first round of adopters with SRA, the tool has come a long way. Once Asset Score executes the updates of the HVAC definitions, use types, and confidence levels, the tool will be a fantastic resource that appeals to more users. Hopefully, this work will improve the scores for Asset Score preview and provide more insight to entry-level users of the tool.
- The project has done an excellent job meeting its goals to date:
    - The tool provides a standardized method for determining the efficiency of the building's system design, and for proposing retrofit opportunities.
    - It provides interoperability with other DOE-funded tools.
    - It provides a simple interface, which is easily understood by the target audience.
- The project team's successful rollout with key stakeholders is good progress. It would be good to see engagement with stakeholder groups less familiar with energy efficiency (i.e., strictly financial groups). The addition of the confidence level will be very positive.
- Whether the market (and therefore, local governments) accepts Asset Score as a credible methodology is still up for debate. The project team will need to focus on case study efforts in addition to improved methods like the confidence intervals. This means engaging with commercial real estate developers and commercial appraisers.
- The team is very professional and experienced. They will deliver on-time results.
- However, the presentation does actually show project status regarding spending or deliverables, so the review response is faith-based.

- Overall, the project is impressive with the tools and the progress. The only exception is that it seems to be a long time coming to have the audit data to flow through to the Asset Score tool. This is inherently challenging, but as a user it feels like it has taken a long time.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration is perhaps the area where Asset Score excels the most. Without the tool 100% final, it is amazing that the team has established strong enough confidence in the marketplace for state and local governments to specify Asset Score as the compliance pathway for audit ordinances. Additionally, the coordination with other DOE efforts as UBID, SEED, Audit Template, etc. make this project critically important. If these tools are co-dependent on each other, it will drive the need for maximum "up-time" of the tool and stability/reliability of the tool in the marketplace.

- The project demonstrates very significant coordination with utilities and municipalities, and with the developers of the BEDES, SEED, and BulidingSync tools. The feedback has clearly been integrated into the project development and approach. As a result, the tool is poised to have a significant impact on existing building decision making.

- However, it appears insufficient coordination has been provided to date with stakeholders related to the real estate industry. Additional efforts should be provided to engage with relevant stakeholders for the real estate industry to encourage the use of the tool in informing real estate purchase decisions.

- It would be good to know if there has been further workshopping with stakeholder groups who are less familiar with energy efficiency, such as the real estate and financial communities.

- The program team has been able to effectively coordinate with DOE and the national labs. Also, they have been able to work with a few key cities.

- The underlying assumption seems to be that "everyone" will be happy (implement efficiency improvements in commercial buildings) if they can provide both asset and operational building ratings, and if they can make it so easy to use that there will be universal adoption. The assumption is that stakeholders would adopt and use these and their results to improve profitability or public goods, in the case of government agencies.

- This requires involvement in program design by both public entities (e.g., FEMP, cities) and the private sector. To me, USGBC has clearly shown that motivating private action is the key to adoption and shifting the market. There is no evidence in the slides of any involvement of BOMA, facilities managers, or leading real estate developers and operators. Where is CoStar? These folks might be able to use slide 9 to establish value of both metrics. Where is the ASHRAE technical committee that deals with ownership costs? Is there any actual involvement of "users" (e.g., advisory committee of BOMA-types) to guide what is being developed? This feels more like implementation of a vision than a response to market needs and how they can be shaped.

- How will output/products deal with inherent uncertainties, such as that all asset-based programs for existing buildings suffer from occupancy and O&M characteristics documented here on slide 9 and others? Asserting a goal of 5% maximum difference between asset and operations seems both ungrounded and probably unrealistic. How can they show that it is realistic?

- The work to date looks to have been effective and there are really good test markets in play. However, it would be good to have partners on the other side of the fence (owners, investors) to get the tools to become more mainstream. Some way to collaborate with those folks and do a better job at selling the value directly to building owners. To use the carrot and stick analogy, the cities are mostly the "stick" end of things. It would be nice to work on the "carrot."

E. Remaining Project Work

This project was rated **3.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Even if the tool completes its proposed scope, the tool will be fantastic. If it incorporates additional scope, the tool can ultimately reach a state such as ESPM, where active development is more of a “bus stop” approach where maintenance is only required with major updates slated is farther spaced time intervals.
- The project’s near-term project work is highly relevant to meeting the project-specific goals.
- Expanding use types to include kitchens and residential multifamily buildings will enhance the capability of the tool to address large portfolios of restaurants, and to address the residential market where energy efficiency information can be a significant driver in the purchase of a condominium or the selection of apartment rental units.
- Adding advanced HVAC systems is critical for an asset rating that is evaluating near zero building performance.
- Completing the integration with the Audit Template, SEED, and BuildingSync are critical to allow tracking of building efficiency attributes based on retrofits that are made in response to the initial recommendations.
- The Beyond 2019 work is also relevant to meeting the project-specific goals. However, careful consideration should also be applied towards the following:
    - Expand usage to real estate industry.
    - Two-way integration with ESPM.
    - Configure the tool to allow energy simulation developers the option to port building-data from the detailed energy simulation model to the Initial Asset Score for the project, and further integrate with BuildingSync.
    - Provide a research study that demonstrates a clear linkage between a high asset score and higher performing operations across a broad dataset of buildings. Note that a two-way ESPM integration designed correctly, could be used to perform this evaluation.
- Is there any thought of integrating renewables toward a zero-carbon asset score in the future?
- Focusing on integration with other tools used for existing building audits is a good direction. Also, the utilization of confidence intervals for explanation of results will be useful for commercial building analysis where the customer is more sophisticated than a residential customer.
- The judgment is based mostly on record and reputation of the team. Not much detail was offered in the presentation.
- The technical aspects of the plan are sound and well thought out. However, in order to achieve the long-term transformation goals, there needs to be some specific elements of the plan that deals with engaging additional partners – particularly with portfolio owners real estate groups, etc. There needs to be a path to get into the room with folks that deal with real estate valuation if there is any hope to get this metric and associated practices to become mainstream in commercial real estate.

F. Additional Comments and Recommendations

1. Project Strengths

- One strength is that it outputs an OSM file. This is incredibly useful and forward thinking because power users can extend the usefulness of the Asset Score.
- Another strength is the simplification of the audit process where it allows a user to complete an Asset Score preview if needed.
- The interaction with ESPM is very useful in that it allows a user to be more able to move from benchmarking to audit.
- The Score report is helpful in that it includes a source energy use by end use. Users really gain a lot of insight about the building by having this included.
- The ranking of building systems, envelope, etc. is very helpful in that it draws comparisons not just about the building, but about the systems.
- There is still a feature that allows the user to enter custom measures and narrative. This is very helpful as well in case the building is unique or certain circumstances require additional insight.
- A strength is the simplicity of the asset score rating, particularly once uncertainty is further developed. A score of 0 to 10, where the middle point is aligned with the middle-point of ESPM is easily understood and easily communicated.
- Another strength is the ability to use varying quantities of information to develop a score with varying levels of uncertainty. This is a unique feature which significantly enhances usability, and encourages the use of the tool by a much broader audience. Marketed correctly, this feature can be used to whet the appetite, and encourage further audits that will lead to a score with a higher level of certainty.
- A third strength is the integration with BuildingSync and the Energy Audit tool. These functions significantly increase usability of the tool.
- The ability to indicate multiple building types within a single building is a strength. This is a critical feature which enhances functionality.
- Asset Score's strengths are its user-friendly, flexible design and standardization.
- Another strength is the technical capacity to add functionality to the model.
- This project has an outstanding team and a well-defined work plan.
- Asset Score is a simplified energy modeling platform.
- A strength is the standardized audit data that is compatible with the universe of DOE building data initiatives
- Another strength is the compatibility with OpenStudio workflows.
- The combination of a simplified model generator (that eventually takes data straight form audit information) then feeds into various automated OpenStudio workflows really has the potential to transform the world of BEM and its ability to impact building energy use.

2. Project Weaknesses

- One weakness is the ability for the Asset Score preview, and in some cases, full, to be able to provide clear differentiation of measure recommendations between buildings of the same type and size in any climate zone. We often see the same measures or scores for buildings that are operated differently, which is not the use case of the score.
- Perhaps, this blind spot of Asset Score is by design. But in a larger context and need of a one-stop tool in some cases, it would be interesting to know how retrocommissioning measures could be understood. If ESPM doesn't necessarily give measure recommendations and Asset Score gives capital improvement recommendations, what is the tool in the DOE portfolio that fills this blind spot?
- There is no clear market-based research proving that the Asset Score is relevant to the actual operational performance.
- The most cost-effective time for developing the asset to achieve the highest performance is during building design. However, the tool currently focuses on existing buildings. It would be helpful to provide further integration for this tool with New Construction / Commissioning / Retro-Commissioning.
- The tool is not assessable from all browsers without indicating security errors.
- ESPM would be the best entry-point for many users of the tool. However, there is no information clearly highlighting the tool in the EnergyStar website, nor is there a way to port the data from Energy Star to the Asset Rating tool.
- The project does not appear to include adequate outreach to the real estate industry to encourage its use as a standardized decision-making tool in real estate transfers.
- No comment.
- Over the 9-year history, there has not been enough effort to tie the tool to real world applications. This is now being addressed.
- DOE program staff don't seem to have the real end users in mind, thinking about what is wanted, what would be helpful within the capabilities of market actors. Instead, it seems to be driven by the idea, "what can the data team really do that is really neat?"
- The project needs to get the audit data connected to Asset Score.
- The team needs to partner in the owner/investor world and show the value of these tools as an asset (rather than a requirement).

3. Recommendations

- The team should consider some kind of workforce aspect to Asset Score. This could be a light-lift certification or list of service providers like ESPM maintains. The team could infuse Asset Score into the Building Operator Certification.
- The team should expand outreach on the policy front for emerging benchmarking/audit ordinances.
- The team should also consider a companion BCL measure that is specific to the OSM models coming out of Asset Score to perform data enrichment post-Asset Score.
- Additionally, the team should port useful data from Asset Score into SEED, BPD and other DOE efforts.

- The team should provide clear market-based research proving that the Asset Score is relevant to the actual operational performance at a macro-level. They should further develop ESPM in conjunction with the Asset Rating Tool to allow analysis of building assets versus building performance.
- The team should further integrate this tool with New Construction Simulations/ Commissioning / Retro-Commissioning.
- They should further develop the tool for compatibility across all commonly used web browsers and develop a process for continuous updates that will keep it up-to-date for ongoing web-based use.
- The team should provide information clearly highlighting the tool in the ESPM website, and a method for porting the data from EnergyStar to the Asset Rating tool.
- The project should increase outreach to the real estate industry to encourage the use of the tool as a standardized decision-making tool in real estate transfers.
- No comment.
- The team should have a continued focus on how the Asset Score can be adapted to real world use cases. The New York City assessment tool is a good example of this. Another example is the capacity to generate pre-scores through an application programming interface connection with SEED.
- All subprograms and projects should have an active advisory team from outside DOE, helping to formulate market-responsive strategies with market stakeholders. This is a key aspect of the Building America projects (much more applied), and at least as relevant for DOE research in this area. How else will they know that the work that they are doing will be picked up by the private sector for its needs and wants?
- None of this is a criticism of the work Wang and her team are doing, but of DOE's historical approach to research, as represented in this case.
- The team should find portfolio owner partners to test these tools outside of city requirements.
- The tool should tie into more projects that utilize Asset Score as part of a larger OpenStudio workflow to start showing how beyond transforming the building market through a reliable building Efficiency metric, Asset Score can actually be part of a great transformation in BEM practices.

Commercial Buildings Integration

Field Validation & Data Frameworks

Project #222117: Using Network Switches to Operate and Control Lighting and Plug Loads in Commercial Building Office Spaces

Presenter: Lester Shen, Center for Energy and Environment
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Reviewers had a favorable view of the project's approach to test the use of network switches in the operation of lighting and plug loads in office buildings. Multiple reviewers noted the importance of answering these research questions and determining the potential energy savings for this technology. One reviewer commended the staged implementation of the project whereby the project team could learn from the experiences of the first project sites and use that knowledge to inform the second set. However, another reviewer noted that the project was focused more on the technology deployment and less on understanding and solving the actual barriers. Others saw the potential for improvement in the Power over Ethernet (PoE) project with one reviewer highlighting the importance of solving the problem of added loads coming from the router.

As for the project impact, reviewers disagreed over the project's potential contribution to program goals with some reviewers uncertain whether utilizing PoE would result in energy savings. Two reviewers recommended recalculating the national savings potential with different assumptions in order to reach a more representative estimate. A different reviewer remarked that the project will likely provide a clear understanding of the potential energy savings of the technology as well as any implementation challenges. On the other hand, another reviewer commented that this study "positions DOE BTO to be a leader in conversations about intelligent buildings."

Overall, a majority of reviewers described progress as "advancing as expected" and "aligned with the individual project goals." These reviewers also mentioned that the project team already produced meaningful results about the presence of parasitic loads, stating that the team's finding was "likely to shape the industry's path forward in developing this technology." Conversely, one reviewer raised the concern that only two buildings have been evaluated, which they stated was far from demonstrating wide-scale deployment success.

Many reviewers expressed a positive outlook of the team's collaboration and coordination efforts for the current stage of the research. One reviewer highlighted the partnerships with the two architecture firms and, also, the cost share element of the project with funding from the State of Minnesota. In terms of future collaboration and scaling the technology, reviewers suggested engaging with industry and other stakeholders like utilities.

Comparable to their comments on the project's impact, reviewers were split on their evaluation of the remaining work. While four of the reviewers found the remaining project work to be appropriate with the presented schedule and goals, the other two stated their concerns. One of those reviewers noticed that the presentation lacked future steps to identify and address the obstacles from the demonstrations. The second reviewer found that the team still needed to make significant progress before they could explicitly show project success.

Weighted Average: 2.88   # of Reviewers: 6
Approach: 3.00   Impact: 2.50   Progress: 3.00   Collaboration/Coordination: 3.17   Remaining Work: 2.67

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This reviewer wanted to give this project a higher grade because it is supposed to be determining the barriers to this technology. However, there seems to be a great deal of focus on technology/deployment but very little if any on establishing the actual barriers to deployment and how they might be overcome.
- Their approach includes studying opportunities for plug load reduction via devices connected to Power over Ethernet. They are exploring this through instrumentation of existing buildings.
- The staged implementation (2 sites for budget Period 1, then 2 for Period 2) should yield better results because Period 2 implementation will take into account learnings from Period 1. Also, the research questions being asked are spot-on for learning both how much can be saved and how a program could be implemented to scale the technology.
- The presentation was not fully effective in describing the technology's value proposition, and the success criteria used to validate it. That said, both can be inferred from the material presented.
- It seems like a good approach, but it needs to solve the problem of additional load coming from the router. They could also benefit from additional connections to utilities and building owner/operators for adoption. They should talk with EPRI and BOMA and figure out how to quell the IT concern by ensuring the system is walled off from the Internet and doesn't gather data that could compromise security.
- There were similar technological demonstrations at Light Fair two years ago. Over time, these adoptions could become quite common. At this point, investigating the real-world cost savings for labor (installation) and energy savings combined should be investigated.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This project was rated as "Fair" for three reasons: 1) The savings assumption of 100% deployment grossly overstates the potential of this technology. In my view this technology will be much more of a new building play, where you can take advantage of capital cost savings, versus existing buildings; 2) Without a clear view of the barriers at the start of the program, it is unlikely to succeed in finding strategies to overcome them; and 3) Given Items 1 & 2, this approach will likely not contribute much to program goals by 2025.
- Power over Ethernet switches have enormous power capabilities so more and more products are being manufactured to be powered by this. It is an interesting opportunity for managing plug loads. This currently does not constitute a significant percentage of plug loads, but this study investigates a growing sector and emerging trend. It positions DOE BTO to be a leader in conversations about "intelligent buildings" and puts energy at the forefront of that branding.
- The project design should give a pretty clear understanding of whether PoE has potential – in terms of energy savings as well as implementation challenges.
- Savings potential is not well characterized – 750TBtu appears to be more of a placeholder for a broad technology category – LED Lighting with controls – than something specific and relevant to PoE implementation of this strategy. Plug load control and occupancy-based HVAC savings derived from this technology are not rolled into the estimate. And these estimates assume 100% adoption presumably across the

existing building stock. The presentation is not clear whether PoE represents a viable approach for retrofit or if it is primarily applicable to new construction / major renovation, which would greatly alter this projection.

- It seems data driven and actionable through government or utility policy, or as a trend among building owners.
- An overall impact on a broader market would need to be derived after successful deployment on a building with more than 25,000 sq. ft.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Progress to date has been good on the technical objectives but if any work has been done on identifying obstacles, it is not apparent (with the exception of standby power). This project should have first worked to identify the potential obstacles and then worked to address them rather than diving into testing first.
- The project is on schedule and advancing as expected. The study has already produced interesting and meaningful preliminary results.
- The approach aligns very well with the goals.
- The project appears to be on track and on budget. The parasitic load alone is a key and very significant finding that is likely to shape the industry's path forward in developing this technology.
- It seems to be progressing well.
- Only two buildings have been evaluated for project demonstration. There is a significant way to go before demonstrating that the project can have massive deployment success.

D. Collaboration and Coordination

This project was rated **3.17** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- They are doing a great job on collaboration and are working with all the right folks.
- 40% of cost share is from the State of Minnesota and they are collaborating with two architecture firms. The project could be improved by expanding instrumentation to more buildings.
- There is not much in the way of C&C described in the presentation; however, the "collaboration" the team is doing with customers is, in fact, appropriate for this particular study. It would be the next stage of research that would appropriately engage with industry and other stakeholders (e.g., utilities) to examine potential scaling of the technology.
- The project team and industry partners are well designed to deliver envisioned and needed impact from this effort.
- The project could benefit from partnership with organizations like EPRI (for utilities) and BOMA (for building owners/operators).
- It’s unclear how each project member is contributing to the project success.

E. Remaining Project Work

This project was rated **2.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The plan for remaining work is logical but lacks any steps related to identifying and addressing obstacles or lessons learned.
- They are ahead of schedule having studied two buildings. The preliminary findings on the significance of standby power are significant.
- They just need to stay on track; progress is appropriate for spend and time.
- The envisioned second phase of work on this project is likely to yield significant value. While the presentation lacked specificity, the performer gives good confidence that the project is on track to deliver intended outcomes.
- The remaining project work is consistent with project goals.
- Significant progress is needed to demonstrate project success.

F. Additional Comments and Recommendations

1. Project Strengths

- They have a good team and a strong collaboration effort.
- They are piggybacking on IT disruption and the smart building movement, which is not necessarily focused on energy. This refocuses this effort on energy savings.
- The project is flexible because it does not require licensed electrician or rewiring, making it easier to sub-meter.
- It addresses DC distribution systems in commercial buildings.
- They are focusing on sorting out the nuts and bolts of converting lighting/plug loads to PoE, and doing it in two stages in the field so learnings from stage one improves stage two
- The promise of PoE as the most robust "digital ceiling" platform has been touted for more than a decade; this will be the most significant third-party evaluation of the in-field performance of this technology to date. Assuming that the project delivers on assessing of the five identified impacts, as well as energy savings and cost/benefit, this study will greatly shape future investment in this technology space.
- It seems well organized and productive. The opportunity to save capital costs by combining network and power systems is promising. The project seems to be at pace with advances in IT.
- No comment.

2. Project Weaknesses

- There is a lack of focus on market obstacles and they have grossly overestimated the savings potential. They may not be able to demonstrate a significant contribution to program goals
- The project may not result in energy savings immediately. It’s difficult to measure energy saved.
- There are no weaknesses of note.

- The presentation did not effectively address how the value proposition of this technology will be characterized – that is the success criteria are not defined, particularly relative to alternative approaches. This gives concern that while significant insight may be gained into the performance of components (such as the extraordinary challenge of parasitic loads), the overall benefit of moving this technology forward may not be well characterized.
- The project weaknesses include the potential for the lack of market adoption, the problem of the router parasitic load, and the potential rejection due to IT security.
- In real-world scenarios the IT team does not work in tandem with operation and maintenance team. The cost of the fixtures and the CAT5 lines would need to be factored into the overall project cost. This reviewer disagrees with the presenter that CAT5 cables can be laid down without any permits or regulations. Every jurisdiction has their own laws.

3. Recommendations

- DOE's program goal calls for 35% EUI improvement by 2025. It's questionable whether this project will contribute to that goal in any meaningful way. DOE should take a critical look at the real savings potential and then make a decision whether to continue. This reviewer strongly suspects that this technology will primarily apply to new buildings where it can take advantage of its lower capital cost versus traditional approaches. In existing buildings installation, it will be seen as a cost and will have to be offset by operational savings. Without penetration of the existing building stock, this technology will likely not make a meaningful contribution in the next six years.
- Defining and clarifying uncertainty around the future work of demonstration projects of DC technology is recommended. How lessons learned be published so they are available to professionals to implement PoE?
- No recommendation. Keep going and make sure to document installation/customer cooperation challenges discovered during the project to inform the next stage of the research.
- The selection of the remaining two projects will need to be more comprehensive in scope than the first two projects. The evaluation plan for the remaining two sites needs to be carefully considered. If one of these sites is the Sinclair Hotel (briefly discussed during the presentation), the proportional value of the PoE component will need to be characterized as an incremental value add in a larger system of whole building distribution of DC power. The same would go for the American Geophysical Union project (not discussed directly during the presentation). Both of these projects also create a challenge around baseline conditions, which will need to be modeled, rather than measured.
- They need to solve the problem of additional load coming from the router. This solution would apply to routers/switches regardless of if they're delivering power, so it could be a valuable market-wide means to reduce building loads. The team should work with EPRI on a program for utilities and BOMA for a program for building owners/operators. They should figure out how to quell the IT concern and ensure the system is walled off from the Internet and doesn't gather data that could compromise security. They could benefit from templates: RFP, code/standard language, policy/rebate language, training manuals/university curricula.
- Implementing the project in a building size greater than 25,000 sq. ft. is recommended, and the team should document the cost and energy savings.

Project #22242: Hybrid HVAC with Thermal Energy Storage Research and Demonstration

Presenter: Brett Singer, Lawrence Berkeley National Laboratory
DOE Manager: Charles Llenza

Brief Summary of Reviewer Comments

Generally, the reviewers took issue with the project's approach to developing an HVAC system that dampens fluctuations in the pricing of the electric grid. Although the project is in its early stages, reviewers found the modeling was too detailed, and the project did not incorporate the development of new technologies. One reviewer noted that the complexities and regulations introduced with this project's approach will not be worth the savings it may attain. As a suggestion for a more cost-effective approach, one reviewer recommended conducting a theoretical study that could highlight a critical area of research in the proposed system.

Many reviewers commented that, if the proposed system were successful, it could theoretically have an impact in improving grid reliability. However, given the high costs of the phase change material (PCM) and limited promotion of the technology by utilities, the majority of the reviewers cautioned that adoption would be unlikely.

Most of the reviewers were pleased with the project's collaboration, commending the good number of experts, academic collaborators, advisors and credentials for the task. More critically, one reviewer would like to have seen more end-user and installer involvement, as market adoption without government incentives can be a challenge.

Despite the early stage, most reviewers agreed that progress has been made on-track and on-schedule. However, one reviewer noted that little progress had been made in this effort up to this point. Reviewers were conflicted on the remaining project work. While some found it to be clearly outlined and reasonable, others found that the final phases may fall short of getting real-world input to drive significant value.

The reviewers applauded the project for its strong team, simple approach, and technical strengths, however they did raise concerns regarding the project team's understanding of the general physics of PCMs, the economic viability of the project, and the practicality and cost-competitiveness of any prototype. To address these challenges, reviewers did make recommendations: two reviewers recommended the involvement of manufacturers as soon as possible, while another reviewer suggested performing a detailed techno-economic analysis.

Weighted Average: 2.25   # of Reviewers: 5
Approach: 1.80   Impact: 1.80   Progress: 2.60   Collaboration/Coordination: 3.00   Remaining Work: 2.40

Program Response

The research staff at LBNL is actively seeking additional industry partners and are currently in discussions to partner with three private entities, including an energy storage manufacturer, a solar panel company, and a battery installer, who have expressed support for the project concept. The project team will focus more on a techno-economic analysis to demonstrate the economic viability of this technology solution in future project plans and reviews.

Project staff also agree that the project needs more real-world input and they have hence focused on industry engagement as a core part of this work. Furthermore, the team will elaborate on the multiple potential business model concepts identified through collaborations with the iCorps program. The team has also added a new team member who can bolster their expertise on PCM building physics.

A. Approach

This project was rated **1.80** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project aims to develop a HVAC system that dampens fluctuations in the pricing of the grid likely for demand response markets. The enabling technology are PCMs (phase change materials) for both cooling and heating coupled to conventional V/C systems (for cooling and heating). Two sets of PCM are used to accommodate cooling or heating events. The PCMs are charged in low pricing conditions and used at peak pricing conditions. The general concept has some degree of novelty to address the growing demand response markets.

- The project has just started. The approach consists of modelling, selection, and implementation. The kind of detailed modelling undertaken at this early stage may not be warranted. Much can be done with simple computation to establish the merit of the case and conditions under which the proposed hybrid HVAC approach can be viable.

- This project doesn't involve the development of any new technology. It is simply an integration of the existing thermal storage and vapor compression technologies. Most objectives of this study can be accomplished through a lot less expensive theoretical study.

- It is not clear what is particularly unique or new about the use of PCMs in a package heating/cooling system. It is still too early to see how the prototype may perform and the modelling of the heat transfer in the PCM has yet to be validated. The team should have the qualifications to make a good run at it.

- While I like the concept of utilizing the PCM vs ice, and having the ability to store heat as well, the challenge is not technical, it is economic. With a few exceptions, the price signal variability is too muted by the regulators, to drive strong adoption without large incentives. As an end user, I was very hesitant to make any investment that was based on regulator or political policy. I do not believe there will be a large market for complex solutions like this, for the energy storage problem. Bottom line, technically I love the idea, and even tested the most similar product the ice-bear. However, ultimately the complexity risk, and regulatory risk, was not outweighed by the savings. Possibly ten years from now when the financial gravity of the current net metering scheme takes hold, there will be more confidence in strong price signals, and the idea could take off. However, the risk is that regulators burry the cost of T&D and storage into the base rates, and we never see strong enough price signals to justify the option of solutions like this.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **1.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The proposed system could have good impact in adding resiliency to the grid, and also benefitting end users to manage better their loads and pricing. The success will depend on the cost of the PCMs, and the ability of the team to properly integrate it with conventional PCMs via controls and sensing.

- The impact is hard to ascertain because even if fully successful technically, there is the question of its economic viability. We need to show that the proposed approach provides the commercial customer with an equal or better option than what they have now. We have to demonstrate that.

- The project may contribute to identifying to challenges not previously considered in integration of thermal storage and vapor compression cycles. As better and more cost-effective approach would been a theoretical study that could highlight critical area of research in the proposed system, with follow up funding to address the identified issues.

- The challenge will be in keeping the product cost competitive and versatile enough to be used in a broad range of applications. The volume and weight of two insulated PCM containers will limit where these can be placed, and the utility time of day rate structure will need to be pretty high to eventually overcome the initial cost. Adoption may be slow if the utilities don't promote it heavily.
- There would be some energy efficiency gains from making the loads more constant, and better delta T in the evenings, which should offset the storage losses. Generally, this type of storage should be more efficient than the electric battery technology of today. However, I do not see large efficiency gains that align with the program goals.

C. Progress

Based on current project efforts, the project was rated **2.60** for the degree to which the project has met ***project-specific goals***.

- The team demonstrated good progress for the early stages of the project; mostly at the conceptual levels and using first order principles.
- Project is at its early stage and it has completed a couple of tasks per schedule.
- So far there is little progress made in this effort.
- Progress to date seems to have been satisfactory and on-schedule.
- According to the schedule the project looks to be on-track. It is still early in the project life. Costs seem high for this project versus other projects at this stage of development.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team appear to understand the market and is open to receive feedback; this is a positive attitude. They are in the process of assembling a team of advisors, and understand the customer discovery process, which will be crucial in the success of the project.
- It is too early in the life of the project to say but the team has a good number of experts and has listed a number of potential collaborators (without specifying who they are and what they will do).
- The project has the right team.
- The project team seems to have well defined tasks for each contributor and have their work plan in place. The project team appears to have good credentials for the tasks at hand.
- The project looks to have engage a good number of academic collaborators. I would like to see more end user and installer involvement. I believe the primary challenge is market adoption without government incentives. This project needs folks that can help validate the financial benefits, ease of installation and maintenance. If these folks are not involved the project should stop, after theoretical models are complete.

E. Remaining Project Work

This project was rated **2.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This reviewer is less optimistic of the proposed final phases. The team does not reflect experience in actual system integration and testing, and same for physics of PCMs. This presents risks in next set of milestones/phases.
- The next steps are clearly outlined, and they seem reasonable.
- Most of the work remains to be done.
- The project plan and schedule appear to be appropriately targeted for the desired outcome if all goes well. The critical timing in the project will be the second year when the prototype is fabricated and the system model validation is performed. The success of that part of the project will dictate whether they can stimulate any industrial partners for ultimate commercialization.
- The project is logically laid out, but I feel that it falls short of getting the real-world input needed to drive significant value.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths are:
    - The intended market of demand response for both heating and cooling,
    - The simple approach to address it using a plug-in technology such as PCMs.
- The team is strong, and the goal of reducing peak power need is worth the investigation. The team has access to excellent modelling programs and has a reasonable technical approach to the problem.
- The project doesn't have a particular strength.
- The project team has diverse technical strengths and can bring to bear a number of attributes from the three institutions involved for the concept generation and modeling phase of the project.
- The project strengths are the ability to get phase change at higher temperatures than ice, and the ability to store heat.

2. Project Weaknesses

- The major concern this reviewer has and is the limited information PIs provide about the physics of PCMs, which raises questions about the expertise on this core subject. Relevant questions/issues; thermal conductivity of the PCM, thermal performance of PCM based HX, mechanical integrity, cycling (there is a claim of 50,000), and energy required to load the systems.
- As noted earlier, it is important to establish the economic viability of the approach before embarking on detailed work and modelling. The latter might yield results, good results, but prove economically not viable.
- This should have been a two-phase project. It should have started with a low-cost techno-economic analysis.
- While I don't have complete bios for each of the research team, it appears that they have little actual commercial product development and manufacturing experience. As a result, they may surely come up with prototype concepts that will "work", but which may be impractical or not manufacturable at a competitive cost to capture significant market share. A manufacturing partner early in the project would be very desirable.
- The project does not address the root cause problem that similar products have had in gaining market adoption, financial viability, and equipment maintainability.

- I am also concerned about the unit's ability to manage latent loads, if phase change temp materials are used.

3. Recommendations

- This reviewer recommends for the team to increase their learning curve on PCMs, perhaps adding additional expertise on the subject, same for system integration and testing. An additional recommendation is for the team to consider adding load forecasting and system response to the technology via artificial intelligence algorithms, or physically based forecasting. This may significant value to the proposed technology for optimum anticipation of the PCM-V/C interactions.

- It would be interesting to consider the annual cost saving if the peak demand in an average sized commercial building is suppressed (by an alternative energy source at peak hours.)

- With that saving, and considering the various costs involved with the supplemental solution (capital cost, operating cost, maintenance, life, and reliability), one can determine what sort of an alternative solution (and technology) is likely to be competitive. This has to be done before anything else.

- I recommend the team perform a detailed techno-economic analysis first. Then, if necessary, define experiments that can address critical questions.

- I think they should get involvement from a manufacturer as soon as possible, and preferably one that is willing to put some skin in the game. Getting comments or suggestions from an advisory group or from interviews or surveys is not the same as a company who is investing their own time and money into developing a commercially viable product.

- I recommend the team complete the models and validate marginal MIRR over a SEER 14 machine.

- Also, they should estimate the global yearly market share in units where MIRR is positive, and make sure to consider actual load shift to price arbitrage value by market. If there is a monthly demand charges, only take savings for summer months. Do not take credit for yearly peaks like PLC in NJ.

- Finally, I recommend they take results to manufactures and see if one will participate in cost share, to continue project.

Project #25342: Mortgages, Brokers, Financial Data

Presenter: Paul Mathew, Lawrence Berkeley National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The majority of reviewers found the approach to be favorable, though they identified the lack of empirical information on the subject as a major gap and noted the need to characterize the field with this early research. The resulting research outcomes were described by one reviewer as valuable, although they also noted that the project team should have chosen studies that explored more insightful research questions. Reviewer feedback also highlighted the importance of understanding what drives building design decisions and how energy savings plays into that decision-making process.

Overall, reviewers had positive comments regarding the project impact with multiple reviewers stating the importance of disseminating the project results. Although reviewers noted the difficulty linking project impact to a decrease in energy savings, they insisted that the findings would help the energy efficiency community better understand the landscape. One reviewer stressed the need to understand whether acknowledgment that a certain technology can lead to energy savings is motivation enough to push the market to adopt efficiency measures. Reviewers also stated that the results could help justify regulatory involvement instead of market-based solutions.

The project progress and the team's collaborations were both highly rated by the reviewers. Four of the reviewers had positive feedback on progress with the fifth citing inconclusive results and a delayed schedule as justification for the "fair" rating. While one reviewer suggested further partnering efforts with organizations, most of the reviewers described the project as having great collaboration with both academia and the real estate industry. Reviewers generally applauded the project's engagement and inclusion of different perspectives and areas of expertise.

In terms of the remaining work, reviewers mainly affirmed that the scope was clearly planned and consistent with project goals. Two reviewers emphasized the importance of disseminating the results and ensuring that the studies reach the relevant audiences. It was also suggested to continue convening the real estate stakeholder working group that was formed through this project.

Weighted Average: 3.14   # of Reviewers: 5
Approach: 3.20   Impact: 3.20   Progress: 3.20   Collaboration/Coordination: 3.20   Remaining Work: 2.80

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project has done a good job identifying an obstacle (investment owners require empirical information before investing in energy efficiency measures) and then designing a program to remove that obstacle.
- The project aim was to generate research studies with empirical data for the real estate industry on connections between energy performance and real estate value. Through stakeholder engagement, the project team discovered that this type of evidence and these types of studies would be most compelling to increase participation in energy saving projects.
- This is an area with little existing research – so it is appropriate to do exploratory research such as this to help characterize the field (of value for energy efficiency in financial marketplaces) and lay the groundwork for further work.
- The research team's approach seems logical. Statistically significant data on the effects of energy efficiency in real estate transactions seems like it would be valuable. This reviewer doesn't know the real estate market well, so it is unclear whether the team missed anything important in their tactics, but it sounds good.
- Some of the projects that were selected from the RFP had rather mundane or inconclusive results (i.e., the project "The Dynamics of Energy Consumption in Commercial Real Estate" concluded that energy efficiency measures saved energy). The team could come up with more valuable research questions.
- The study thus far seems to suggest EEM don't add a lot of value to buildings compared to features like high-end kitchens, landscaping, location, etc. It's clear that EEM will save money over time, but it's important for policy makers to know that those savings are not sufficient to push the market to adopt EEM so they can cause them to be done through incentives or code. The results of this study should show the unvarnished truth about what really drives building design decisions and if they're not energy savings, that's a very important finding that will help justify regulation instead of market-based solutions.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- It is difficult to foresee the extent to which this project will make a difference in national energy consumption. The reason is that we cannot know for sure how much information it will take to motivate additional action. That said, this project is doing everything they can to address this barrier and it is likely the findings will indeed make a difference.
- This project does not result in immediate energy savings. Its intent is to provide data as a basis for making the case for increased real estate participation in energy efficiency projects.
- The expectation for this research was not to save energy directly, but to move us toward enough understanding to develop further studies and, eventually, program ideas that could affect the market.
- The fact that this project takes another industry's perspective and tries to fit efficiency into their line of work in a mutually beneficial way is appreciated. It is unclear whether this research is more beneficial for us (the energy sector) than for the real estate sector. Do real estate brokers need this information, or do they already have a gut sense of it?
- It seems data-driven and actionable through government or utility policy.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- This project has clearly made great progress and has demonstrated preliminary findings that support their goals and show the desired linkages.
- The project is nearly complete – there is very little work left to do to finish.
- The project is finished.
- It seems like they're behind schedule. Also, it seems like at least a couple of the RFPs/projects that they chose had inconclusive results. The research on "hurdle rate" was unclear.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- They have great collaboration with academia, real estate research organizations, and portfolio owners – all the required parties.
- There is strong collaboration with real estate partners and academic institutions.
- The project involved a number of different folks with different perspectives and areas of expertise; it is appropriate for the research being conducted.
- This reviewer doesn't know the real estate world, but it seems like they included the relevant entities.
- Project collaboration seems strong but it could benefit from partnership with organizations like EPRI to promote findings to utilities and ICMA, National League of Cities, National Association of Counties, National Association of Local Councils, and Council of State Governments to promote findings to state and local policy makers.

E. Remaining Project Work

This project was rated **2.80** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This work is clearly very well-planned, and it is expected that the project will meet all of its goals.
- The real estate stakeholder working group should continue to convene regularly to meet the defined project goals. It will be difficult to meet the intended project outcomes without carefully considering how these studies can reach the right audiences at the best impactful times.
- None.
- Finalizing the reports and disseminating the information is the logical next step. They need to make sure they disseminate this information well, however. The research team could, perhaps, put more emphasis on disseminating this information.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- The project addresses an important, and difficult to solve, problem in a very organized and logical fashion. They have great collaboration, a strong team, and excellent preliminary results
- The strongest part of this project is the stakeholder engagement. The project team has done an exemplary job of considering diverse perspectives in this research.
- The project has breadth of subject matter and perspectives across the reports.
- One of the project strengths is that it is addressing the real estate market. They are influencing owners/REITs to do energy efficiency by showing them the value.
- It seems well organized and productive. The great value in this study is conveying the truth, no matter how disappointing, about the economic impact of EEM on the building/real estate industry. It's important for policy makers to know if those energy savings are not sufficient to push the market to adopt EEM so they can achieve them through incentives or codes. This study's results should show the truth about what drives building design decisions and if they're not energy savings or consumer demand, that's a very important finding that will help justify regulation instead of market-based solutions. The demand for EEM is low and growth is slow. We need empirical data to show why so we can't put optimism and hope for ethical decision making aside and do what it takes to get these technologies in place to fight climate change.

2. Project Weaknesses

- There are no weaknesses.
- The project team does not reference other existing studies that have conducted similar research. There is an existing body of work on this topic that should have been referenced or built upon in this project.
- There are no weaknesses apparent, given the purpose.
- Some of the research projects that they chose from their RFP were mundane and didn't yield actionable results. It is unclear whether they have a robust enough dissemination plan after the research is done.
- Project weakness is the potential for lack of findings becoming known and acted upon by policy makers.

3. Recommendations

- No recommendations.
- They should plan for continued stakeholder group meetings to communicate the outcomes of this study broadly.
- No recommendations.
- They should improve the dissemination process once the research is complete.
- The team should work with EPRI to promote findings to utilities and organizations like ICMA, National League of Cities, National Association of Counties, National Association of Local Councils, and Council of State Governments to promote findings to state and local governments to convey what appears to be the truth about the lack of value associated with EEMs so policy makers can implement regulatory solutions instead of relying on economics, consumer demand, or ethical decision making to drive design and purchasing decisions.

Project #22292: Smart Energy Analytics Campaign

Presenter: Jessica Granderson, Lawrence Berkeley National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The approach to the Smart Energy Analytics Campaign was well-received by reviewers as a solution to address the lack of adoption in Energy Management and Information Systems (EMIS), and the associated loss of operational savings. Reviewers stated that the use of a DOE Campaign was "the perfect tool to spread awareness and comfort with EMIS systems", comprising an excellent approach. Several reviewers remarked that the project team had done a great job of engaging building owners and operators about their experiences using the technology. Success stories and cost-benefit information was also mentioned as part of the approach to encourage further adoption. In addition, a reviewer suggested that the team establish a long-term method to spread awareness and lessons learned by creating an EMIS course for trade schools and universities.

The project impact also received positive feedback and was described as addressing real-world challenges to energy efficiency measures. Reviewers highlighted the benefits that this project would bring to the building management community and commented that it would likely achieve real savings while contributing to BTO's goals specific to the existing building stock. However, one reviewer stated that the team's estimated impact was overstated compared to the reviewer's internal calculations and hence suggested re-examining the figures to confirm they are representing a realistic estimate for the target commercial buildings market.

Reviewers found both the project progress and the team's collaboration and coordination efforts to be very positive. The project was said to be progressing well with good results in accordance with the presented schedule. As a DOE Campaign, reviewers noted that the project was largely about collaboration and that the team had outstandingly engaged all the relevant stakeholders. The collaboration was said to reach a wide audience of all the relevant stakeholders. Another reviewer recommended that the peer network continue even after the project is finished in order to ensure stakeholders can benefit from the structured collaboration.

Regarding the remainder of the project, reviewers looked favorably on the planned work and final steps for the DOE Campaign. The majority of reviewers found the remaining work to be logical and consistent with the overall project goals. One reviewer noted that the team produced research and resources that have "already served as a powerful resource for property owners and managers."

Weighted Average: 3.20   # of Reviewers: 5
Approach: 3.20   Impact: 3.20   Progress: 3.20   Collaboration/Coordination: 3.20   Remaining Work: 3.20

Program Response

The project team will continue to engage with building owners at any stage in the process of adoption and work to ensure that it's calculations of the relevant target market size and estimates of technical potential are based on the best available data. The team will also review its stakeholder engagement efforts and reporting activities to clarify its approach to engaging building owners and reporting savings and successful strategies as appropriate.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The lack of EMIS adoption is primarily an issue of lack of understanding of how to do it and the resulting benefits. The team has done a very good job addressing this.
- This project is a campaign to drive wider adoption of building energy feedback systems through supporting building owners that already have these systems. They are collecting cost-benefit data and success stories of systems that are already in place as a way to encourage more building owners/managers to adopt this technology.
- The project addresses implementation issues in a very straightforward way – developing multiple value streams, talking to actual building owners/operators about what it's like to use the information and management tools, the problems they face, and the tools they need (and how they should work), etc. It's an excellent approach and it's the most likely of any to actually achieve real savings.
- A campaign is the perfect tool to spread awareness and comfort with EMIS systems. The barriers are likely a lot less technical and lot more social – most building operators don't have a high enough understanding of this technology. They're in need of education, trust (listening to their peers), and a little hand holding. A campaign is the perfect tool to deliver that.
- This seems like a very good approach, but the project would benefit from establishing a long-term method to foster continual adoption of EMIS by creating an EMIS course that could be taught in trade schools and universities.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This project has already contributed to BTO's goal and will continue to do so. The only note, as in several other cases, is that the estimated impact is grossly overstated. Our internal estimate is that 40-50% of US commercial office buildings either still have pneumatics or an old BAS that will not support these advanced analytics. Until that roadblock is solved, the impact of this effort will be limited.
- Approximately 90% of buildings do not use energy management and information systems. I'm not sure how the presenter calculated energy savings potential associated with this – is this based on median 7% savings? This is a low-cost high-impact way to meet 45% GHG reduction goal. It also focuses on the existing building target.
- This project is more likely to achieve real savings than any of the others I've reviewed this year.
- I'm a fan of any project that addresses real-world challenges to energy efficiency measures, that aren't energy related. Focusing on getting building operators comfortable with this technology will address the real barriers. And the technology itself has the potential to harness a lot of low hanging fruit.
- Clearly the building operator community would benefit from making better informed decisions with EMIS.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The project has made excellent progress and demonstrated good results.
- The next step is to hand-off activities to multiple partner channels – What does that mean? It's important to ensure that the peer network continues so the campaign can keep operating.
- They appear on track and have meaningful interim results.
- It seems like they're done with the brunt of the work and the technical aspects of the project. It seems like they're making good progress.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project team is engaging all the relevant stakeholders and reaching out to a wide audience to disseminate their results.
- The team has engaged with building owners/managers and vendors that are already using these products. Outreach to building owners/managers that have not adopted this technology was not addressed as clearly.
- The inclusion of multiple key partners who actually operate large numbers of commercial buildings is outstanding. The approach of engaging with stakeholders (owners/tech folks/standards folks etc.) as well as building operators (the people who actually have to implement what the others ask them to do) to triangulate on solutions is outstanding as well.
- This project is largely about collaboration. Collaboration in order to spread comfort with new technology. At 122 partners and 200+ participants to the peer group webinars, it seems that this project is doing very well in respect to collaboration.
- The project would benefit from establishing long-term methods to foster continual adoption of EMIS by creating curricula and collaborating with universities and trade schools to teach classes on EMIS.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project work is logically planned and will support continued progress.
- The research and resources produced by the team have already served as powerful resources for property owners and managers. There is tremendous opportunity for the peer network and other activities to continue following the end of the project schedule so the campaign can continue to contribute to EMIS success. This should be better defined to meet project goals.
- They seem to be collecting data and seeing how their early work plays out in real world performance –which is a good thing since they seem to be low on money, but it's probably appropriate given the project design (i.e., most of remaining budget is probably labor to analyze data and report results).
- The remaining work seems logical.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- They are addressing an important need in the market (better information on the "how to" and benefits of EMIS). They have a strong team and the project has good collaboration and outreach. Overall, they have an excellent record of progress so far

- This is the first study I've seen that takes an honest and comprehensive look at EMIS already in place in buildings. This will serve as an important resource for property owners and managers that are seeking effective ways to optimize operations in existing buildings.

- Their thoughtful focus on understanding and then designing to real-world needs of the people who own and operate buildings is extraordinary (unfortunately). This is a great project. And, not only did they attack the real barrier to energy efficiency in commercial buildings, their "campaign activities" are very thorough in addressing the multiple, related complex of barriers to improving energy efficiency in commercial buildings.

- This project focuses on the real barrier to implementation of new technology: Fear, trust, and comfort.

- It seems well organized and productive. Clearly, the building operator community would benefit from making better informed decisions with EMIS.

2. Project Weaknesses

- A project weakness is that the contribution to meeting BTO goals will be limited to buildings with BAS infrastructure that will support this type of effort.

- The project excludes buildings under 100,000 sq. ft. How can this be scaled to all buildings?

- No project weaknesses that were identified.

- This project doesn’t seem to provide any guidance on which vendor to choose or offer any guidance on key decision-making criteria.

- A project weakness is the potential for the lack of market adoption and discontinuation of promotion after the project is complete and advisory groups cease.

3. Recommendations

- The project team should develop a more realistic estimate of the potential savings that reflects the buildings that are actually addressable.

- The team should refine how the peer network can continue with or without project team facilitation. They should address outreach to property owners and managers that can be encouraged to adopt EMIS technology in the future.

- The project team should be given more money.

- The project looks good, and it's almost over.

- The project would benefit from establishing a long-term method to foster continual adoption of EMIS by creating an EMIS course that could be taught in universities and trade schools. They could benefit from templates: RFP, code/standard language, policy/rebate language, in addition to training manuals/university curricula.

Project #22291d: ESIF Commercial Buildings Integration Lab

Presenter: Grant Wheeler, National Renewable Energy Laboratory
DOE Manager: Stephanie Johnson

Brief Summary of Reviewer Comments

Reviewer comments on the development of the Energy Systems Integration Facility (ESIF) were overwhelmingly positive. Several reviewers specified that the project goal was to build the facility as opposed to conduct simulations or validation testing. Overall, the project team's approach was applauded for its great concept and flexible design. Reviewers highlighted the potential implications on future research and the contributions the ESIF could make to the advancement of energy efficiency and grid-interactive efficient buildings (GEB) technologies.

The project impact was equally well-regarded with reviewers stressing the importance of the ESIF as a research and development tool. One reviewer considered the project to be highly impactful because it will "provide critical operations data that will drive the acceptance and adoption of multiple technologies." Another reviewer commented on the increased reliability and reduced cost of evaluating potential technological solutions through the ESIF compared to field demonstrations that often have multiple uncontrolled variables. In addition, reviewers stated that the ESIF would be a great venue to offer much needed hardware-in-the-loop services for utility and private sector projects.

In terms of progress, reviewers were pleased with the team's effort to meet project-specific goals and complete ESIF development on-schedule and within budget. On the other hand, two reviewers found areas of improvement in the team's collaboration and coordination with stakeholders. Those reviewers suggested involving more organizations in the project such as other labs, commercial building owners, utilities, manufactures, and other groups in need of technology validation. Another recommendation was to expand the technical advisory group to receive more broad input on the different applications for the facility. The other two reviewers considered stakeholder engagement efforts to be appropriate for the project and inclusive of diverse perspectives. It was also noted that the private sector and utilities have already demonstrated interest in both using the ESIF and the forthcoming results.

Weighted Average: 3.43   # of Reviewers: 4
Approach: 3.75   Impact: 3.75   Progress: 3.50   Collaboration/Coordination: 2.50   Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **3.75** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This particular project is about getting the test facility built rather than actually conducting simulations. The team has done a great job conceptualizing the facility and designing it for flexibility. The approach itself is well designed and has the potential to make significant contributions to energy efficiency and grid interactive building technologies.
- They constructed the simulator to see how equipment performs in different climates. NREL currently has a lab like this for residential applications but is planning to build one for commercial purposes. It includes space for testing electric vehicles. It can connect to another thermal lab that can test HVAC. This project is just for constructing the lab.
- This project involves the creation of a tool (the test lab) that can be used to evaluate building efficiency technologies/strategies, so the question doesn't apply except in the sense of whether this lab design will effectively facilitate future research. There is no reason to believe it won't, and the design appears to incorporate an appropriate level of flexibility to allow a wide range of future work.
- This seems like a very practical and achievable approach.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.75** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- A test facility of this sort will be highly impactful because it will provide critical operations data that will drive the acceptance and adoption of multiple technologies. Real estate is a very conservative industry and real-world data is an important starting point for adoption. Also, this reviewer particularly likes the flexibility of the facility (this will improve impact) and its ability to investigate grid interactive buildings, an important area of interest for industry.
- This facility will have the ability to test controls, grid technology, and other systems for other projects that can save energy. This is a huge need for utilities and private sector owners. The studies that can be conducted in this lab will aid with utility incentive programs and private sector adoption of technologies that directly contribute to DOE goals. This is also a useful lab for validating energy modeling results.
- Again, this lab is a tool for facilitating research that achieves the program goals, so by itself does NOT achieve them, but will make it possible to more reliably evaluate potential technological solutions at lower cost than one-off field experiments/demonstrations that suffer from too many uncontrolled variables.
- The hardware-in-the-loop service is sorely needed and ESIF is a great venue to offer it.

C. Progress

Based on current project efforts, the project was rated **3.50** for the degree to which the project has met ***project-specific goals***.

- Progress is on target and it appears that the facility will be completed on schedule.
- The project is on schedule and nearing completion.
- The project is on track in terms of cost and time.

- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **2.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The level of collaboration is appropriate for this project.
- A small group was engaged for the technical advisory group, but it includes diverse perspectives.
- It seems like they could expand stakeholder engagement to include the other labs, at least, as well as more commercial building owners (BOMA?) and representatives from major equipment manufacturers (lighting, HVAC, etc.).
- They could benefit from partnership with organizations in need of technology validation, e.g., EPRI for utilities, manufacturers, GSA, etc.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- They have very little work remains and it appears to be well planned.
- The project is set up to meet defined goals. Utilities and private sector building owners have demonstrated enormous interest in results that will be generated from experimentation in this facility.
- It appears to be on track.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include a strong team with a well-conceived and targeted approach. The implementation to date has been excellent.
- The scope is well-defined. It is based on the success of the residential lab that the team has already constructed. Utilities and building owners have demonstrated interest in experimentation results generated from this project.
- When complete, the lab has the potential to accelerate vetting of new technology/strategies for commercial building technology improvement – particularly for internal load management technology.
- It seems well organized and productive. The hardware-in-the-loop service is sorely needed to reduce logistics and costs around demonstration and validation. ESIF is a great venue to offer it.

2. Project Weaknesses

- No weaknesses.
- More partners should be engaged outside of the technical advisory group (or expansion of the technical advisory group) for more broad input on applications.

- None of note.
- One project weakness is the potential for the lack of market adoption.

3. Recommendations

- This is a great project that is nearly complete. There are no specific recommendations outside of beginning an aggressive program to line up equipment/concepts to test.
- The team should expand the technical advisory group membership and representation. Also, it would augment the project to consider experimentation on existing buildings in tandem with lab experimentation to gather and validate more data.
- The team should increase the breadth of stakeholder involvement, though it may be a bit late at this point.
- The project could benefit from partnership with organizations in need of technology validation, e.g., EPRI for utilities, manufacturers, GSA, etc.

Project #22293: IoT-Enabled Troffer Lighting Challenge

Presenter: Felipe Leon, Pacific Northwest National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The majority of reviewers found the project approach for an IoT-enabled troffer lighting challenge to be positive and appropriate for the goal of advancing the adoption of energy-efficient connected lighting. Reviewers commented on the decision to issue a challenge to manufacturers and noted that the approach "maximizes the chance of success" and is "a great way to push lighting controls forward." However, one reviewer remarked that they were unclear whether this particular technology goal was an appropriate application of the challenge approach. In terms of the challenge's goals, one reviewer stated that the barrier to adoption of smart troffer lighting was not necessarily technical but more a lack of demand for the capability. On the other hand, a separate reviewer cited the high cost of the technology as the barrier, which they explained would be addressed in the project.

Comments on the impact of a "future-ready" troffer lighting challenge varied with reviewers disagreeing on the potential contribution to DOE goals. One reviewer expressed that the project could have a significant impact on almost the whole commercial building stock, while others found it more difficult to assess the level of energy savings that could be expected. Since the cost target for the challenge was not chosen, reviewers were uncertain whether there would be a strong business case for the technology leading to higher stakeholder uptake.

Reviewers noted the early stage of the project but agreed that it was progressing as planned and according to the schedule. In terms of progress, one reviewer highlighted the limited engagement with manufacturers and suggested that this step in the process should occur earlier in the project. A few other reviewers agreed that the team's collaboration could be improved, recommending coordination with state and local governments as well as utilities, Better Buildings, and a code making body. Contrary to the other opinions, one reviewer stated that there were no identifiable gaps in the collaboration plan. Reviewers reiterated that the project was early in the team's timeline, however, several reviewers commented that the remaining work was well-considered and consistent with project goals.

Weighted Average: 3.05   # of Reviewers: 5
Approach: 3.20   Impact: 3.00   Progress: 3.00   Collaboration/Coordination: 2.80   Remaining Work: 3.20

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This team is taking a very deliberate and rational approach that maximizes it chance for success. Specifically, they are engaging early with all stakeholders to set goals that a both meaningful and challenging.
- The approach is to build upon the success of other challenges issued in the past to manufacturers (e.g., efficient RTUs, inexpensive sub-metering equipment, etc.). This challenge will be for "future-ready" troffers as a way for buildings to accept energy-conserving lighting technology in the future.
- The "challenge" approach is appropriate for addressing an end-use that needs a "game-changing" solution to improve efficiency. What's not clear is whether this particular technology is an appropriate application of this approach. While there are still IoT issues that affect compatibility of different communications technologies that may require a "game-changing" solution for troffer-lighting as well as other end-uses, the basic barrier to adoption of smart troffer lighting has to do with demand for the capability, not technical performance or operation. So, the project approach should include development of a business case under current rate/tariff conditions that offsets the added costs with added value to the customer (in addition to "future-proofing").
- A challenge is a great way to push lighting controls forward. Cost is, of course, the main driver behind lighting decisions, and challenging manufacturers to create lower cost, IoT enabled devices is a good fit for the industry. However, it’s unclear whether adding the capability for future control upgrades is the best path forward. Perhaps lowering the price of the controls themselves might be more effective. I've heard that "system on chip" design for lighting controls can drive down the costs exponentially. It might be better to challenge industry to create very cheap LLLC (luminaire level lighting controls) luminaires?
- It seems like a good approach, but it could benefit from the creation of template language that could be used in a code requirement. Also, they should figure out how to quell the IT concern and promote the idea of the system being walled off from the Internet and not gathering data that could compromise security. Finally, they should promote the idea that IoT connected troffers won't impact occupant comfort.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- There is certainly a gap here that, if overcome, will generate energy savings. It is too early however, to have a good feel of the level of savings that might be generated. Once the cost target has been set, we will have a much better feel for the likelihood of adoption and therefore the potential level of savings.
- The presentation could have included more clear information about how significant lighting energy is in terms of overall building energy use. This is significant though and the presenter shared compelling information about troffer lighting in buildings and the potential for this product. This challenge can contribute in important ways to the DOE's 45% greenhouse gas reduction goal.
- The impact of the challenge depends on the potential for uptake more than the success of developing the technology, and uptake will depend on whether cost-effectiveness under current rate structures – and a business case for a more complicated technology – is part of the performance metrics.
- Lighting controls are the backbone for smarter buildings. They're an easy way to reduce lighting energy consumption, and they're the gateway to more advanced building controls and integration with other systems (i.e., HVAC). Figuring out a low-cost way to add lighting controls can have a significant effect on almost all of the commercial building stock in the country.

- The potential impact isn't very clear, but this reviewer is optimistic that making room for IoT sensor retrofits as proposed would have a big impact.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- It is still very early in the project. That said, progress to date has been good and in accordance with the plan.
- The project is on schedule and progressing as expected. The only shortcoming in my opinion is stakeholder engagement – Manufacturers have not been engaged sufficiently yet and that should've occurred earlier in the project timeline.
- They seem to be on track.
- Their progress seems fine.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **2.80** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- No gaps or omissions in the collaboration plan were identified. If executed properly, it will engage all the right stakeholders.
- A list of potential partners that this team has engaged with should be noted as to gauge interest. The broad categories of partner "types" were listed but more information is needed on this. Getting sufficient user feedback is critical to the success of this project.
- This is a competition, so collaboration and coordination are not really part of the plan, except to the extent that stakeholders are involved in the development of the performance targets – and that process was not articulated in detail.
- Partnering with Better Buildings seems like a great way to get good industry feedback. The other partners seemed logical and well chosen.
- They could benefit from a partnership with a code making body to eventually make the enhancements proposed by the project a code requirement. Also, they could benefit from connection to EPRI to promote findings to utilities and organizations like ICMA, National League of Cities, National Association of Counties, National Association of Local Councils, and Council of State Governments to promote findings to state and local governments.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining work is logically planned and will get the project to the desired end point if executed as described.
- The project is well-considered and defined to meet project goals.

- It is a bit early to tell how well the project could meet the goals – a lot depends on the specifications/challenge "targets" that come out of the first stage.
- The remaining project work seems logical and these Challenges have been performed before, so they're most likely following a similar template and building on previous successes.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- The project has a strong team and is following a proven path (industry challenges), and the team has identified an opportunity that, if the cost goal is met, will contribute to DOE’s goal.
- There is a tremendous opportunity in lighting technology based on energy codes and efficiency goals for buildings. Also, it addresses the great demand we're seeing for building retrofits for increased energy efficiency. It builds upon success of challenges that have been issued in the past.
- The "problem" of rapid uptake of LED lighting-without controls- over the next few years is compelling. The solution (low cost IoT-enabled LED Troffers) is appropriate.
- Lighting controls are the backbone for creating smarter buildings and cost is the biggest barrier. Thus, this project will likely be highly impactful. The DOE Challenge format is perfect for this.
- It seems well organized and productive. This reviewer is optimistic that making room for IoT sensor retrofits as proposed would lead to a big impact.

2. Project Weaknesses

- Hitting a cost target that will actually drive adoption is going to be difficult due to the low baseline consumption of LEDs. As noted in the presentation, there are only $4,300 in potential savings in a 100,000 sq. ft. building.
- More information about stakeholder engagement is needed.
- A potential project weakness is the lack of specifically-articulated intent to develop control capabilities that can realize sufficient savings to offset the additional costs under the current rate/tariff designs. This may be assumed by the research team; it just didn't make it into the presentation.
- It’s unclear whether lowering the cost for an IoT capable luminaire is the best path forward. It’s unclear just how cheap LLLC controls could be if manufacturers produced them with "system on chip" design, instead of adding additional parts to a troffer. It might be more impactful to skip adding upgradability and just focus on making LLLCs much cheaper.
- Project weaknesses include the potential for the lack of market adoption and rejection due to IT security.

3. Recommendations

- No recommendations at this time.
- More information about stakeholder engagement is needed.
- The team should make sure the performance targets include cost-effectiveness under current rates/tariffs so the technology has both current benefit and future-proofing for demand response, dynamic rates, renewable integration, etc.

- The team should investigate how much cheaper LLLCs would become if manufacturers incorporated system-on-chip design and analyze what their uptake would be at that price point.
- It's recommended to use results of the project to create language that can be added to code to make project results a requirement. They should work with code making body to implement code. Also, they should figure out how to quell the IT concern and promote the idea of the system being walled off from the Internet and not gathering data that could compromise security. The team should incorporate studies on occupant comfort or lack of intrusiveness when promoting troffer enhancement. It could benefit from templates: RFP, code/standard language (as mentioned), policy/rebate language, and training manuals/university curricula. Also, to spur adoption through incentive programs or code requirements, the project could benefit from connection to EPRI to promote findings to utilities and organizations like ICMA, National League of Cities, National Association of Counties, National Association of Local Councils, and Council of State Governments to promote findings to state and local governments.

Project #222116: Integrated Controls Package for High Performance Interior Retrofit

Presenter: Scott Hackel, Seventhwave
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The project approach received positive comments from reviewers and several reviewers approved of the team's decision to use a lighting retrofit opportunity to combine and manage multiple end uses (HVAC, lighting, and plug loads). In terms of deployment, the reviewers appreciated the idea of developing controls packages for utility portfolios and remarked that the team's approach could effectively address the cost barrier to lighting controls. Despite the positive comments, a couple of reviewers were uncertain whether the team could achieve the presented whole building energy savings with one reviewer describing the nationwide impact as "unrealistically large." Another reviewer noted that during the project, the team would learn about installation and commissioning challenges, which would lead to a better estimate of the potential savings.

Many of the reviewers found great potential in the project's impact with the condition that the team could demonstrate cost-effectiveness of the proposed controls package. Reviewers reiterated their position that the impact estimate was overstated and suggested that the team recalculate the figure as well as break it down by HVAC, lighting, and plug load savings. One of the reviewers also mentioned that there was a lack of market assessment and social research conducted by the team. The reviewer followed up by saying, "simply developing a great technology solution is insufficient to guarantee market uptake." It was recommended that the team validate and quantify the savings in multiple building types and continue to pursue the approach of utility program offerings.

Overall, the team's progress was applauded by reviewers and described as "an impressive start, which may be indicative of strong probability of ultimate project success." While reviewers remarked on the team's difficulty finding suitable sites, the majority of reviewers found that the project was progressing well, and the findings were well-documented.

With regards to collaboration and coordination efforts, reviewers were split with comments ranging from "fair" to "outstanding." Many reviewers highlighted the pilot program with the utility in Minnesota and agreed that this approach was likely to drive adoption. Some reviewers commended the team's wide variety of stakeholders, but others noted that the project was somewhat internally focused and provided recommendations for potential partnerships with other organizations. Another reviewer suggested that the team initiate additional pilots with utilities in order to accelerate adoption.

Weighted Average: 2.91 # of Reviewers: 6
Approach: 3.00 Impact: 2.83 Progress: 3.17 Collaboration/Coordination: 2.83 Remaining Work: 2.67

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project identified a barrier to deeper savings and is tightly targeted on solving the problem they have identified (cost barrier to lighting controls). Several technical questions were asked, and their answers directly addressed the concerns.
- This project includes a lighting, HVAC, and plug loads controls package for utility portfolios. The plug load control is with a specific provider, but they are working to be product-agnostic in other areas. The target audience is utilities, which would provide more exposure to owners/buildings.
- There is a bit of a disconnect between the ambitious project outcomes listed and the actual project. The approach for figuring out how to integrate controls and sensors and manage loads across multiple end uses is very good. The team should be able to learn quite a bit about installation and commissioning challenges as well as operational needs and get a good measure of energy impacts; however, there is not much in the presentation about the project's plan to achieve the anticipated market impact outcomes.
- A well-designed presentation makes the most of a streamlined approach. While lacking the comprehensive ambition of the TRC project, this implementation may be more viably implemented in a cost-effective manner. The success criteria both in terms of whole building energy savings and nationwide impact are rolled up into a number that appears unrealistically large.
- It seems like a good approach, but it needs additional connections to utilities and building owner/operators for adoption. They should talk with EPRI and BOMA. They need to figure out how to quell the IT concern by ensuring the system is walled off from the Internet and doesn't save data that could compromise security.
- Traditional utility programs rebates and retrofits offer easy wins in terms of energy savings. Using a lighting retrofit opportunity and combining plug loads and HVAC loads seems to be an extremely good idea. It’s unclear whether Lutron has a product that can control HVAC and lighting fixture at the same time but adding plug load to the mix would be a game changer.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.83** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Like project 222114 the impact estimate is grossly overstated (100% of CBECS applicable buildings) and should be reconsidered. However, in this case there is a clear pathway to significant impact if they can demonstrate cost-effective lighting controls.
- Traditional retrofits are based on a single widget or technology instead of holistic approach. In line with DOE Beyond Widgets initiative, they are moving toward more holistic program offerings. They target utilities as a way to get to more buildings (wider exposure than approaching individual owners). Thus addresses major energy end uses to meet 45% GHG reduction target.
- The project outcomes listed are to "inspire the retrofit market", "spur market demand", "transform the market" etc. One would expect a substantial amount of market assessment, possibly some social research, and other work to characterize the market, identify barriers, and develop implementation strategies/pathways that would lead to significant market uptake. None of that is really articulated in the presentation. Simply developing a great technology solution is insufficient to guarantee market uptake.

- Technical potential of 760 TBtu energy savings and 25 – 40% whole building energy savings seems unrealistically high. It was preferred to see a breakdown between lighting, HVAC, and plug load.
- It seems data driven and actionable through government or utility policy, or as a trend among building owners.
- This reviewer does not see an opportunity for significant impact if the approach is validated and savings quantified through few projects on multiple building types.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met ***project-specific goals***.

- The progress to date is reasonable given the issues they have faced finding suitable sites.
- It seems to be ahead of schedule and findings have been well-documented and coordinated with other BTO programs throughout the process.
- Progress on project tasks appears to be on track, though the difficulty getting sites on board is of some concern; however, given the project timeline and remaining budget, one would expect the additional sites to be on board in time to retrofit, instrument, and collect data.
- The team appears on or ahead of schedule – very impressive start, which may be indicative of strong probability of ultimate project success.
- It seems to be progressing well.
- At this stage, some promising developments have been made with respect to outreach, project designs, and issuing purchase orders.

D. Collaboration and Coordination

This project was rated **2.83** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This team has done a great job reaching out to a wide variety of stakeholders.
- The pilot for Xcel Energy represents the only utility engaged so far. Legrand is providing receptacle control to reduce plug loads.
- The project seems a bit internally-focused (as in on the participants – including industry participants), which may be appropriate for this type of research.
- The differentiation between this and ISOP is that they are focused on utility rather than building owners, which may simplify uptake. Their approach to stakeholder engagement appears to be well designed, and likely to engage key parties needed to drive adoption.
- They could benefit from partnership with organizations like EPRI (for utilities) and BOMA (for building owners/operators).
- Having a utility to provide rebates, two lighting manufacturers, and an implementation partner seems like the right mix.

E. Remaining Project Work

This project was rated **2.67** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project appears to be logically planned however there are issues with the schedule: 1. In Step 3.2, they forecast completion of retrofit by 8/20/19, yet they are still in the outreach process to finalize the remaining sites. The date looks like it will be missed; 2. Future tasks need to be reforecast to reflect the delays encountered earlier in the project.
- The project is slightly ahead of schedule and well-positioned to execute remaining work on schedule and meet project goals. Engaging other utilities within the timeline seems somewhat ambitious. How can they turn a pilot into more broad adoption?
- The progress on obtaining the additional sites should be carefully monitored.
- The project appears to be ahead of schedule and on/under budget, and likely to remain so.
- Remaining project work is consistent with project goals but confirming occupant comfort should be made a priority.
- Project success will depend upon the findings after final execution and verification of savings, so will program success.

F. Additional Comments and Recommendations

1. Project Strengths

- The project is well targeted, and the team is thinking about a number of technical challenges including cost, how to apply this approach to open office configurations, and how to establish the measurement baseline.
- It’s a great collaboration with a wide variety of stakeholders.
- They have good coverage of different building types – tested on 4 different building types, including open office environments. The scope includes occupant comfort surveys. This will help owners adopt more holistic retro-commissioning in straightforward and hopefully cost-effective way.
- It’s good basic approach to working out the technical details of creating a cross-platform system. The results should be useful and interesting.
- Project design would appear to conform to the "80/20" rule – 80% of the benefit from 20% of the "kitchen sink" of possible elements identified for the example in the ISOP project. The platform approach (luminaire with integrated sensors and controls) rather than the integrated kit of parts approach is promising from a replicability and install-ability perspective. The utility focus is promising in terms of establishing viable incentive driven uptake.
- It seems well organized and productive. An integrated approach to EEM is known to be an effective best practice. The opportunity to improve human health and productivity are other bonuses. The project seems to be at pace with advances in IoT.
- Working with a utility provider for rebates and multiple manufactures towards a market solution seems to be the key project strength

2. Project Weaknesses

- The impact estimate is grossly overstated. Also, the remaining schedule is unlikely to be met and needs to be reforecast. The slippage is likely not due to missteps by the project team. Conceptually this work appears to be quite similar to 222114 in that it is aimed at increasing the number of projects that roll out multiple ECMs simultaneously. This project is better targeted and more likely to succeed than 222114.

- It only works with buildings that are BACnet compatible. The success of BACnet may make this a minor issue. It seems too similar to other existing projects – Does it reference those existing initiatives and efforts (through BTO and otherwise) enough to not confuse the market and leverage progress that has already been made? Also, owners are concerned about security. Some have declined participation based on this concern.

- The only weaknesses are in the comparison of the "project outcome" list, which is quite ambitious, and the actual project design – which is largely an experimental demonstration across a small number of buildings of control integration.

- A key challenge for this project will be cost/payback and cyber challenge of integrating HVAC and plug loads. Hennepin County pulling the system outside of their Building System Network raises a red flag relative to broad adoptability. Documenting the capability of installers to achieve the multi-system integration will be important; the approach to this and whether it is "in scope" was not characterized in the presentation.

- One project weakness is the potential for the lack of market adoption and rejection due to IT security.

- The incremental cost for controls on each fixture, programming, commissioning and recommissioning cost will need to be considered in the payback. So, the question is what would be the payback on traditional retrofits vs deep retrofits.

3. Recommendations

- Conducting a reforecast of the potential impact and rework the remaining schedule to better reflect current progress is recommended.

- Initiating pilots with other utilities as quickly as possible is recommended to accelerate adoption.

- To the extent the budget and scope allow, the team should describe the challenges the team faces in installation, working with building owners/operators, actually coordinating the equipment, etc. in the form of a "lessons learned" or "best practices", which would be helpful to future researchers.

- The team should separate value streams – how much incremental value is provided by each component of the system, i.e., LED efficacy, vacancy control, daylight dimming, HVAC control, plug load management. It will be important in both clarifying cost/effectiveness of this technology, and further refining the most effective approach to move "beyond widgets". Clearly documenting the value proposition of non-energy benefit will also be important.

- The team should work with EPRI on a program for utilities and BOMA for a program for building owners/operators. They should also add the validation of occupant comfort. They should figure out how to quell the IT concern and ensure the system is walled off from the Internet and doesn't save data that could compromise security. They could benefit from templates: RFP, code/standard language, policy/rebate language, and training manuals/university curricula.

- No recommendations.

Project #222115: Bringing Fault Detection and Diagnosis (FDD) Tools into the Mainstream: Retro Commissioning and Continuous Commissioning of HVAC and Refrigeration Systems

Presenter: Ravi Gorthala, University of New Haven
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Most reviewers approved of the project's approach and several reviewers mentioned that AFDD technology has been commercially available for some time but has lacked adoption due to a number of market barriers. AFDD was described as an example of a technology that "has a ton of technical potential but suffers in uptake due to a lack of awareness, trust, and (perhaps) data overload." The reviewers commended the project team's goal of researching and characterizing these market challenges but identified areas of improvement. It was suggested that the team should engage further with key decision makers like building owners and management firms as well as include field studies specific to office buildings.

The project impact was well-received due to its focus on reducing energy and operating costs associated with HVAC systems in existing buildings. One of the reviewers highlighted the team's goal of having utilities offer FDD rebates as a means of increasing adoption of the technology. Another reviewer was pleased with how the team developed the monitoring element for the field sites but was uncertain how the lessons learned would be scaled to the market. Another noted concern was the importance of installing the technology such that it does not overwhelm the operator and makes their jobs easier instead of more complicated. If implemented in a user-friendly way, reviewers reiterated the potential of AFDD to provide both energy and cost savings.

Reviewers disagreed about the current project progress and had a range of comments on the team's efforts to engage stakeholders. While some reviewers noted that the project was progressing well and according to plan, others expressed concerns that the team was too focused on the technical challenges as opposed to understanding and addressing the barriers to adoption. Similarly, many reviewers found the team's collaboration thorough with a broad group of identified stakeholders. However, the other reviewers commented that the project's definition of stakeholder was too narrow and omitted both management companies and those who would actually be using the technology such as building engineers, facility operators, and owners. A reviewer concluded by stressing the importance of education and training when installing new technologies like FDD.

Weighted Average: 2.83   # of Reviewers: 7
Approach: 2.86   Impact: 3.00   Progress: 2.86   Collaboration/Coordination: 2.57   Remaining Work: 2.86

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **2.86** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- One of the goals of the project is to actually identify the barriers preventing wider adoption of FDD tools. In and of itself this is a very worthy objective that merits endorsement. However, there are two concerns. First, although the presentation indicated they are engaging with owners and management firms, little evidence was presented to demonstrate the depth of that engagement. These two audiences are critical because they are key decision makers, users, and recommenders. Second, the demonstration locations include education, food service, government and retail facilities. This misses the critical commercial office use.

- AFDD tools used in this study have all been commercially available for some time but have not been widely utilized. This study asserts to promote more use through education, rebate programs, etc.

- While the approach to the technical elements of the study is sound, the approaches to identifying market barriers, developing sufficient impact potential data to support utility program justification, and contributing to education/workforce development, etc. was not well-described and appeared to lack much focus. There was a stakeholder meeting held, but the "stakeholders" appeared to include primarily energy efficiency folks, fellow researchers, and vendor/manufacturers, and not the market players who would have to implement it in the real world. There was no description, for example, of how "market barriers" were being identified, or how the requirements for justifying utility programs to PUCs/Boards would be met (i.e., impact potential, cost-benefit analysis, etc.). They vaguely mentioned "developing materials", but "for whom" was not articulated.

- The combination of field studies and research on market barriers is a good approach for this technology. This technology is a great example of something that has a ton of technical potential but suffers in uptake due to a lack of awareness, trust, and [perhaps] data overload. This study feels like a great "baseline" study to put all the barriers together in a comprehensive way.

- IT seems like a good approach but needs additional connections to utilities and building owner/operators for adoption. They should talk with EPRI and BOMA.

- The project approach is comprehensive. The approach addresses the market adoption barriers and challenges and does a good job of overcoming these by engaging appropriate stakeholders – numerous AFDD products, owner/project types, and utility program managers.

- The marketplace is moving towards FDD but it is lacking on communication with the building owners. My hope for this project is that the stakeholders will work to bridge that gap.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- FDD is a well know approach that is somewhat more widely deployed than the investigators have indicated. Within a major management company's portfolio alone, there are hundreds of facilities on FDD platforms. We know wider deployment will serve DOE's program goals; the question is whether this project will contribute to wider FDD use. Convincing utilities to offer rebates, which this project is piloting, is a good start. They should have delved more deeply into other barriers such as cost.

- Their focus is on existing buildings. Cooling and heating are major end uses and make major contributions to 45% GHG emission target.

- They have done good work on developing the monitoring elements for the sites, but there was very little described on how what they learn could be scaled to the market.
- AFDD seems to have a ton of technical potential, but it must be implemented in a way that doesn't overwhelm facility operators, and that makes their lives easier, not more difficult. Delivery of the information and user friendliness are key here.
- The project seems data driven and actionable through government or utility policy, or as a trend among building owners.
- The outreach events were successful at attracting the targeted stakeholders. Site selection opportunities include relatively broad owner types to obtain meaningful energy savings data for utility programs to utilize. Incentive programs are effective for increasing adoption.
- HVAC and HVAC related operations have the largest cost for most of the organizations. Translating the FDD and having a real-time feedback for building owners would significantly reduce the operation and energy cost.

C. Progress

Based on current project efforts, the project was rated **2.86** for the degree to which the project has met ***project-specific goals***.

- Progress appears to be in accordance with the project plan. It is too early to judge the actual contribution to the project specific goals because installation work is not yet complete.
- They have identified security as a major concern for users (can only read results, not control systems). It is unclear if they identified the barriers/obstacles for adoption. Project progress seems to be more focused on technical issues than engagement and really understanding what has prevented adoption so far.
- Their progress per plan appears on track.
- Their progress seems good. The development of a full-blown EM&V plan is done and installation of 6 out of 10 sites seems like good progress has been made.
- The project seems to be progressing well.
- Installation and testing at 6 sites are complete and the remaining 4 sites are expected to be completed by mid-May. This allows the project team to obtain baseline data and implement retro-commissioning/continuous commissioning activities in a timely manner.
- The actual progress made towards realization of technology to calculate savings potential was not significant.

D. Collaboration and Coordination

This project was rated **2.57** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This program does not have an adequate depth of engagement with facility owners and management firms. The management firms, in particular, are important because building operators/managers are the ones who receive and are supposed to act on the faults that flow from the system. If that part of the engagement is not handled properly (for instance there are too many false positives) the operators will become disillusioned and stop engaging with the system.

- They listed broad groups that they reached out to, but they need more specificity. They convened an outreach event in Connecticut and invited stakeholders outside of region to participate via web conference. More information is needed about who have been engaged outside this event and whose input is most critical. This seems like the most important part of this study because adoption is about listening and responding to stakeholder concerns. It seems to be missing many private sector stakeholders (such as management groups brought up in Q&A). Also, it is unclear what concerns were brought up from these stakeholder groups and how they are being addressed through the study.

- The presentation and the discussion leave the impression that the people who would actually have to adopt and use the FDD tools do not have much of a role in the research, i.e., the "stakeholders" group is too narrowly defined (does not appear to include building engineers, building owners, etc. who would have to buy and use the FDD tools).

- The collaboration seemed fine. There are no glaring omissions.

- It could benefit from partnership with organizations like EPRI (for utilities) and BOMA (for building owners/operators).

- Collaboration with multiple AFDD product manufacturers, utility programs, and building owners allows the project team to gather a broad spectrum of data to effectively develop incentive programs and educational materials.

- The team had a strong team to work towards the implementation.

E. Remaining Project Work

This project was rated **2.86** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The planning and tasks on this project appear to be complete and very well organized.

- The project is on track to completion on originally proposed schedule.

- The project appears on schedule, but whether objectives will be met is discussed in other categories.

- There's a lot more to research here than just the technical potential. How facility operators interact with this technology, and how the AFFD tools present the information is key. Getting the technology to work is one thing but getting people to use it is another. The "education and training" portion of this project is way too light. It's also important to study the facility manager and how they would prefer to interact with these tools. And finally, more emphasis could be put into disseminating information after the project is over.

- The remaining project work is consistent with project goals.

- The planned activities can be reasonably accomplished in the remaining schedule.

- The presentation did not provide a straightforward path towards the completion of the reaming work. It appears it had significant challenges to figure out.

F. Additional Comments and Recommendations

1. Project Strengths

- FDD has good potential and working to convince utilities to provide incentives will certainly increase deployment. Their progress to date is good and on target. It appears to be well organized and their plan makes sense.

- This is a resourceful project. They are using existing technology in existing buildings to identify inefficiencies. There is a high-impact outcome potential for owners at relatively low cost.
- The actual field experiment appears on track to be successful and useful.
- This technology shows tons of technical potential. RTUs are notorious for having faults, and automated detection of those faults would be a significant improvement.
- It seems well organized and productive. It seems data driven and actionable through government or utility policy, or as a trend among building owners. An integrated approach to EEM is known as a best practice.
- Engagement of multiple AFDD product manufacturers and identification of numerous project types will provide meaningful results for utility programs to develop an incentive program. Incentive programs are an effective way to increase adoption.
- Most manufacturers are working towards a similar solution and will eventually offers services such as periodic or annual maintenance plans based on FDD output. The availability of data and outputs from built controls and FDD would be a key strength for the team.

2. Project Weaknesses

- They do not appear to engage deeply enough with facility managers/operators, a critical user of these systems. Also, cost is likely a key barrier and that is not being directly addressed. The comprehensive monitoring system described in the slides is likely too expensive to support a cost-effective deployment with a 3 year or better simple payback. The project should consider evaluating the incremental cost versus the incremental benefit of standard OEM instrumentation packages versus their more advanced package. The evaluation should consider the fact that the additional instruments would have to be field retrofit.
- The stakeholder engagement and understanding/addressing concerns were not well-addressed. Does the demonstration project address the obstacles that were identified? This was not clear in the presentation.
- The project seems focused on the first of the 4 main objectives, which is fine. The others are a big lift and would require additional budget (i.e., for empirically-sound efforts on market barrier identification; sufficient data collection and analysis to support utility program development; education, workforce development/training curriculum/methods). Maybe the issue is that the objectives were too ambitious for the actual scope of the project.
- This project seems light on the study of market barriers and the use of the tools from the perspective of the facility managers. What's needed is something akin to the "Nest", but for facility managers. The problem that the Nest solved was that it made programing your thermostat easy for the consumer. What we need out of this project is something that makes AFDD easy for the facility manager.
- One project weakness is the potential for the lack of market adoption and rejection due to IT security.
- There should be a stronger plan for disseminating information about the success of AFDD. They should consider case studies that can be shared and education/training about the available incentive programs.
- No project weaknesses were identified.

3. Recommendations

- They should engage with building operators/engineers who are using these systems to determine lessons learned. Utility incentives will certainly help on the cost front but the team should also look into the cost versus benefits of the systems and determine if cost is a barrier. It would also help to report on what combination of cost and incentives would drive more adoption.

- They should include a clear report of stakeholder groups that were engaged and what the concerns and obstacles to adoption are.
- Given that the project really isn't designed to meet 3 of the 4 objectives, the team should focus on identifying work that should follow to 1) expand the (sample) data with additional field work to better represent impact potential; 2) design a research plan to identify market barriers and develop strategies for increasing adoption of FDD tools – it would likely include pilots/demonstrations; 3) articulate a strategy for identifying the market participants who require "education" "development" and "training" and how they could be reached and engaged.
- They should include more research on how these tools could/would be used by facility managers, and what would get them to use these tools more.
- They should work with EPRI on a program for utilities and BOMA for a program for building owners/operators. They should add validation of occupant comfort and figure out how to quell the IT concerns. The team should make sure the system is walled off from the Internet and doesn't save data that could compromise security. They could benefit from templates: RFP, code/standard language, policy/rebate language, training manuals/university curricula.
- The team should develop educational materials and identifying ways to share – conferences, local industry events, etc.
- Collaboration with multiple vendors on factory-built controls and their outputs would be a key for project success.

Commercial Buildings Integration

Technology Systems & Packages

Project #22294: Multi-Functional Composite Panels for Building Envelope Retrofits

Presenter: Diana Hun, Oak Ridge National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The project approach received mixed comments, though reviewers agreed that the purpose to the project aligned with DOE program goals in addressing retrofits to existing buildings and that the technology was more likely to succeed in the commercial sector. Some reviewers found the prefabricated approach promising, while others noted the challenges that face the project team. In particular, several reviewers brought attention to the need to optimize the size of the panels, improve the installation process, and gain acceptance by the construction industry. One reviewer also suggested utilizing construction techniques that already exist in order to minimize the need to further train tradespeople.

Reviewers were also split on the potential impact that the new panels would provide. Multiple reviewers reiterated the need for improvement of current retrofit technology and the potential of overclad technology. Reviewers remarked that adoption would depend greatly on the overall cost and the long-term performance of the panels so more research is needed to determine market potential. It was noted that public acceptance might be limited due to factors such as high cost, complexity of installation, and panel geometry. One reviewer recommended getting more specific feedback from stakeholders about the proposed technology and the joint design between panels.

The majority of reviewers agreed that the project was progressing as planned, but they acknowledged that the project was at an early stage, which made it difficult to judge. The team's work on panel design and testing of the new apparatus was cited as progress and described as the groundwork for the remainder of the project. Based on the presented progress, reviewers provided recommendations on future project tasks as well as improvements to stakeholder engagement. While a few reviewers suggested further partnering with the construction industry, several other reviewers applauded the team's collaboration efforts, especially with the team's manufacturing partner. In addition, a reviewer suggested collaborating with international organizations such as those in the Netherlands that have extensive experience with retrofit panels.

Weighted Average: 2.79   # of Reviewers: 7
Approach: 2.71   Impact: 2.71   Progress: 2.86   Collaboration/Coordination: 3.00   Remaining Work: 2.71

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.71** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Conceptually the idea of prefabricating panels to perform retrofit of existing buildings has its merits. The example given of the museum retrofit and the focus on commercial construction may improve the chances of success, but this reviewer finds the prospective execution challenging. Creating a continuous water, air, vapor, and heat control layer with such system demands a matching of the system with the existing facade.

- The approach is consistent with the goals: design and characterize lighter and thinner prefabricated over-clad panels.

- While the team has proposed one potential solution for the over-clad panels, some work is needed to optimize the performance and especially the installation of these panels. It is not clear that the proposed installation approach and even the size of the panels are practical and will be widely accepted by the construction industry. Additional design options should be considered.

- The path that the team is following to accomplish the project outcome of designing fiber-reinforced polymer (FRP) composite panels seems well planned. This includes the integration of insulation with FRP facers. Further evaluation of the panel joints for continuity of the air- and moisture-resistive barrier is planned.

- There is a need to decrease the costs of over-clad panels, which this project addresses through the following mechanisms: 1) Thinner panels reduce transportation costs; 2) Lighter panels require less reinforcement and easier installation; and 3) Developing FRP enables the panels to be lighter and thinner while also meeting fire resistance requirements.

- This project will assess the viability of FRP panels through the following tasks: 1) Linking the insulation to FRP facers; and 2) Designing and evaluating the panel joints.

- The project works directly on addressing the economic challenges of over-cladding.

- Using the attractive structural polymer as cladding, with insulation adhered to the back, seems like a promising way to make modular panels that are thinner and potentially cheaper than current panels. There are still issues to contend with how the panels will be connected together. It’s unclear whether the proposed spline technique will be sufficiently easy to manipulate in the field. As much as possible, the team should look to existing construction techniques so that they don't need to train tradespeople on something new. It’s appreciated that the team is trying to minimize caulk as necessary to achieve thermal/air/moisture performance, which the team is correct in identifying are a major point of failure in many panelized systems.

- There were also some good questions raised by the audience about the best size and shape for the panels, but those can be handled after proof-of-concept.

- The project approach seems reasonable, albeit the stage/scope/focus of this project is outside of my expertise.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.71** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This reviewer is skeptical about the adoption of such solution in large scale to deliver a fraction of the technical potential desired. Installing a panel over existing cladding is a much more challenging solution than other prospective retrofit measures that could be considered. In certain existing commercial buildings, it may be an option, but the market transformation necessary to achieve the goals is extensive.

- The goal is to increase the adoption of over-clad panels in the U.S. by driving down site installation costs. These panels may not be more readily used even if installation cost was reduced.
- Due to the reasons noted earlier, the impacts of the proposed panels are expected to be limited especially for retrofitting residential buildings. The team needs to engage various stakeholders to get more specific feedback about the proposed panels including the design of the joints between panels.
- The impact from this technology may not be that high as a result of public acceptance. Public acceptance is related to geometry issues, window covering, cladding something new over something old, cost, etc.
- Making over-cladding panels thinner and lighter may make over-clad more cost-competitive. Over-cladding has large opportunity for the retrofit market, which is often difficult to access.
- The technology definitely has the potential to dramatically improve building envelopes. More research needs to be done on cost as well as what form factors would make it most widely adoptable/applicable. Perhaps there will need to be different sizes for different types of buildings.
- This project targets retrofits for existing buildings. This is both a very challenging, but also very important class of building that needs to be addressed to attain the program's goals. The goal of making panel delivery and installation less expensive via thinner/lighter panels and fewer/simpler connections can make a meaningful dent in overall costs.

C. Progress

Based on current project efforts, the project was rated **2.86** for the degree to which the project has met ***project-specific goals***.

- The project started six months ago, so it is difficult to judge its current progress. The team delivered designs and is working on concepts.
- Everything appears to be on schedule. The joints between panels has been designed and testing is ongoing.
- Some progress has been made but it's not significant enough to tackle the practical challenges for the installation of the proposed panels as well as their long-term performance. The engagement of stakeholders including installers of these panels seems to be lacking and needs to be enforced in the remaining period of executing the project.
- It seems that progress has been made as proposed.
- The testing apparatus has been designed, meaning that the capabilities for fabrication and testing are in place. The project has developed a joint design for the panels that will reduce installer error and improve installation.
- The project just started but appears to be on schedule.
- The project is about 25% along their timeline. They appear to have made reasonable progress and to have laid the groundwork for their planned work.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The level of stakeholder engagement is low. They attended a few workshops with NYSERDA and the CEC and initiated discussions with potential partners. The team did not share any information on industrial partners that are directly working on the project.

- They partnered with a manufacturer of FRP panels and engaged state agencies that could push for adoption of these panels.
- The engagement of the stakeholders needs to be strengthened. So far, only discussions and workshops have been initiated with potential stakeholders. No specific demonstrations and installation testing (by the stakeholders) have been conducted to receive more constructive and actionable recommendations by the professionals.
- There seems to be a good collaboration between the parties involved. The team seems to have good leadership.
- The group includes a partner that is an installer of over-cladding. The team engaged in workshops with multifamily building retrofit agencies, who would be supporting and promoting the installation of over-cladding. The team has also connected with the fiber composite group at University of Tennessee, adding additional technical expertise.
- The team's collaboration with Kreysler appears to be very tight and good. Are there any other manufacturers of the structural polymer panels the team should also be talking to?
- The team should consider more collaboration with construction trades when they are considering different methods of connecting the panels together. Also, based on audience comments, it sounds like they may not have the latest information about the panels they are using in the Netherlands. The team should collaborate with them to understand their latest designs and what the team may be able to learn from them (and they from the team).
- This project is a joint venture between ORNL and Kreysler & Associates. Kreysler & Associates makes these kinds of panels and so the stakeholders are already folded into this project.

E. Remaining Project Work

This project was rated **2.71** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The manufacturing of mockups and panels are the steps for FY19, but its execution will leave many questions to be answered. Durability of the new wall assembly is one that comes to mind.
- They have good descriptions of the short-term goals and the tasks as well as the longer-term goals.
- Significant challenges remain for the project including testing of long-term performance of the panels and especially the simplification of their installation. The engagement of the relevant stakeholders needs to be accelerated for the proposed panels to be adopted by the industry.
- The project seems to be on track to deliver what was proposed.
- The progress to date has focused on putting capabilities in place. The remaining work focuses on manufacture, testing, and economic analysis, which are all directly appropriate for the project goals. Proceeding with VIP panel manufacturing should be contingent on a cost model showing that it would be cost-competitive.
- The project seems on track for FY19 to get to a testable panel using poly-iso insulation. The project was less convincing in that the FY20 VIP project will be as easy because of the challenges of VIPs.
- The remaining project work appears reasonable.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths include: 1) the concept of panelized construction to apply to retrofits mirrors measures being implemented in other parts of the world; 2) The recognition that fire is relevant and needs to be addressed; and 3) The understanding that joints of panels need attention.
- The project strength is that it specifically targets the perceived obstacles to the increased adoption of over-clad panels in the U.S. It has a clear and well-thought-out work plan.
- The main strength is the potential to have low-cost insulating panels for retrofit of existing buildings.
- The project strengths include the expertise of the team and the development of thin FRP panels with poly-iso foam.
- The project directly addresses the cost-competitiveness of over-cladding, which is an important strategic play for retrofit applications.
- This appears to be a potentially practical solution to a real-world problem. Using a structural cladding material and bonding the insulation to the cladding eliminates the need for framing inside the panel, which should make it thinner and, hopefully, less expensive to produce.
- The stage/scope/focus of this project is outside of this reviewer's expertise and so there are no comments with regards to this.

2. Project Weaknesses

- The project does not address the prospective durability issues. They need to account for the moisture performance of the final assembly. Panel failures can be catastrophic if water and air sealing fails and accesses the original cladding of the building. Details of the attachment of the panels to the original construction are lacking.
- Some questions remain about whether it will even make an impact if it works. The use of over-clad panels in the U.S. market may be limited by factors beyond installation cost.
- The main weakness of the project is that the proposed solution for the installation of the panels (including their size, and the connecting joints) does not seem to be optimal and has not been tested by third parties (i.e., potential stakeholders).
- Their expectations on how the vacuum in the FRP w/VIP will be maintained is unclear. A potential weakness is a lack of public acceptance.
- It is not clear that the thickness reductions would be sufficient to address the cost-competitiveness of over-cladding, and even if it does, it is not clear that other barriers (such as aesthetics, consumer acceptance, building valuation, long-term performance) would not remain as obstacles.
- The biggest immediate challenge will be joining the panels together in a way that is easy to apply in the field and can maintain thermal/air/water performance and withstand temperature variations. My other concerns include: 1) How will the team affix the panels to the wall without thermal bridging? 2) Are there other manufacturers of structural cladding materials that the team can work with, too? Other industry collaborators? 3) What is cost? and 4) How much of a benefit is the somewhat thinner panel if it only works with poly-iso (obviously VIPs would be dramatically thinner, but also more expensive and potentially have other issues)?

- The stage/scope/focus of this project is outside of this reviewer's expertise and so there are no comments with regards to this.

3. Recommendations

- They should consider performing a series of hydrothermal simulations with different original wall systems in several climates to evaluate a few panel systems that could be applied. The team should consider panel systems with different external compositions with different levels of moisture permeability. It is also recommended to explore alternatives to vacuum insulated panels until some of their own issues are resolved.
- No recommendations.
- The team should engage as soon as possible with the stakeholders and the intended users of the proposed panels. They should provide other options for sizes and joint connections. Also recommend clearly testing the long-term performance of the panels and defining the delivered and installation costs of the panels.
- Studying acceptance problems in similar past projects is recommended.
- The team should move up the preliminary cost estimates to earlier in the project, and project continuation should be tied to the results of the cost estimates.
- The team should have a broader collaboration with others making structural cladding and structural insulated panels both domestically and especially in Europe. They should also more options and creativity around how to join the panels together. The team will likely need to do some significant iteration on this.
- This reviewer likes that this project is targeting retrofits, which will be very important part of this program reaching its goals. This project focuses on making delivery and installation less expensive via thinner/lighter panels and fewer/simpler connections, which would make a meaningful dent in the overall costs.
- Naturally, methods of (1) quickly developing custom designs to existing buildings (i.e., window, door, etc.), (2) quickly fabricating said design, and (3) installer/designer training will be very important barriers in this type of retrofit market. However, these topics are beyond the scope of this particular project.

Project #222113: A Systems Approach to Achieving Deep Heating Savings Through Measurement, Management & Motivation

Presenter: Jason Block, Steven Winter Associates
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Reviewers were split on the project's approach to achieve deep heating savings through sub-metering and behavior change in multifamily buildings. Several reviewers commented on the studies that were conducted in the European Union (EU) with many reviewers citing this as a strength. However, they also highlighted the cultural differences between the US and the EU and warned that the team should not assume that the same approach will save energy in the US as well. A reviewer also mentioned their uncertainty regarding the project's success with commercial multi-tenant buildings due to the longer lease terms and the more complex nature of the buildings. A separate reviewer commented that the narrow approach to multi-family buildings with central heat was appropriate due to the potential savings and large size of the sector.

Similarly, reviewers were divided on the project impact and many noted potential areas of improvement for the project team to consider. The majority of reviewers were uncertain about the exact level of contribution this project would have towards DOE goals. With the project's narrow focus, reviewers questioned how relevant the research would be for different building types and/or different climate zones. Another main topic of contention amongst reviewers was the impact of behavior change. While some reviewers expressed doubt as to its application in real-world scenarios, others viewed behavior change as a cost-effective strategy to lower energy consumption. In terms of adoption, one reviewer stressed the importance of developing a good method for billing that would be appropriate for both tenants and building owners.

Reviewer feedback on project progress and stakeholder engagement tended to agree more frequently, and comments were fairly uniform. Despite a minor setback with finding suitable participants, several reviewers commented positively about the team's progress in installing the equipment and collecting data. Other reviewers noted that the project was still relatively early in the presented schedule, even though many of the key hurdles were already addressed including preliminary stakeholder engagement. Numerous reviewers approved of the team's collaboration efforts and described them as "excellent across all stakeholders." Some of the other reviewers found room for improvement in collaboration outside the Northeastern region to other climate zones and building types.

Weighted Average: 2.89 # of Reviewers: 7
Approach: 2.86 Impact: 2.71 Progress: 2.71 Collaboration/Coordination: 3.14 Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **2.86** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project's approach is a blend of technology and behavior modification that is aimed at a hard-to-reach market (multi-family). The unique approach combined with attacking this particular market warrants a rating of "3". The fact that they are building off successful EU experience is good. This may not transfer directly to the US market, particularly in view of different cultural norms regarding sustainability, but trying something here that succeeded elsewhere strengthens this project's approach.
- This approach may not work with commercial multitenant buildings due to longer lease terms, more complex lease agreements, more sophisticated lessors and the more complex nature of the buildings and their systems.
- This project focuses on user behavior to reduce one of multi-family building's highest energy end uses. Multi-family is a significant portion of the building sector and is growing quickly. This approach can influence users and building owners to use less heating, contributing to the 45% GHG reduction goal.
- The approach has merit even though the approach is tailored narrowly to this sector (central heat multi-family buildings) because the sector is relatively large, as are the potential savings.
- Behavior change with thermostat set-points has been studied extensively for single family homes, but not for multifamily residences. Additionally, comparing a single-family home's energy usage to their neighbors has limitations – all homes are very different, and customers don't know how close the neighbors in the comparison really are. In a multifamily building, neighbors are literally right next door, making for a truer comparison (also homes, i.e., units, are much more comparable).
- However, assuming that since this approach saved energy in the EU, that it will save energy here, is not realistic and shouldn't be used for validation. The culture in the EU is very different when it comes to energy and home comfort.
- The use of controls to mitigate overheating is also a highly beneficial research endeavor. It’s unclear how the controls were operating, however.
- Finally, it would have been beneficial to include more of a focus on building operator training for this effort, as well. As we all know, keeping buildings operating optimally is always a challenge.
- Precedent in EU. It seems like a simple, mostly economic solution with an easy retrofit. The method to estimate heat use is going to be tricky and the project may encounter pushback from tenants because it's not a meter.
- The data seems to indicate exterior exposure is not the energy driver so installing wireless thermostats for occupant controllability alone will not achieve deep energy savings. Behavior changes appear to be an important aspect. Just sharing what neighbors are doing may not make this change, but tenants receiving separate bills based on energy usage could help change behavior.
- The main challenges of this approach are sub-metering difficulties, stakeholder engagement, knowledgeable staff to review the outputs and take action accordingly.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.71** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- There will certainly be some level of contribution. However, the level of the contribution has been grossly overestimated by the project team. Specifically, the 2,500 TBtu statement of the potential impact of this approach assumes it can be rolled out to the entire US inventory of multi-family and multi-tenant office facilities. This proposition ignores the diversity of the existing building stock and the fact that the approach may not gain much traction in multi-tenant office facilities. Some attempt at using engineering judgement to establish a more realistic estimate would be very helpful in judging the potential impact. My own subjective estimate is that the potential is under half of the figure provided.
- The project is targeting existing buildings and one of buildings' highest energy consumption end-uses. This is a cost-effective way to meet 45% greenhouse gas reduction goal.
- The program goal applies to the entire commercial building sector. This project is good in that the approach is adapted to the specifics of central heat multi-family buildings typically found in Northeastern urban areas; but it is so specific that adapting these results for replication in different building types would probably not be any less difficult than starting from scratch.
- Behavior change is often one of the most cost-effective methods of reducing energy consumption. Also, controls for multifamily have the potential to be very cost-effective, since they effect the energy usage of so many homes at once. And finally, multi-family buildings are on the rise.
- This seems actionable through government or utility policy, or even as a trend among building owners who want to displace cost, thus could have a big impact.
- The challenge to implementing this strategy is not only the disruption to tenants but the building owner's needing to develop a new methodology for tracking sub-meter data and billing. This may require them to hire more staff. It may be challenging for others to replicate.
- Ongoing commissioning can yield significant energy and cost savings. Behavioral change is the most questionable at this point. It is not that easy to achieve in real world scenario.

C. Progress

Based on current project efforts, the project was rated **2.71** for the degree to which the project has met ***project-specific goals***.

- The project appears to be on track and has begun gathering the data required to demonstrate the extent to which the goals have been met.
- The project has had minor setbacks related to engaging buildings to participate, which has influenced budget and timeline. Overall, progress is still advancing toward project-specific goals as expected.
- They're still relatively early in the project, but they appear to be on track—biggest hurdle is usually getting to the point of actually installing equipment and getting the data collection going (i.e., have gotten past the institutional and cooperation barriers for field work). So, good for them.
- Installation of the system at 50% of the way through the project timeline seems a little slower than desired, but the obstacles are understandable.
- Good progress on demonstrating opportunity for savings.

- No meaningful data has been gathered to date. Equipment has finally been installed and commissioned. My concern is that equipment alone will not realize the anticipated energy savings.
- The impact has been measured across a single project.

D. Collaboration and Coordination

This project was rated **3.14** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This team is collaborating with all of the right entities: owners, utilities, local government, and tenants.
- There is good engagement in the region. This reviewer would like to see plans for expanding to other climate zones and possibly other building types.
- The biggest collaboration/coordination issues will come with the billing – still to come.
- It seems the appropriate Northeastern stakeholders were addressed. Perhaps a better overview of control technologies would have been beneficial. But, it's still not clear what the control strategy was for this project.
- The project needs more utility or building owner partners. They could engage Electric Power Research Institute (EPRI), the National Apartment Association, and NMHC (National Multifamily Housing Council).
- Building Owners that have been engaged have been very committed which is demonstrated by their cost sharing contribution for installed equipment. Hopefully, they will also be committed to share lessons learned so other Owners will replicate.
- Collaboration was excellent across all stakeholders.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining work appears to be well planned. All required steps are accounted for and an adequate amount of time has been allocated for completion.
- The preliminary findings are interesting. The timeline seems ambitious for the remaining items left to complete the project, as the operator interface development seems critical to success.
- The remaining project work seems appropriate given the level of information provided on the project.
- Installation of the system at half-way through the project timeline is a little slower than desired, but the obstacles are understandable. Developing the customer interface, the building operator interface, and the finalized control algorithm are highly important steps, but the timeline that they left for these tasks is reasonable and we shouldn't expect perfection in these tasks, either, for a first round of research.
- The project team needs to come up with a good method to create heating bills (e.g., set points) that is accepted as fair by tenants and AHJs. More empirical data from the EU example would be preferred.
- There are multiple activities identified for the remaining work: data gathering, operator interface, heat allocation algorithm, developing tenant interface and feedback – it is unclear how these tasks will be deployed. Does one task inform another task based on data results? How does the team determine what efforts are most effective?

- The presentation did not talk about specific steps required to achieve program/project success.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strengths include 1) It is a good combination of technology and behavior modification, 2) It addresses an underserved market segment, 3) The approach has been proven (in the EU), and 4) They have a good team.
- The project is focused on behavior change in a challenging building type (in terms of engaging users).
- This is very difficult to assess given the small amount of information provided on this project. The question and answers session did help, but not that much.
- Sub-metering gas is a novel approach to multi-family building savings. It also aligns the incentive for the tenant – the more energy they save the less they pay in utility bills – with the decline of sensor costs and the increased consumer interest in living in cities – and thus multifamily buildings. This is a timely and effective technology to be studying.
- Combining sub-metering with behavioral change tactics seems like it could result in a real synergy of energy savings – they complement each other perfectly.
- There is a precedent in the EU. It seems like a simple, mostly economic solution with an easy retrofit.
- The strengths of this project are: 1) Installing zone thermostats via wireless controls is a good solution for existing buildings and 2) Sub-metering data will provide building owners with data that can inform operational strategies to further drive energy savings. This allows them flexibility to implement an operational strategy that works for them.
- The project strengths included the implementation partners’ ability to adapt to various challenges and come up with solutions that will overcome the challenges. The example provided was how they realized the data points that were being collected where overwhelming their servers.

2. Project Weaknesses

- The project weaknesses include 1) It’s application to most commercial office space unlikely to succeed so it’s recommended not to pursue that market segment and 2) The potential impact is grossly overstated even if the 50% heating reduction is reached.
- The project does not seem like it would "travel" well to other climates. How can they instrument multi-family projects in other climate zones that are cooling-dominated?
- The behavior change approach seems a bit oversimplified. For example, one organization found impacts for utility bill comparisons achieves ~2%, so where does the larger percentage expectation come from? It's not impossible. The presentation doesn't really cover the “how” of the behavior change very well. For instance, "neighborhood" or "houses like yours" comparisons as done previously by other groups are anonymous – in fact some of the early work on bill comparisons tried comparing to actual neighbors (houses "on your street") but generated some very negative feedback regarding privacy. It seems like that could be a problem with tenants in the same building. They may not have had time to talk about it if they did.
- The control algorithms that this project is studying are unclear. They're described as "system balancing", but more detailed information is needed to understand what's actually happening. It seems they're using wireless temperature sensors to better understand the average temperature in the building, and to better control the boiler, but that is an assumption.

- Additionally, the inclusion of other control algorithms would have been nice. Would outdoor resets be a worthwhile addition to the control strategy? This is the type of question that can't be answered because of a lack of information on what the controls were actually doing.

- The radiator labs product (a smart radiator cozy) is really novel approach to the same problem, and this reviewer would like to see/understand if that could be added to this retrofit package for added savings (that is another project in-and-of itself, but the mention of future research potential is always beneficial).

- It’s unclear how much attention was placed on building operating training, which is likely a huge factor in the persistence of these savings.

- It's hard to say if the new billing method would be accepted by tenants and owners.

- The tenants that do not pay utility bills based on energy usage are not sufficiently motivated to save energy. The project needs to integrate a strategy that incorporates a benefit beyond just raising awareness.

- It is not clear in the process implementation plan how the project will be able to identify the strategy that makes the most impact so lessons learned can be shared and best practices replicable.

- The project weaknesses are behavior change and end user engagement.

3. Recommendations

- It’s recommended to consider concentrating only on multi-family and to develop a more realistic estimate of the potential impact.

- The project team should work out who will realize the savings (how tenants and managers get billed), as it will significantly influence user engagement and behavior change. How this project "travels" to other climate zones and expands in scope should also be developed as the focus on heating will not be as impactful in cooling-dominated climates.

- The project should pay more attention to the customer messaging and the billing change. They could conduct some preliminary interviews or even focus groups to gauge customer response to possible changes (and even the messaging that precedes the changes). This could help avoid a strong reaction from tenants that could jeopardize the project.

- Since the understanding of the control technology is unclear, these comments may not be applicable: 1) Address whether the addition of outdoor resets could improve the control algorithm, 2) Address whether the addition of the radiator labs product could improve the control algorithm, and/or compare those results to these, and 3) Better address the role of building operator training.

- They need more feedback from tenants and building owners on billing method. They should try to turn the billing method into a standard. They should work with EPRI (utilities), American Institute of Architects, National Apartment Association, and National Multifamily Housing Council (apartment owners/operators), and Building Owners and Managers Association to promote recommendations. They could also benefit from templates: RFP, code/standard language, policy/rebate language, and training manuals/university curricula.

- The project should isolate implementation of behavior change strategies with data gathered so that this can be measured. They could possibly implement different strategies by groups (1/3 floors provide guidance with good/bad, 1/3 floors include sharing energy usage of neighbors, and 1/3 floors incorporate separate tenant billing by energy use). Each of these groups should meet to provide feedback on information shared and pros/cons from their perspective.

- The project team should implement a dashboard-based approach to communicate with end users.

Project #222114: Integrated Solutions for Optimized Performance (ISOP) Packages

Presenter: Rupam Singla, TRC Energy Services
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Reviewers were divided about the project team's approach to develop and test integrated solutions for optimized performance (ISOP) packages. The project was applauded by some reviewers in part due to its holistic and straightforward strategy to coordinate between building systems. However, other reviewers expressed concerns that the approach did not do enough to address the major barriers to adoption. There was also confusion surrounding the specific energy efficiency measures that the project team would install and monitor. One reviewer commented that the solution might be too specific for the team's partner site, which, they said, could lead utilities to the decision not to adopt the project as a full utility rebate program.

The disagreement between reviewers continued for both project impact and overall progress. While many reviewers argued that the partnership with the utility could have a major impact on energy savings, others were uncertain whether the potential was overstated and unrealistic. Several reviewers suggested that the team provide clarity on how each individual technology would save energy and then further clarify how the energy conservation measures would work together in synergy. According to these reviewers, the impact would depend significantly on the technologies chosen by the individual participants, so the estimated impact presented should be reassessed. In terms of project progress, many reviewers mentioned the contracting and procurement challenges with the partner site.

Comments on the team's collaboration and coordination efforts were more uniform with reviewers highlighting the relationship and cost-share between the project team, manufacturers, partner site, and utility. Many of the reviewers stated that additional building owners and utilities should be added and suggested sharing more information on the teams plan to expand their efforts after the initial research. It was unclear to reviewers whether there would be a focus on higher education or all commercial building types. For this reason, a reviewer made the distinction that the project was "more of an experiment from which a broader-based pilot could be developed to move closer to the replicability anticipated in the goals." Additionally, one of the reviewers commended the project's inclusion of ASHRAE guideline 36 and acknowledged that the team was considering standardization.

Weighted Average: 2.63   # of Reviewers: 8
Approach: 2.50   Impact: 2.75   Progress: 2.50   Collaboration/Coordination: 2.88   Remaining Work: 2.50

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project barriers do not seem to be clearly stated so it is difficult to understand if the project will contribute to overcoming them. There are no real technical challenges related to the technologies that are being deployed – they are just not typically used in combination. One challenge that has been encountered is that owners will tend to cherry-pick technologies by asking the question: What is the differential payback of going from a simple answer (LEDs) to a more complex one (LED plus other tech)? This project does nothing to address that objection.
- This project involves a retro-commissioning "package" that looks at major energy end uses. They say it goes beyond how retro-commissioning usually works – implementing one product or strategy – which is not holistic. This package makes it straightforward, hopefully more cost effective, and addresses the most impactful energy end uses.
- Projects that take on the challenge of coordinating lighting, daylighting, HVAC, and FDD approaches are needed, and this will contribute.
- This project is all about integrated packages, but five different technologies is a lot to study at once. Additionally, the presenter noted that each site will study "at least two measures" – which means we can't even tell which measures will get chosen for the study. It's not clear enough what's actually going to be studied here.
- With the inclusion of automated shades, model predictive control could potentially be a beneficial add-on to this project. Understanding how the building responds to weather and solar radiation could help offset peak demands with the addition of model predictive control.
- It has a well-thought-through problem statement, use case, and value proposition. The project approach, including "problem solving" to overcome challenges, as well as evaluation design, demonstrates good understanding of what needs to be proved out and how to do so.
- It's concerning that the procurement issues eating up most of the time and money. It's also concerning that the solution will be too specific to Princeton and may not be seen by New Jersey Board of Public Utilities as general enough to base a rebate policy on.
- It's unclear how the proposed HVAC integrated solutions strategy for lighting or daylighting and how this is innovative. For instance, automated shades will reduce the solar heat gain to the space, the HVAC system will sense this reduction via the local thermostat and modulate via existing controls. What is the enhanced benefit of the ISOP? It should be clarified what the control strategy is and how it will be replicable especially if utility programs offer rebates for incorporating into existing buildings.
- With regards to the lighting controls, what is the "aggressive controls strategies" proposed that is innovative and would contribute to the projected energy savings potential?
- The project team had the right approach to solve an extremely real-world problem. The energy efficiency work is almost all done in one or two ECM's instead of taking the whole building approach. It would be really interested to see how the utility programs that provides rebates for energy efficiency would benefit from the data generated from this approach to tailor energy efficiency rebates

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.75** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This reviewer almost rated this item "Poor" but there could be some energy reductions that flow from the work. That said, the savings estimates are grossly overstated (assumes roll out to 100% of the building stock). Before continuing the team should reassess this to ensure the potential savings are worth the remaining investment.

- The package is based on largest end uses from CBECS, so it directly contributes to 45% GHG reduction goal. Also, it is focused on existing buildings and "beyond widgets" initiative.

- The project will contribute to a better understanding of the current challenges (as set out in the presentation) and the problem-solving approaches seem reasonable. But, the project's narrow field test (one entity; one climate) will have to be repeated with other participants/building types/owner types before they could reasonably expect to develop "replicable" "standardized packages".

- The impact depends on which technologies will be studied, which isn't 100% clear. It also seems like many of these technologies have already been studied (i.e., the Beyond Widgets research). The addition of automated M&V and FDD/CCx are noteworthy, but do those technologies add synergy to the other three? The point of integration is that each measure should make the other measures more successful. Automated M&V and FDD/CCx may not add any synergy with the other measures (or, if they do, it’s unclear exactly how). Perhaps in extended measure life (that makes sense), but is that the intent of the study? It's hard to tell.

- Also, the presenter mentioned plug load energy savings on Slide 9, which was unclear. It’s unclear what measures effected plug loads at all.

- The project appears on track to validate value of integrated package of ECMs in a manner consistent with the program objectives and goals. The market transformation strategy seems generally well-thought-through. If successfully demonstrated, the "ISOP" would have a major impact on energy reduction.

- This was rated as outstanding even though the project seems to be in jeopardy because of the procurement issues because of the relationship with NJBPU and their goal of creating a rebate program. That is a great opportunity to have significant impact.

- Given my limited understanding of the HVAC controls integration, it is unclear how the projected 25-30% HVAC energy savings will be realized. Additionally, a 10% reduction in plug load energy use is estimated. What control strategy is proposed for plug load reduction? The team should clarify the proposed strategy that supports the estimated energy savings.

- The impact provided seems unrealistic to me. For a whole building deep energy efficiency project, the main barrier would be access to finance tools and not the lack of energy data.

C. Progress

Based on current project efforts, the project was rated **2.50** for the degree to which the project has met ***project-specific goals***.

- Project progress has been good, in particular when considering the fact that they have had to overcome a number of implementation challenges.

- They had an eight-month delay, but they are on budget (Princeton to become a sub-recipient of the grant because of how much they are contributing). This process is taking some time on Princeton's side, but seems worth the delay to get more involvement and funding from a significant partner.
- The challenges with the site owner probably should have been anticipated – these things always come up; however, the team appears to be successfully resolving the issues as they come up.
- The fact that bids haven't gone out yet, makes it look like this project is a little behind.
- Well-thought-through approach to overcoming multiple unforeseen project barriers. The agility of the team gives the confidence to believe that the likely unforeseen barriers that will arise after procurement, installation, and commissioning will be effectively addressed. That said, this is an ambitious project in scope that has a high risk of not delivering a conclusive finding.
- The procurement issues with Princeton related to Department of Energy funding are harming progress.
- The project is lagging due to a funding/procurement change, but a deployment partner has been engaged which will provide this project with some useful data. Through the funding process, bid documents were required to be developed which can become a shared resource.
- The progress is limited to a site and one project partner. The energy savings has not been quantified.

D. Collaboration and Coordination

This project was rated **2.88** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Given the New Jersey focus of this project the collaboration is appropriate.
- Good collaboration with Princeton, NJIT, and many manufacturers. There is good cost sharing. They are evaluating five buildings at Princeton and Princeton is contributing significant costs. DOE contributing 15% of costs.
- They need to do more engagement with owners to understand why they're not engaging in holistic retro-commissioning. Need more information about how this will be expanded to owners beyond Princeton. Will the focus be higher education or all commercial building types?
- Maybe the level of C&C is appropriate given the experimental nature of the study, but in general it seems like an internally-focused effort without much external coordination.
- This reviewer really liked the inclusion of ASHRAE Guideline 36. It's refreshing to finally see some standardization! That's what we need – interoperability and functional standardization.
- Approach to partnerships appears well-thought-out. Presentation did not offer sufficient detail to determine how effectively these partnerships are being managed, particularly relative to similar effort by the Building Technologies Office peer group, particularly SeventhWave/Slipstream and LBNL.
- They need to change the relationship with Princeton because of the procurement challenges and focus on working with NJBPU on the rebate program.
- The project team has engaged with a broad range of stakeholders including coordinating with other research efforts, utility incentive programs, and BTO Peer Groups. This collaboration will broaden the reach of lessons learned.
- The project team have a solid project partner and a test sites for building size over 250,000 sq. ft.

E. Remaining Project Work

This project was rated **2.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining work appears to be well planned and aligned with project specific goals.
- Overall, the progress still seems to be advancing as expected, but the formal partnership with Princeton is worth the delay.
- My earlier comments mention the narrowness of the field work, maybe not in terms of building type/age, but in terms of uses, climate, and owner type. This affects the ability of the project to live up to the ambitious project goals (i.e., standardized retrofit package development, moving the solutions from experiment to program-ready). This is more of an experiment from which a broader-based pilot could be developed to move closer to the replicability anticipated in the goals for this project.
- The remaining work seems logical.
- The project plan as originally conveyed is well-thought-through to meet project goals; although the project is behind schedule, the recovery plan appears solid. However, there appears to be significant risk that additional unforeseen issues will arise that will further challenge the ability of the team to deliver the remaining work effectively on time.
- They need to change the relationship with Princeton because of the procurement challenges and focus on working with NJBPU on the rebate program.
- The project plan for the remaining work is organized and seems reasonable. There is still concern regarding the specifics of the integrated solutions and whether the predicted energy savings will be realized.
- The remaining project work is doable based on the amount of work left to implement and then quantifying the energy savings for market transformation.

F. Additional Comments and Recommendations

1. Project Strengths

- A project strength is that it attempts to solve a real issue – retrofit programs typically involve only one or two technologies.
- The payback is ~5 years, even for Princeton with low utility rates. A best practices guide seems helpful to other owners – will it be applicable to other owners (different building types, different climate zones)?
- The fundamental problem definition is, in my opinion, very much on-target. As are the goals of reducing costs/increasing uptake through the creation of standardized, replicable retrofit packages.
- There are a lot of good technologies included in this project, but most of them aren't that unique. The most unique research is AHRAE Guideline 36. This reviewer is excited to see what the effects of that are.
- The characterization of the current market state, the value proposition of the proposed package of innovative technologies, and the demonstration plan are well thought through.
- Their connection to New Jersey Board of Public Utilities is very valuable in achieving the goal of a rebate program.

- The deployment partner is committed to providing field demonstration sites to capture real operation data, providing the team with a great database to develop guidance relative to building type/use and appropriate integrated energy saving solutions.
- Project strengths include multiple stakeholder engagements and the opportunity to demonstrate energy savings opportunity with less than five years payback.

2. Project Weaknesses

- We do not have a credible estimate of the potential impact if this work is successful. Therefore, this project's ability to contribute to DOE's goals in a meaningful way is questioned.
- The scope seems to be very limited: one state, one utility, and one large educational institution. This calls into question the future scalability of the findings.
- It seems very similar to project 222116.
- It's unclear whether all the occupants will accept the use of perforated shades. Having an unobstructed outside view is becoming a wellness issue that could defeat this portion of the proposed package.
- Lights and HVAC are not directly integrated.
- Are these end uses for all climate zones or just New Jersey? Is the lack of a package what kept owners from retrocommissioning? The ISOP package is not unique enough from other services that already exist (M&V, energy as a service, etc.). It doesn't use data from ESPC accelerator program.
- The target market and market penetration are not defined.
- The main weaknesses really come from the project goals being ambitious. This is really a case study for a particular client (type) in a particular climate. They're also testing some approaches for which not much experience exists, e.g., coordination of daylighting/lighting/HVAC. So, it's really more experimental; there is likely to be a big gap between what they find here and having sufficient best practices to roll out in a utility program.
- There are too many technologies being studied at once. It's not clear which technologies will actually be studied, since each facility will only have two of the five measures implemented. Most of the measures aren't unique to this research and have been studied before. It's not clear how FDD and automated M&V add synergies here that enhance the effects of the other measures.
- Effective delivery of ISOP is the "proof point" of this project, and the rocky start is indicative of future challenges with such a comprehensive "beyond widgets" approach. While this project is well designed to prove out success, it would appear to be less well designed to characterize systemic failure that could enable a "no-go" determination of what is simply not workable at this time.
- The project weaknesses include the logistics around procurement and thus installation schedule and cost.
- It's not clear what the specific integrated solutions are for the HVAC systems coupled with lighting or automated shades and how this contributes to the projected energy savings.
- To be honest ISOP methods are no more different than other ESPC's or Sustainability as a Service companies who offer deep energy savings opportunity. The only unique offering is quantifying the savings and the creation of a template that could eventually be used by different companies and customers for implementation.

3. Recommendations

- DOE should reconsider whether to continue with this project. As a minimum, a pause is recommended to assess: 1) What is a realistic estimate of potential savings? 2) Are this project and 222116 too similar to continue funding both? 3) Is the scope of this project actually too narrow with its focus on New Jersey and a higher learning institution? 4) Will the project design actually contribute to wider adoption of multi-ECM projects by building owners?

- Are end uses based on all commercial buildings or just higher education? Does the package need to be modified more between different building types?

- Honestly, they're doing fine. They should spend some effort documenting what they now realize they need to know (in terms of adapting technology to different types of end customers, building types, climates; coordination of multiple technologies; barriers to replicability and standardization; challenges of standardization, including how to do the inevitable customer hand-holding on a tight budget) and planning for moving either to additional experiments/case studies or possibly to pilot testing to develop sufficient experience to support utility investment/program development.

- Choosing a clear set of measures and implementing all of them in each facility is recommended – so that we have clarity on what is actually being studied. They should focus on ASHRAE Guideline 36 which is the most unique research topic in the project. Also, they should describe more clearly how FDD and automated M&V add synergies to the other measures.

- None.

- Focusing totally on the rebate program with NJBPU is recommended and the partnership with Princeton should be pivoted in a way so they could help you validate the value of the proposed solution, but the team shouldn't actually install the equipment. It seems too logistically challenging because of the procurement issues. They could benefit from templates: RFP, code/standard language, policy/rebate language, and training manuals/university curricula.

- Developing the HVAC integration sequence of operations is recommended, and it should be compared against industry standard sequences. Perhaps consider reaching out to controls vendors for input/feedback to optimize the energy savings potential. This will help educate mechanical engineers/controls vendors and facilitate implementation.

- Finding a unique proposition that is scalable is recommended. For example, the interaction between daylight sensor and window blinds, so if these measures are implemented in tandem, then energy savings will be X, which can now be incentivized by the utility across America and implemented by customers.

Project #22244: Integrated Systems Packages Optimized for Real Estate Life-Cycle Events

Presenter: Paul Mathew, Lawrence Berkeley National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Reviewers found the project approach to optimize integrated systems packages for real estate life-cycle events to be very sound. The premise was applauded for the project's inherent strategy to look at energy efficiency from the perspective of existing real estate industry practices. Several reviewers commented that the project would result in increased uptake in energy conservation improvements and lead to cost and energy savings for building owners. While one reviewer agreed with the other three reviewers about the approach, they questioned how the team would successfully disseminate the results across the industry.

In terms of the potential impact, reviewers agreed that the project could contribute significantly to BTO goals by increasing adoption of deep energy efficiency upgrades and addressing the existing building stock. Reviewers stressed the importance of developing packages that are not too disruptive and that balance effectiveness with market viability in order to ensure widespread adoption by the real estate industry. The idea of incorporating this strategy into a utility incentive program was mentioned as an effective method to increase participation.

Despite the early stage of the project, comments on progress were overwhelmingly positive as all of the reviewers rated the section as either "Excellent" or "Good." Two reviewers highlighted stakeholder engagement as an area that was particularly strong at this phase of the project, while a different reviewer agreed, but mentioned that the next stage of the project where the team actually develops the packages will be the real challenge. The same reviewer continued and noted that the team has had "a good start with their improved understanding of stakeholder needs from the front-end work."

Collaboration was generally well-regarded, and the majority of reviewers considered stakeholder engagement to be one of the project's main strengths. The stakeholder group was described as "well considered" and "one of the most impressive aspects of this project." One reviewer stated that keeping the group engaged throughout the project would be critical to its success. On the other hand, another reviewer offered suggestions of potential organizations for further partnership opportunities. Also of note, a reviewer questioned whether it was necessary to do original field research to validate the savings from the packages. The reviewer followed up and noted that if the team utilized pre-measured packages, the project could focus more completely on understanding the market barriers.

Weighted Average: 3.38   # of Reviewers: 4
Approach: 3.50   Impact: 3.50   Progress: 3.25   Collaboration/Coordination: 3.25   Remaining Work: 3.25

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will leverage the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project is developing an energy retrofit package targeted to the real estate industry. The team has identified an opportunity to implement this retrofit at regularly occurring "real estate life cycle events." This focus minimizes disruption and cost, therefore increasing adoption by users.
- The premise that leveraging "real-estate lifecycle events" will result in increased uptake of energy efficiency improvements is solid. A solution that develops "packaged" solutions to reduce adoption costs (cost and hassle) seems viable but depends on how well those "packages" find the sweet spot between effectiveness (at saving energy) and market viability. Developing packages using FLEXLAB is a reasonable first step and the remaining elements of the approach seems mostly complete and carefully thought out.
- This project's approach is appreciated. It behooves us (the energy industry) to think about how we can better integrate energy upgrades into the practical applications of other industries. And to really look at things from the perspective of another industry. More projects like these would be a great addition to DOE's research.
- It’s a great approach, but how will the team get the word out? It seems this would benefit from collaboration with AIA (architects) and BOMA (building owners/operators).

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project has strong alignment with DOE goals – focus on existing buildings and beyond widgets programs. This could make a realistic and significant contribution to the 45% greenhouse gas reduction goal.
- If they can develop packages that customers are willing to go with, this could make a big difference in the rate of uptake of (deep) energy efficiency upgrades.
- Projects like this – that focus on another industry's perspective – make it much easier for utilities to offer effective incentive packages. Utilities can actually align an incentive with the real-life concerns of their customers. We (the energy industry) should do more projects like this.
- This reviewer really liked the idea of fitting energy efficiency measure improvements into the real estate lifecycle so as to reduce push-back.

C. Progress

Based on current project efforts, the project was rated **3.25** for the degree to which the project has met ***project-specific goals***.

- They’ve had impressive progress in a short time period. Stakeholder engagement is particularly strong, especially considering the insights and obstacles that have been identified.
- It is still early in the project, but so far it seems on track. The next stage – package development – is the real challenge; they have a good start with their improved understanding of stakeholder needs from the front-end work.
- In six months, they've held 33 stakeholder meetings – sounds pretty good.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **3.25** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- This is one of the most impressive aspects of this project. The stakeholder group was well considered and covers diverse perspectives. The key themes identified in these sessions are insightful and will have positive influence on the outcomes of this project.
- So far, their engagement with industry/stakeholders appears excellent. Keeping them engaged through the remaining steps will be critical, though.
- No deficiencies noted.
- It could benefit from partnership with organizations like AIA (for architects) and BOMA (for building owners/operators).

E. Remaining Project Work

This project was rated **3.25** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The progress made to date and preliminary findings demonstrate that the project is well-positioned to meet or exceed defined outcomes.
- The planned work seems well thought-out and viable.
- The remaining project work is logical. One question/concern is the following: is it necessary to do original field research on the energy savings from different integrated packages for this project? Can this project leverage research on measure packages from other projects, in lieu of doing original research in this area? If so, this project would be able to focus more on the real estate lifecycle and customer barriers, instead of energy efficiency packages.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- This project has deep stakeholder engagement. The perspectives and key themes from this engagement hold promise for this package to be adopted by the target user group.
- It’s excellent that they started with the market analysis rather than their technology solutions – they now have a much better chance of designing something that the market will actually buy. The intent to keep stakeholders engaged is critical to project success.
- The project integrates energy efficiency into the real-world problems of customers and other industries.
- It seems well organized and productive. The idea of fitting energy efficiency measure improvements into the real estate lifecycle so as to reduce push-back is appreciated.

2. Project Weaknesses

- The project would benefit from defining a plan for expanding deployment beyond the current stakeholder group.

- There should be an opportunity to use field validation findings to tweak, or even redesign, packages and then run them back through FLEXLAB testing. If that is actually included (but not articulated in the presentation), great!
- The scope of this project might be a bit too wide. The project tries to fit a lot of different research into a single project (i.e., research on the efficiency of different measure packages in addition to research on the real-estate lifecycle and how to address those barriers). The more important research question is about the real-estate lifecycle – perhaps the research team should focus on that more and leverage past research for the development of recommended measure packages.
- One project weakness is the potential for the lack of market adoption.

3. Recommendations

- The project would benefit from defining a plan for expanding deployment beyond the current stakeholder group.
- Adding time and money (subject to already-identified go/no-go off-ramps) is recommended so as to add a demonstration phase (beyond the field validation testing) – this could be a Phase 2 that would be green-lighted at the point the field validations begin showing positive results.
- The team should focus more on the real estate lifecycle and the customer and less on technology. Recommend leveraging prior research to develop measure packages.
- The team should work with AIA (architects) and BOMA (building owners/operators) on a program to promote recommendations.

Project #22230: Getting Beyond Widgets: Utility incentive programs for commercial building systems (CBI Open Lab Call)

Presenter: Cindy Regnier, Lawrence Berkeley National Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

Overall, reviewers found the Getting Beyond Widgets project to have a strong approach that was likely to succeed. Most reviewers noted the need to validate the benefits and savings of a systems approach so as to justify support from utilities. It was further stated that utility incentive programs would help address the high cost and misperception that energy efficiency projects are complex and disruptive. One reviewer commended the approach but recommended that the team increase the number of building owner and utility partners associated with the project.

The ratings and comments on impact were overwhelmingly positive with three out of four reviewers scoring the project impact as “Outstanding.” Reviewers remarked on the project’s clear alignment with DOE’s program goals especially with regards to improved energy efficiency in existing buildings. A reviewer commented that the packages appear viable but would need the support of utilities in order to spur adoption. There was uncertainty surrounding the uptake of the first cohort’s projects, which the reviewer stressed was important to consider when evaluating the project’s value and impact.

While reviewers were generally complementary about how the project was progressing, their comments on collaboration and coordination were slightly more critical. One reviewer began by recognizing the level of stakeholder engagement, but then noted the lack of participation from commercial building owners. The reviewer continued and remarked that while working with the Federal Energy Management Program (FEMP), US General Services Administration (GSA), and energy service companies (ESCOs) was a great starting place, these organizations likely have viewpoints that differ significantly from other building owners. It was also mentioned that there are plans to engage more professionals in the building space such as architects, engineers, and designers.

As for the remaining project work, most reviewers found the team’s plan to be consistent with the presented schedule of work. One reviewer disagreed and stated that the team needed to engage additional stakeholders in order to ensure adoption by utilities. The same reviewer noted that utilities are not positioned to deploy these programs so the project team would need to address these remaining barriers before the utilities could successfully administer a Beyond Widgets program.

Weighted Average: 3.10   # of Reviewers: 4
Approach: 3.00   Impact: 3.75   Progress: 3.00   Collaboration/Coordination: 2.75   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This approach is likely to succeed. The problem is real. Creating utility incentive programs will help address the cost issue and developing pre-tested packages that are easily understood will help industry get over the perception of these projects as complex, risky and disruptive.
- This project is demonstrating the value of holistic building energy retrofits to utility companies. The aim is to launch a "package" program that utilities can adopt.
- This study addresses a need to validate the premise that a systems approach has substantial benefits, and that the savings can be sufficiently estimated to justify utility support.
- It seems like a good approach, but it needs additional connections to utilities and building owner/operators for adoption. The team should talk with EPRI and BOMA.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.75** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This is a major issue that is being addressed with a very solid approach. As a result, it is highly likely to make a significant contribution to program goals. One question about the project remains. No information was provided on uptake of the Cohort 1 projects. This information should be considered in any final evaluation of this program's value and potential impact.
- It has clear alignment with multiple DOE goals – it demonstrates significant contribution to 45% GHG reduction. It directly addresses the beyond widgets program with a focus on existing buildings.
- The project results are better than expected. The packages seem viable, presuming the utility partners follow through with support for adoption.
- It seems data driven and actionable through government or utility policy, or as a trend among building owners.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- Only the lack of uptake information for Cohort 1 prevented this project from being rated as Outstanding.
- A proposed package has been developed and overall project is progressing as planned.
- The project is almost finished.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **2.75** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration by this team has been good. My one criticism is that there does not seem to be any participation by commercial building owners. FEMP, GSA, and ESCO's are a good starting point but they likely will not reflect the views of most commercial building owners. It's important to note that the ESCOs have gotten very little traction outside the MUSH market.
- There is a good spread of stakeholder engagement with utilities and industry partners. This program will be complicated for utilities to adopt, so there are future plans to engage more architects, engineers, and designers.
- The appropriate stakeholders were included.
- They could benefit from partnership with organizations like EPRI (for utilities) and BOMA (for building owners/operators).

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining work appears to be very well planned.
- There are still additional stakeholders to engage and work to do in order to ensure that utilities can adopt programs like these. They are not currently set up to offer such packages, and the project has more work to do to position utilities appropriately. The project team acknowledges this and seems to have a good understanding of what barriers still need to be addressed.
- The project is almost finished.
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- They are addressing an important problem with a very logical, and strong approach. The key barriers are being addressed and they have a strong team.
- Holistic retrofits in existing buildings hold tremendous opportunities for energy savings, and this project maximizes adoption by developing programs for utilities to offer (for widespread use).
- They are focused on developing integrated packages that meet customer needs and utility requirements (i.e., for funding justification).
- It seems well organized and productive. An integrated approach to EEM is known to be an effective best practice. Other strengths include an opportunity to improve human health and productivity. The project seems to be at pace with advances in IoT.

2. Project Weaknesses

- They don't have participation from commercial building owners – an important stakeholder group. Also, the results on the uptake from Cohort 1 projects were not presented.
- There is a dire need to engage architects, engineers, and rest of AEC industry.
- There are no apparent weaknesses.
- A weakness is the potential for the lack of market adoption.

3. Recommendations

- The team should bring commercial building owners into the program to gain perspective on their barriers to adoption. Suggest making the data available on the results from Cohort 1 – has there been any uptake? This information should be used to assess program value and potential impact.
- The team should provide assistance and support for public policy.
- More follow-through support with utility program rollouts is recommended.
- The team should work with EPRI on a program for utilities and BOMA for a program for building owners/operators. They could benefit from templates: RFP, code/standard language, policy/rebate language, and training manuals/university curricula.

Project #22240: Building-Level DC Distribution Systems

Presenter: Willy Bernal, National Renewable Energy Laboratory and Richard Brown, Lawrence Berkeley National Laboratory
DOE Manager: Charles Llenza

Brief Summary of Reviewer Comments

Reviewers were split regarding the team's approach to the building-level direct current (DC) distribution system project – several reviewers provided positive comments and the remaining two offered suggestions for improvement. One reviewer commended the team's decision to begin by defining obstacles and noted that this approach made it more likely that the team would overcome the identified barriers. Similarly, another reviewer mentioned that due to the early nature of the research on the topic, the team's wide perspective would be useful in determining barriers and potential solutions. Some of the reviewers expressed concern that the research was either too focused on lab-level details or had already been completed in-part by other projects. To address these issues, reviewers recommended concentrating more on defining and overcoming the technical and market barriers as opposed to measuring energy savings.

In terms of the potential impact of the project, reviewer comments were also mixed with a variety of outlooks given on the future use of DC in buildings. While reviewers were uncertain how quickly results could be expected, several reviewers agreed that this project would be beneficial in the long term and could possibly position DOE as a leader in the field. However, one reviewer questioned how widespread DC distribution systems would actually be in the future but noted the importance of the study in developing a baseline. In addition, reviewers emphasized the importance of including a quantification of benefits for buildings with on-site solar photovoltaics (PV), electric vehicle (EV) charging stations, and/or battery systems.

The comments on progress were generally more uniform, as reviewers agreed that the early stage of the project made it difficult to determine. On the other hand, reviewers had opposing impressions of the team's collaboration efforts ranging from "Outstanding" to "Fair." Two of the reviewers applauded the team's stakeholder engagement and described the team as "collaborating deeply with all of the relevant parties." Conversely, the other reviewers recommended further stakeholder engagement and suggested working with more designers, building contractors, and owners earlier in the process. It was also mentioned that adding another 2-4 sites would be a potential challenge for the team to secure in the allotted time and could jeopardize the remaining work.

Weighted Average: 2.69   # of Reviewers: 5
Approach: 2.60   Impact: 2.60   Progress: 2.80   Collaboration/Coordination: 2.60   Remaining Work: 3.00

Program Response

The project team acknowledged reviewer comments and will better clarify the project's approach does not involve lab-level measurements and will not reproduce existing research. Industry stakeholders, through the Technical Advisory Group (TAG), stressed that third-party validation is lacking and necessary to promote technology in addition to addressing technical and market barriers. The team noted that its revised work plan will include appropriate updates to address this feedback.

A. Approach

This project was rated **2.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The fact that they are starting by defining challenges and opportunities is appreciated. That in and of itself makes it highly likely this program will succeed in contributing to overcoming those barriers.

- There are existing research projects that are focused on modeling and demonstrating energy savings of using DC rather than alternating current (AC) systems in buildings. This project builds on those studies and starts to define and overcome technical and market barriers associated with DC systems. Defining and overcoming technical and market barriers is the most effective part of this study and should be the focus of the project. The energy saving opportunities seem well established and don't require significantly more study.

- The project is designed to figure out some of the basic technical issues (i.e.. what are the conversion losses and how should they be measured? Is the premise that avoiding conversion losses in real world applications will actually save energy?) but seems focused on lab-level details. That's probably okay, but there should be some assessment of how such systems might be used in the real world to guide the research.

- It's not very clear exactly what the research team is going to study. However, research on DC distribution is relatively nascent, so a wider perspective may be useful in this case – it can inform other research areas and potentially uncover barriers that wouldn't have been studied otherwise. That being said, a clearer delineation between the benefits of DC distribution system to buildings with solar PV versus buildings without solar PV; and buildings with EV chargers versus buildings without EV charges would be useful. Two key takeaways should be: if a building doesn't have onsite solar PV installed, is a DC distribution system worthwhile? And if a building has EV chargers, is a DC distribution system worthwhile?

- Also, the research team should consider "middle ground" solutions, that don't include DC distribution all the way "to the desktop" (meaning, installing DC ports at each workstation). It's likely very expensive to install DC distribution throughout an entire building, and to each workstation. The research team should consider cases where only certain systems in a building are powered with DC, which may transfer 80% of the benefit at 20% of the cost (obviously those fractions are only demonstrative). One key example is low voltage ceiling grid systems for LED lighting. These systems have a number of non-energy benefits as well, such as reduced lighting installation time, and the ability to easily reconfigure the lighting system in a facility (which is important to building owners that lease their space). These "middle ground" solutions may be the most cost effective.

- It seems like a good approach to understand detailed obstacles and solutions for DC building circuits, but market adoption and code compliance are concerns.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.60** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This project was rated as "Fair" because DOE's goal is short term – a 35% energy use intensity (EUI) reduction by 2025. The use of DC in buildings is a longer-term play with potentially large results and this reviewer fully supports this research effort as part of a longer-term view.

- This project may not immediately result in significant energy savings for buildings but it has potential to contribute significantly to DOE's 45% greenhouse gas reduction in the future. This project positions DOE as a leader in this emerging area of interest.

- There's a bit of a "if we build it, they will come" expectation of market uptake once the benefits have been measured and quantified. Accelerating adoption of DC systems (should they prove cost-effective) will require more than a report saying it's a good idea. That could easily be a next steps project, but this project includes this as one of the expected outcomes.

- This is a tough one. A thorough "baseline" study on the benefits of DC distribution would be beneficial for the industry, since, to my knowledge, no such study exists. In past research, the majority of information found was from articles and other less-formal sources. It would be useful to have a definitive study performed to fully understand the technology, the benefits, and the shortcomings.

- It would also be disappointing to see a study performed on DC distribution that didn't quantify the benefits for buildings with onsite solar PV, EV charging stations, and/or batteries. EVs and batteries are clearly on their way, and solar PV is clearly here to stay – these are the systems that would benefit the most from DC power systems, and the research questions should quantify the benefits for these systems.

- All that being said, it is uncertain whether DC distribution will play a big role in saving the world. But that's why we need a study performed. Just how much will this technology help?

- It seems data driven and actionable as a trend among building designers and owners, but it could be hindered by code obstacles.

C. Progress

Based on current project efforts, the project was rated **2.80** for the degree to which the project has met ***project-specific goals***.

- The work is at a very early stage, but progress has been good.

- The project is progressing as planned and will achieve its first major milestone soon.

- It’s hard to comment; the project just started.

- It's hard to tell how the project is progressing only six months in. However, the first phase was to define challenges and opportunities, and clear progress was not presented on that front. It still seemed unclear what the challenges and opportunities are.

- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **2.60** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team is collaborating deeply with all of the relevant parties.

- The primary challenge with adopting DC systems is based on technical and market barriers. Further studies on energy savings will likely not make the case to overcome these barriers. The partnerships engaged in this project so far are appropriate and impressive but needs broader stakeholder engagement. The AGU study will be most impactful. This project should engage more design, construction, and owner/developer stakeholders in order to understand and address technical and market barriers.

- The team should consider involving stakeholders earlier in the process, to help guide the lab work and especially the field validation.

- The collaboration seems fine. They could maybe include a solar PV organization as a partner. No big deficits here, though.
- They could benefit from partnership with organizations like AIA (architects), IEEE (electrical engineers), and BOMA (for building owners/operators).

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project plan is very logical and highly achievable.
- Additional stakeholder engagement tasks should be added to fully define challenges and opportunities. This reviewer is not confident that this project can fully achieve this project goal without further conversations with the design and construction industry, as well as owners and developers.
- The project team said they plan to add 2-4 test sites to this project, which would be helpful. It seems that it will be challenging to recruit that many test sites in the remaining time period.
- The reports that will be delivered should be organized as "design guides" targeted to designers, contractors, and owners. This will make the information better utilized.
- It's hard to comment; almost everything "remains".
- Task 2 and Task 3 (develop metrics and field validation) are logical next steps.
- It seems well organized and productive.

F. Additional Comments and Recommendations

1. Project Strengths

- They have a strong team with a strong approach, work plan, and collaboration. The deployment of DC in buildings has great long-term potential to improve EUI as well as generate additional benefits.
- DC systems have tremendous opportunity and this project is appropriate to position DOE as a leader in this market. The project builds beyond existing studies on energy efficiency to examine and address the technical and market challenges with wider adoption of DC systems.
- This is a necessary area of research – lots of interest in the literature, the industry, and even popular press – so this needs to be done.
- This project fills a gap where there hasn't been a lot of research, at least not that this reviewer is aware of. It would be great to see a report that clearly outlines the benefits and drawbacks of DC distribution in buildings that have solar PV, batteries, and EV chargers. With the influx of EVs and behind-the-meter batteries, DC power might be a more important factor than meets the eye.
- It seems well organized and productive. The capital cost savings seem possible by combining power and network systems into one DC infrastructure. The energy savings seem feasible by reducing need for AC-DC converters, thus improving efficiency of whole system. The project seems to be at pace with advances in IT.

2. **Project Weaknesses**

- It's unlikely to contribute much to the 2025 goal, although it has great long-term potential.
- The most significant technical and market barriers are grounded in architecture and construction. These groups should be engaged to strengthen the project outcomes.
- What happens with the results is not very well thought out (i.e., is there a plan to make sure there is real impact rather than just another report on the shelf?).
- The project team didn't seem to have uncovered the true barriers to adoption yet. Also, "middle ground" solutions – that use DC power only for certain tasks, and don't run DC distribution to the desktop – might be a more feasible approach in the near term, which didn't seem to be a part of the scope of the project.
- One project weakness is the potential for the lack of market adoption and rejection due to code issues.

3. **Recommendations**

- No recommendations.
- The reports and articles from this project should be framed as a design guide for use by architects, engineers, contractors, and owners.
- The team should include stakeholders early in the process and planning for how the results will help reduce energy consumption and GHG emissions.
- The team should include task specific DC distribution systems in the scope (i.e., lighting only systems and not DC distribution to the desktop). Specifically, DC powered ceiling grids for LED lighting fixtures should be investigated, since they have a number of energy and non-energy benefits. Also, the benefits and drawbacks of DC distribution should be quantified for buildings with onsite solar PV, behind-the-meter batteries, and electric vehicle charging stations.
- The team should work with AIA (architects), IEEE (electrical engineers), and BOMA (building owners/operators) on a program to promote DC. Creating template code language for any AHJ to adopt is recommended. The team could also benefit from templates: RFP, code/standard language, policy/rebate language, and training manuals/university curricula.

Project #22245: Controls and Integration Science to Embed EE and DERs into Advanced Manufacturing of Buildings

Presenter: Shanti Pless, National Renewable Energy Laboratory
DOE Manager: Amy Jiron

Brief Summary of Reviewer Comments

The approach for the project to embed energy efficiency and distributed energy resources (DERs) into advanced manufacturing of buildings was generally well received. Several reviewers applauded the team's partnerships with the modular construction industry and cited this collaboration as the predominant factor that would lead to the project's ultimate success. While reviewers appreciated that the team took the perspective of another industry, two of the reviewers expressed concern with maintaining the industry's engagement and disseminating results and information. The established industry advisory group was also mentioned in coordination with the offsite construction factory partnerships.

Reviewers disagreed slightly about the potential contribution that the project could have on DOE's energy efficiency goals. The majority of reviewers recognized that offsite construction was an emerging trend, but their comments differed regarding the degree of energy savings and BTO's role in the industry's near-term growth. One reviewer noted that a baseline manufactured building will likely be more energy efficient than a building built on-site. The reviewer continued by explaining that the metric to consider in the project should be the "marginal improvement between standard practice manufactured/modular buildings and the integrated solution this project is intended to develop."

In terms of the team's progress and collaboration with its partners, reviewers found the project to be well thought through and progressing as expected. Several reviewers commended the engagement with stakeholders with one reviewer highlighting the three secured partnership agreements as confirmation of the significant progress the team has made in the short period of time. It was recommended that the team expand their collaboration to include more factories, contractors, architects, and engineers. Also, reviewers suggested partnering with specific project groups and organizations in order to broaden stakeholder engagement.

The reviewers raised multiple unanswered questions about the project's remaining work and provided additional comments for the team to consider moving forward. One reviewer inquired about the presented flowchart idea that would document the manufacturing process and was uncertain whether the process would be applicable to more than one manufacturer. Another reviewer proposed using the Better Buildings format to model the development of a peer network so that the factories could work together on energy improvements.

Weighted Average: 3.18   # of Reviewers: 5
Approach: 3.60   Impact: 2.80   Progress: 3.20   Collaboration/Coordination: 3.20   Remaining Work: 2.80

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Teaming with modular constructors gives this program a good chance of success.
- The approach is to establish an industry advisory group and offsite construction factory partnerships to make recommendations for energy improvements in offsite construction and validate performance.
- The approach is to engage industry partners in creating specifications, designing/modeling, developing manufacturing requirements, etc. for advanced manufactured buildings – in other words, leveraging the trend to explicitly include energy efficiency and DERs into manufactured buildings. This seems viable, though a plan for keeping industry engaged (or developing standards) will be needed.
- This reviewer really likes this project's approach. The project integrates energy efficiency into the real-world lifecycle of another industry, to benefit them both. We (the energy industry) need to start looking at efficiency from the perspective of other industries, in order to get higher levels of adoption. This project addresses that directly.
- This project has a great approach, but how will the team get the word out better? It seems this would benefit from collaboration with AIA (architects), NAA and NMHC (apartment owners/operators), and BOMA (building owners/operators).

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- There is limited opportunity for this particular project to contribute to DOE's goal. During the review meeting it was asked how much of the apartment market is expected to be modular. The answer was 10% by 2030. That does not give the scale needed to hit DOE’s 35% by 2025 goal. The more interesting play is the comment in the deck about modular HVAC. If DOE continues with this work, that is where they should concentrate.
- Offsite construction is emerging – it does not constitute a large percentage of buildings currently, but positions DOE at forefront of this design and construction trend. The potential for energy savings is significant in this building sector.
- One observation was that manufactured buildings are likely to be much more energy efficient than site-built. The efficiency barriers describe in the 'project outcome' are a bit of a strawman – the more important metric (and attributable improvement) will be the marginal improvement between standard practice manufactured/modular buildings and the integrated solution this project is intended to develop.
- New construction is a large market segment, although not the largest. The beauty of this project, however, is that it's integrating energy efficiency into another disruptive industry, for the benefit of both. Also, the integration of controls and smart-home equipment is a great value-add to this project. Again, anything that bridges the gap between the energy sector and the rest of the world is beneficial, and smart controls perform this perfectly.
- It seems data driven with good market validation and actionable through building designers and developers.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The progress is appropriate for this stage in this program.
- They have made significant progress in a short time period. They have secured three partnership agreements.
- It seems early in the project, so it's difficult to tell – but the plan for engaging industry and developing strategies to improve the products appears thoughtful, thorough, and viable.
- The progress seems fine.
- It seems to be progressing well.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Bringing together modular manufacturers and NREL is a great approach to this task.
- It has good engagement with factories and owners/developers. They should have more engagement with more factories, as well as contractors, architects, and engineers. This will consider input from a broader range of stakeholders, and can develop a better understanding of the demand and obstacles associated with incorporating more energy efficiency into offsite construction.
- The plan seems to include the right folks, but their success at achieving the high level of engagement anticipated will be the true measure.
- It may behoove the research team to look into the research performed by the Levy Partnership on energy efficiency for manufactured single family homes. It may be worthwhile to include the them in this project.
- It could benefit from partnership with organizations like AIA (architects), NAA and NMHC (apartment owners/operators), and BOMA (for building owners/operators).

E. Remaining Project Work

This project was rated **2.80** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Future project steps were not presented. It can only be assumed that they do not exist.
- The project scope and progress made to date has tremendous opportunity and can exceed project goals.
- It's early in the project, so it's difficult to assess.
- The next steps seem logical. The progression of "Assess", "Develop", and "Evaluate" seems like a good fit for this project. One question: will the flowchart documenting the manufacturing process be applicable to other manufacturers? How similar or the manufacturing processes between different companies?
- The remaining project work is consistent with project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- It’s an interesting idea. They have a good government/industry team.
- The factory commitment partnerships are impressive and critical to the success of this project. Offsite construction is already positioning itself as being more durable and sustainable, so this project asks factories to add rigor to this claim.
- It’s ambitious, but it’s a viable plan. They have a thoughtful approach to engage and facilitate change in the industry. The project is timely in that it's catching the industry, it seems, early enough to positively influence the evolution of what could be a major industry in the future.
- Addressing the multifamily market is a strength in-and-of itself, since that market is growing so quickly. However, addressing it in a way that could be transformative to the construction industry is even better. This project benefits every stakeholder by delivering cheaper, faster, higher quality, more efficient, and smarter multifamily homes.
- It seems well organized and productive. They are leveraging the trend of pre-fabricated, modular housing units. It has a good EEM validation at ESIF and market validation with commercial partners.

2. Project Weaknesses

- It’s unlikely to produce significant energy savings over the next 10 years due to the very limited penetration of the apartment market by modular technology.
- The factory commitment is one year – is that enough time to implement recommendations by project team and test for success?
- There are no weaknesses that are immediately apparent.
- The research team should leverage existing research on manufactured single-family homes done by the Levy Partnership.
- A project weakness is the potential for the lack of market adoption.

3. Recommendations

- This project is not a good use of $4.5 million because it will not advance DOE's EUI goal in any meaningful way. My recommendation would be to cancel the program unless significant savings are possible via modular HVAC systems.
- The project is focused on offsite construction for apartments and hotels. The industry is seeing offsite construction used on many other project types – it should address more building types in this approach. It seems like the findings could apply to different building types. The team should look at Better Buildings program as a format for factories to come together as a peer network to work together on energy improvements.
- No recommendations at this point.
- The team should leverage existing research performed by the Levy Partnership on manufactured single-family homes.
- The team should work with AIA (architects), NAA and NMHC (apartment owners/operators), and BOMA (building owners/operators) on a program to promote recommendations. It could benefit from templates: RFP,

code/standard language, policy/rebate language, and training manuals/university curricula. They should push module manufacturers to get state certifications/approvals for mass production and installations, if they're not already doing that.

Residential Buildings Integration

Building America

Project #1111: Development of Laboratory Test Methods for Low-Cost Indoor Air Quality Sensors

Presenter: Mike Moore, Newport Partners
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most of the reviewers approved of the project team's approach to develop a test method for low cost indoor air quality (IAQ) sensors. They noted that the test methodology is straightforward, will contribute to overcoming barriers, and is squarely aimed at building the technical background needed to evaluate low-cost IAQ sensor performance across all types of platforms. One reviewer highlighted that IAQ sensors need to be tested in a standard way in order to be evaluated for their efficacy, hence this project.

In general, reviewers agreed that the project's impact will be significant, particularly if they are successful in their plan to make it an American Society for Testing and Materials (ASTM) standard. Although there is still more work to accomplish, this project should result in an affordable and reliable way to assess sensors and provide them a target for effectiveness. One reviewer stated that this project is highly likely to make meaningful contributions, but it will need to be combined with results from other projects.

Overall, reviewers agreed that the project is on track to meet the project-specific goals. The team seems to be well on their way to establishing the industry-accepted standard the project seeks to create, but multiple reviewers expressed concerns about the timing being too ambitious and outside the timespan of the project, particularly for publishing the test method standard. One reviewer recommended the project team just focus on the top 4-5 contaminants.

Reviewers unanimously agreed that the project includes good collaboration and coordination with stakeholders. The project team has assembled an impressive team of collaborators and stakeholders whose buy-in will be critical in the ultimate adoption of the proposed test method. Industry partners, government, industry standards organizations, and laboratories are actively engaged in the project's well-rounded collaboration.

Many reviewers expressed concern about the long duration of the ASTM process and the possibility that this process may end up being too far beyond the influence of the project team and stakeholders. Other reviewers praised the team for having a clear goal and plan to make it an ASTM standard, commending their success in establishing the test method and making progress towards the project-specific goals within the timeframe. One reviewer suggested considering how to more consistently generate known concentrations of PM 2.5.

Weighted Average: 3.60   # of Reviewers: 7
Approach: 3.57   Impact: 3.57   Progress: 3.57   Collaboration/Coordination: 3.71   Remaining Work: 3.57

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.57** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach is solid and squarely aimed at building the technical background needed to evaluate low-cost IAQ sensor performance across all types of platforms. Development of an ASTM test standard that doesn't favor one technology over another is essential to developing the market for optimal ventilation controls.

- Test methodology is straightforward and has been met.

- The development of a test method is a fundamental process that is needed to encourage implementation of better IAQ monitoring. The team is consulting with a wide range of partners, which is important in development of consensus standards. The test plan seems to be appropriate.

- This project, while based on small scale testing, will ultimately have wide-scale implications by establishing a standardized, industry-supported test method for a component that is critical to the deployment of affordable IAQ control systems. It is a smart investment of DOE funds.

- Tighter homes need more tightly managed IAQ. Low-cost IAQ sensors enable IAQ management. IAQ sensors need to be tested in a standard way in order to be evaluated for their efficacy, hence this project.

- The approach / methodology in the development of the test methods for low cost indoor air quality sensors is adequate. The test parameters and preliminary testing phases are acceptable for the development of test methods.

- The sensor test method development is sound and will contribute to overcoming barriers. As it was not clear what control algorithm would be used to control the ventilation, the goal sensor precision and reliability is not known.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.57** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- One of the biggest hindrances to optimized, demand-oriented ventilation strategies centers on the reliability of control sensors responsive to the broad range of IAQ pollutants. Without an ASTM test method to be able to measure and compare sensors performance, the market would be left with manufacturers' self-serving claims of reliability and performance. An impartial program to reliably test and ultimately rate sensors is critical to opening the market for optimized ventilation demand control systems.

- They are starting to perform lab testing to demonstrate feasibility and adjust if necessary. They have a clear goal and plan to make it an ASTM standard.

- This project is an enabling one that will help the program meet its intended impact. The lack of good IAQ sensors that could more effectively ventilate homes is certainly an impediment to the implementation of smart ventilation strategies. While this project will not deliver those sensors, it will help in the critical step of assessing these sensors and providing them a target for effectiveness. More importantly, development of test methods is vital for users of these sensors.

- Products that manage a wide range of IAQ issues are becoming increasingly necessary as we continue to venture into making homes more air-tight and less forgiving of the introduction of pollutants generated by normal occupancy. These products must be affordable and reliable. This project helps support those goals.

- See answer number two.

- Although this project is critical to maintain acceptable IAQ through tested sensors, there is still more work to accomplish (maybe these are beyond the scope of this project), namely: (a) sensor drift (it is understood that the PIs are attempting to introduce ageing of sensors inside the chamber) and (b) issues related to on-site sensor calibration.

- This project is highly likely to contribute, but it will need to be combined with results from other projects.

C. Progress

Based on current project efforts, the project was rated **3.57** for the degree to which the project has met ***project-specific goals***.

- Progress toward project specific goals is marching along on target in a coordinated and logical fashion. Timing may be ambitious, but goals are expected to be achieved.

- They are on track.

- The project appears to be reasonably on schedule. They still have over a year to go, and it seems like a lot of effort has gone into developing a draft test plan. They will need to do a fair amount of work in testing according to that plan to ensure that the scheme is correct. It is not clear whether they will need to conduct testing over a wide range of contaminants of interest or whether they will focus on a couple. One recommendation would be to focus on the top 4-5 contaminants.

- The team seems to be well on their way to establishing the industry-accepted standard the project seeks to create.

- The project seems to be on track. However, I imagine getting through the ASTM process and finalizing a standard is probably still a lot more work.

- The project is on track to the set project-specific goals.

- They have made good progress on the test method. There is concern about the progress within the ASTM committee to produce the published test method standard. The timing of this may be outside the timespan of the project.

D. Collaboration and Coordination

This project was rated **3.71** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The project team has assembled an impressive team of collaborators and stakeholders, so much so that the project goals appear to be well-vetted and are expected to face little opposition going forward.

- They have a good team with complimentary skill sets. The right groups are at the table.

- It is good to see that the advisory work group has many of the key players who will need to sign on to an ASTM standard. Home Ventilating Institute as a partner will be good since they should represent much of the user community. Does there need to be more representation from private test laboratories? Those contributors often provide the best input on test method development, particularly by giving a reality check on costs and feasibility.

- The team appears to have a robust and well-represented stakeholder group whose buy-in will be critical in the ultimate adoption of the proposed test method.

- A lot of important stakeholders seem to be engaged in this project.
- The project team is actively working with industry partners, government, industry standards organizations, and laboratories.
- They have excellent, well-rounded collaboration.

E. Remaining Project Work

This project was rated **3.57** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Lab testing of methods and adjustments are well established within the project and testing is proceeding as planned. No serious obstacles appear other than perhaps an underestimation of the time needed to finalize the ASTM test method. This reviewer does not have independent experience with establishment of ASTM test methods. However, the Reviewer is cognizant of other reviewer and audience member comments regarding timing. It certainly is possible to achieve project objectives, but the ASTM process may end up being too far beyond the influence of the project team and stakeholders. Stakeholders could certainly help move things along.
- They are starting to perform lab testing to demonstrate feasibility and adjust if necessary. They have a clear goal and plan to make it an ASTM standard.
- The remaining project work seems logical to achieve an initial test method. The team will need to be involved in the ASTM process for a long duration, as these standards take a fair amount of time to get approved. It sounded like they would hand over the heavy lifting to others, but it will be important to have a champion who will shepherd the proposed test method through the standards process from start to finish.
- The remaining tasks are reasonable within the project's budget constraints and it appears the team will be successful in establishing the test method the project seeks.
- See question number six. They need to figure out how to more consistently generate known concentrations of PM 2.5.
- The project team is on track to achieve the project-specific goals within the timeframe.
- As previously stated, there is concern about the timing of the ASTM consensus process.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include the depth and diversity of the project team and stakeholders, the need from the ventilation community for outcomes of the project to advance the industry, and the project's approach focusing on validating performance of low-cost sensors.
- They have a clear goal and plan. It is good that they are working with HVI to promote the expected end result (ASTM standard and products that can meet said standard).
- This project is one that needs to be done, yet it is unlikely that any individual company would take the lead to develop such a test method that would benefit the entire industry. It is an ideal candidate for funding through a government agency such as DOE.
- The collaboration with key players is important for the standards development process.

- It has a well-defined goal and purpose and the team has done well by not over-reaching in their initial testing aspirations. It is smart to limit the initial testing to a manageable sample of pollutant/sensor types and plan for future investments to support the testing of additional sensor types. They are also working with the right partners and stakeholders from the beginning to ensure critical buy-in and acceptance of the standard being developed.
- This seems to be filling an important need in creating a methodology for testing IAQ sensors.
- 1) The project focuses on a critical need that will help maintain adequate IAQ.
- 2) Stakeholder engagement to develop test methods is crucial for actual implementation/compliance by the industry.
- A project strength is the technical test method development methodology.

2. Project Weaknesses

- This reviewer has general concerns with the long-term performance of IAQ sensors, regardless of test method consensus or approved ASTM testing methods. Accordingly, the power of establishing an ASTM test method to test the reliability of low-cost sensors could be eroded over time if the sensors do not end up living up to the expectations.
- There are none.
- The Reviewer worries that the resulting test method will be overly burdensome and costly. The Reviewer is afraid that a single lab's assessment of a test procedure that it developed is not sufficient to warrant faith by the industry broadly.
- No specific weaknesses were identified.
- One weakness is the repeatability of tests. There are stated issues around creating consistent PM 2.5 concentrations. It is critical that tests can be created in a repeatable manner.
- There aren't significant weaknesses. However, more clarity is required to address the following.
    - 1) How will the sensors be selected from the lot? Will they be selected randomly? This may not be part of the project scope. However, this must be discussed.
    - 2) Once the sensors are certified (for accuracy), what is the validity of this certification?
    - 3) If there is a significant sensor drift, what are the options? What are the on-site calibration approaches?
- It would be nice to have seen a better description of how the sensor data would be used in ventilation control.

3. Recommendations

- Some sense of how long sensors can be expected to last and a requirement that they be accessible for easy replacement by homeowners would be very useful.
- There are none.
- Bring test laboratories into the advisory group if they are not already represented. The Reviewer is admittedly not aware of the backgrounds of all members of that group.
- See if the test method can be simplified.

- Ensure that the ground truth is accurate for all these assessments (e.g., how easy is it to measure the contaminants, even with the most accurate measurement approaches?).
- Just make sure to get the standard across the finish line, even if it is initially limited to one or two sensor types.
- There are clearly other things one should test for IAQ besides PM 2.5 and CO_2 (maybe formaldehyde and other VOCs next). It makes sense to go one pollutant at a time, but there are more to do after you formalize the test for the first pollutants with ASTM. Try to make the methodology extensible, so that it is relatively less effort to add new pollutant tests.
- 1) Discuss the term 'low-cost' (per your project).
- 2) Provide acceptable accuracy ranges for certification and the sensor operative conditions (temperature, RH, etc.).
- 3) Discuss useful life of sensors (end-of-life, in years) and drift characteristics, if you haven't in the report.
- One recommendation is to develop scenarios for ventilation control. Currently, only cooking source control of cooking-produced pollutants is alluded to. But this is not the same as a full home ventilation strategy.

Project #1112: Minimally Invasive Retrofit Insulation of Enclosed Roof Cavities

Presenter: Douglas Lamm, Building Envelope Materials
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

The reviewers were split on their opinions of the project's approach, but three reviewers agreed that the team is working to solve a very challenging problem. These reviewers expressed many concerns and emphasized that there is too much risk involved in decoupling a risky roof insulation strategy from the age and quality of the roofing material and material installation. It is unclear if they were prepared to "push the limit" to see where failure occurred, and what to do if the insulation job failed. There is a great deal more field work needed to prove this concept, and it is unclear on the final foam composition. Two reviewers praised the approach for being well laid out.

Two of the reviewers praised the project's focus on existing buildings and homes, as this is an area of great potential to reduce energy consumption. However, many of the reviewers noted points of concern about the project's impact, particularly the risk this approach represents to the long-term durability of roof assemblies, environmental risks of foam, and uncertainty of market size. In addition, this project is only for cathedral ceilings; they are still working on flat roofs.

All reviewers generally agreed that the project is on-track and showing good progress. The project team has shown itself to be disciplined and creative in solving practical installation issues related to installing closed cell spray foam in existing roof assemblies, exceeding their project-specific goals. However, reviewers voiced their uncertainty about what the end result will look like, if the team considered typical "brownstone" roofs with larger 2-3 foot cavities and how best to treat those, and if the foam is replaced by a new low GWP foam and whether that will affect the process, or how much re-work would be necessary.

Many reviewers praised the project's collaboration with a manufacturer (CertainTeed) and the project's use of a council of contractors. The partners and stakeholders the team has engaged are good choices and should be helpful in crafting an ultimate solution. Two reviewers provided suggestions on improving project collaboration and coordination: a broader reach within the building science community may be warranted to fully vet risks and benefits and it would be good to have more than one contractor involved.

Overall, the reviewers agreed that the project team has logically planned remaining work to meet the project-specific goals. The project is on track and remaining project work is expected to be completed, but reviewers did suggest additional remaining work, such as moisture monitoring and a way to provide this information to more practitioners. Two reviewers pointed out that more field testing is needed to prove this concept.

Weighted Average: 3.17   # of Reviewers: 6
Approach: 3.00   Impact: 3.00   Progress: 3.17   Collaboration/Coordination: 3.50   Remaining Work: 3.33

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The efforts of the project team to translate a wall insulating technology to roof assemblies are applauded. However, there is little margin for error in installing the foam in roof assemblies. The efforts the team takes to mitigate risks and ensure a quality installation are appreciated. But the Reviewer is not convinced that level of scrutiny and quality can be maintained across the board. The problem the project teams hopes to solve in under-insulated assemblies is a challenging one that may not be best addressed by looking only at space between joists in cold climates. For this Reviewer, there is too much risk involved in decoupling a risky roof insulation strategy from the age and quality of the roofing material and material installation.
- The critical questions are spot on. They clearly know what they are doing.
- The demonstration aspect of the project is key to prove that this approach will result in success in meeting its goals. The work to date has been logical, developing the system and the parameters to properly insulate cathedral ceilings, flat roofs, and dormers. The team has also acknowledged the challenges to come. It is unclear if they were prepared to "push the limit" to see where failure occurred, and what to do if the insulation job failed.
- The current research is a starting point and seeks to address a retrofit challenge for which there is currently no easy solution. However, there is a great deal more field work needed to prove this concept.
- It seems like a good balance of novel approach with a proven material and system. The steps are well laid out.
- It would be nice to see more validation by additional contractors to determine broad market feasibility. It is unclear on the final foam composition (low GWP being developed?).

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This reviewer appreciates the focus on insulating roofs of existing buildings as this is likely an area of greatest benefit to reduce energy consumption. However, the risk this approach represents to the long-term durability of roof assemblies, especially old "triple decker roof assemblies" from "Boston to Baltimore" limits the overall impact and reach of this technology.
- This is only for cathedral ceilings; they are still working on flat roofs.
- This has opportunity for huge impact if they can find a low GWP product.
- This project is very important towards improving the energy performance and thermal comfort of existing homes in a cost-effective and relatively low hassle manner. Solutions such as these are needed for the BA program to decrease energy use of existing homes.
- There is a need to find a solution for the building types targeted by this project, and it is worthwhile to explore this application as a potential solution. However, upon completion of this project, there will continue to be many unanswered questions. Additional research will be needed to test the viability of this approach in real world field conditions, to work out the details to ensure moisture is effectively managed, and demonstrate cost-effectiveness as compared to alternatives already in the market (e.g., dense pack cellulose).

- This seems like a potentially promising alternative to other foams. It still has the environmental issue of being foam, however.
- It is unclear about the market size, which is needed to determine the full impact.

C. Progress

Based on current project efforts, the project was rated **3.17** for the degree to which the project has met ***project-specific goals***.

- The project team has shown itself to be disciplined and creative in solving practical installation issues related to installing closed cell spray foam in existing roof assemblies, exceeding their project specific goals.
- The project appears to be on track.
- The team has made good progress in developing the apparatus and testing it on sample constructions and a few in-field applications. It is not entirely clear what the end result will look like. Is it an approach that will be "owned" by CertainTeed, or are there guidelines planned for conducting work like this by any contractor?
- The project seems to be progressing along mostly as planned.
- They are making good progress on goals. However, it is not clear that you've considered typical "brownstone" roofs with larger 2-3 feet cavities and how best to treat those.
- The project appears to be on track. It is unclear if the foam is replaced by a new low GWP foam and whether that will affect the process, or how much re-work would be necessary.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The nature of the project is narrow and focused, and so is the stakeholder group. The narrow focus may limit input on relative risks and benefits and may contribute to group-think. While collaboration and coordination among the project team appears good, a broader reach within the building science community may be warranted to fully vet risks and benefits.
- This is a comprehensive project team, from manufacturer to installer to clients: CertainTeed, Massachusetts Clean Energy Center, and Massachusetts weatherization programs.
- The team has put together a building supplier, a council of contractors, and local jurisdiction. This combination includes manufacturers, users, and implementers of the technology. It should encourage success of the endeavor.
- The partners and stakeholders the team has engaged are good choices and should be helpful in crafting an ultimate solution.
- They seem to have good industry partnerships, especially with CertainTeed. It is particularly good that you have a "contractor council" to help guide your development work. It seems like right now you are the only ones who are doing this. Can you actually get other contractors to try using the rig and methodology to see if the process is transferable and trainable?
- The project has well-rounded collaboration, although it would be good to have more than one contractor involved.

E. Remaining Project Work

This project was rated **3.33** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project team demonstrates a committed attitude and aptitude toward completing remaining project work. Remaining project work is expected to be completed.
- They are solving realistic real-world issues (i.e., dealing with soffit vents). CertainTeed will run the commercialization plan. They need to do moisture monitoring.
- The remaining project work will complete the promised approaches for the remaining construction types. Hopefully, there is some effort planned at the end to provide this information to even more practitioners, not just as a final report.
- The team seems to be well on their way to fulfilling their planned work. However, additional field testing will be required to prove this concept.
- Generally, the remaining work plan seems doable. However, on slide ten, you show a test with average thickness of 3.9 inches, minimum thickness of 2.5 inches, and standard deviation of 0.7 inches. While this is not terrible, it still feels like a high variance in material thickness. Are you planning to do more testing to figure out how to even out the material more?
- The project is on track to meet the project plan.

F. Additional Comments and Recommendations

1. Project Strengths

- Strengths include the focus on improving energy efficiency of existing buildings, the commitment and creativity of the project team, and the efforts to address installation consistency and effectiveness.
- They are solving realistic real-world issues (i.e., dealing with soffit vents), and they have good partnerships, such as the BEM contractor council.
- They are addressing a key issue, insulating under-insulated existing buildings in a manner that should overcome a barrier of too much hassle to insulate cavities.
- Demonstrations are key in assessing any unknown factors. More would always be better, but this project provides a start.
- It seeks to address a real market need with an innovative solution that is minimally invasive.
- It seems like a potentially promising technology instead of a conventional spray foam.
- It is great to see that CertainTeed is developing lower GWP materials. That would help give this technology a further edge over others.
- This project has good deployment and end-user collaboration, as well as good laboratory testing.

2. Project Weaknesses

- The greatest project weakness lies in the assemblies created once the roof assemblies are insulated. Closed-cell spray foam roof assemblies have limited tolerance to moisture intrusion and are highly susceptible to air leakage condensation problems, even through small crack openings. The risks associated with these types of roof assemblies, in this reviewer's opinion, mitigate heavily against broad adoption of this technology.

- This project is still in proof of concept, and it is too early to say it will work in a real-world application. GWP of foam is high, so it must be low-GWP.
- There will be many variabilities in building types, so there is some risk that the suggested approaches may not be broadly applicable.
- There are some concerns with moisture management. The discussion of the foam filling up the soffits brought to mind the question that the soffits are there for a reason, often to provide a pathway for ventilation air on the underside of the roof structure. Will filling that soffit up cause a problem?
- With more people expressing concern of the contaminants released from spray foam, will there be pushback to putting more foam in homes?
- Additional field work is needed to develop protocols for safe and effective installations in a wider range of applications. Additional field monitoring is needed to understand any potential issues with moisture management.
- It is still a foam with high GWP until new materials are created.
- It is potentially difficult to apply (e.g., punctured rafter vent). They need to "idiot-proof" the methodology in order for other contractors to adopt it. The application tube with line markings showing at which points to fill again is a good example of making it easy. Still, it seems like there is a fair amount of field measurements to figure out exactly how much material to use. This only complicates installation.
- The final low-GWP foam is not developed yet. They may need to do significant rework on the new foam.

3. Recommendations

- A protocol addressing the age, quality, and type of roof membrane is part and parcel of a successful roof insulation program that eliminates roof venting in favor of using closed-cell spray foam. In addition, the building science knowledge and skill of the installer and specifier cannot be overstated. Very specific requirements spelling out when, where, and how this insulation system may be successfully installed should be a part of the product literature. Consider a testing program to approve applicators as well.
- Low GWP foams are needed. Work on solutions that minimize contractor application errors. Track moisture content and performance of pilot products.
- Consider a more thorough assessment of moisture management and the impact of this process on the existing management approach.
- If more funding is available, expand the evaluation to more homes to better capture potential drawbacks in the approach.
- On the contractor's website, it says that they have considered other alternatives to polyurethane foam. Perhaps consider this process of infill insulation with more benign insulating materials.
- The project needs more field testing in different framing scenarios and real-world conditions (e.g., lathe and plaster interiors, balloon framing, etc.) for the market segments the project seeks to address. The project needs moisture monitoring.
- Think about how to deal with larger cavity flat roofs (2-3 feet). Also, if there does come to be a low GWP option, maybe this can be useful in other conventional foam applications?
- The project needs more field trials with multiple different contractors.

Project #1113: Integrated HVAC Control Methods for Supplemental High Efficiency Mini-Split Heat Pumps in Existing Homes

Presenter: Eric Martin, University of Central Florida
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Reviewers generally approved of the project approach, an early stage research project to analyze and make the case for supplemental mini-split systems. They have a sound experimental and implementation plan, and the mid-stage progress of the project means the project team likely has time to sort out the necessary aspects/components needed to achieve enough savings to make the proposed system a viable and relevant option. One reviewer suggested that the project team help familiarize people with mini-splits before they completely phase out their central system.

Most of the reviewers agreed that this project addresses the Building America goals of reducing space conditioning energy consumption (by 10%) while improving thermal comfort. This impact is well-quantified, with large market potential, since commercially available multi-system controls are necessary to achieve the wide-scale goals of reduced energy consumption and carbon emissions. However, one reviewer pointed out that the actual impact once the project is complete may be limited to a relatively small subset of homes seeking deep energy retrofits and having a central air conditioning system that isn't ready to be replaced.

Reviewers unanimously agreed that the project is showing good progress and that progress is logical and on-track. The project was applauded for an excellent job of meeting its goals. However, one reviewer expressed unease that the project appears to have a fair amount of work remaining prior to the expected end date of September 2019.

Overall, reviewers praised the project's collaboration and coordination, particularly with Mitsubishi. Reviewers suggested increasing broader engagement as the project nears completion and expanding their direct stakeholder involvement. Another reviewer commented that they need to more actively engage with equipment (heat pump) manufacturers if they are not already.

All reviewers agreed that the remaining project work is logically planned and on-track for completion. One reviewer noted that there is a fair amount of effort remaining in the short time until the project is scheduled to be completed. However, other reviewers praised the project for a sound schedule, plans that are anticipated to produce the desired results, clearly defining the problem and plan, and coordinating buildings with both mini-splits and central systems.

Weighted Average: 3.26 # of Reviewers: 6
Approach: 3.17 Impact: 3.00 Progress: 3.67 Collaboration/Coordination: 3.17 Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes the peer review as an effective program management tool and will leverage the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.17** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach is built upon a sound understanding of central and mini-split systems and the challenges of using central systems for homes facing increasingly lower loads. This reviewer appreciates the stepped approach using mini-splits to supplement central systems that aren't ready to be replaced. Hinging ultimate success on developing a smart thermostat under $300 is also intriguing, if 10% energy savings can be achieved. Early testing on a limited number of homes appears to show that actual savings approach the 10% range, which could limit the reach of the technology. The mid-stage progress of the project means the project team likely has time to sort out the necessary aspects/components needed to achieve sufficient savings to make the proposed system a viable and relevant option.

- They have a good definition of goals. They are using the stop-gap approach to HVAC. Get people comfortable with mini-splits before they completely phase out their central system.

- This project is an early stage research project. The use of thirteen field sites will help transition those results into practice. The approach taken is logical and should lead to good results for a hot and humid climate. It is hoped that a guidance document will be sufficient to promote the use of this type of controller where it is most effective. Key collaborators could help increase the uptake of innovative solutions such as this controller.

- Being early stage research, the basic approach which focuses on gaining a better understanding of how multi-system integrated control strategies impact energy consumption and comfort is a reasonable starting point. However, it is not clear that the premise scenario (put in a ductless mini-split as supplemental space conditioning on the way to a deep energy retrofit) is representative of the most compelling market needs. We have a much more urgent need for commercially available integrated controls to support electrification strategies that leave a consumer with a heat pump intended to offset and ultimately displace an existing fossil fuel system.

- It is clear what the project is trying to do, and it does a good job of analyzing and making the case for the supplemental mini-split as an energy saving device in humid cooling climates. But overall, it is unclear if there will be much demand for this.

- They have a sound experimental and implementation plan.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project is promising in its ability to achieve energy savings. However, the actual impact once the project is complete may be limited to a relatively small subset of homes seeking deep energy retrofits and having a central air conditioning system that isn't ready to be replaced.

- The impact is well quantified.

- This project addresses the BA goals of reducing space conditioning energy consumption while improving thermal comfort. The challenges in distributing heated and cooled air in homes with tight envelopes requires innovative approaches such as the one described here. Incorporation of better control is key to making these systems most effective. It was particularly interesting to hear how the approach of adding a mini-split to supplement a central unit is a good way to transition homeowners to full use of this efficient technology.

- Commercially available multi-system controls are necessary for us to achieve our wide-scale goals to reduce energy consumption and carbon emissions.
- Even if successful, the overall goal of this research would reduce space conditioning energy by 10%. That is not insignificant, but given its likelihood to get adopted at any scale, there is reason to be skeptical. The research does contribute to our overall understanding of potential control strategies for mini-splits and zoned cooling more generally, and this could be incorporated into AC and control strategy design.
- The project addresses existing home energy consumption for large market potential.

C. Progress

Based on current project efforts, the project was rated **3.67** for the degree to which the project has met ***project-specific goals***.

- Project progress is logical, iterative, and managed by a capable team expected to achieve project goals.
- There are three test sites. They achieved significant energy savings from only installing integrated control. The project is right on track.
- They seem to have made good progress to date, but they appear to have a fair amount of work remaining prior to the expected end date of September 2019. The approach is logical.
- It appears that the team is making good progress toward developing a prototype controller and logic strategy. It will be interesting to see how the design and logic evolve as the system is tested in different use cases.
- The project seems to have done an excellent job of meeting its goals.
- They are proceeding on track with good results.

D. Collaboration and Coordination

This project was rated **3.17** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Project collaboration and coordination appear appropriate for this stage of the project. Broader engagement is expected as the project nears completion.
- They have a strong team. Mitsubishi is key.
- The work is early stage research, so it is not expected to have a great deal of collaborators. From a research perspective, the team's solution appears to be focused in the Southeast, so there probably isn't a great need to expand the research team beyond those at FSEC. As the project progresses, it would be good to bring in commercial partners. From the presentation, it sounded like Mitsubishi may be involved. Considering that integration would be needed with both the central system and the mini-split, finding the correct vendor to implement the solution requires a bit of thought.
- The team has engaged some good partners and developed relationships with additional funders to test the concept in different applications, which is great. They need to more actively engage with equipment (heat pump) manufacturers if they are not already.
- The team seems to have a strong partnership with Mitsubishi, a leading manufacturer of mini-split heat pumps. Ultimately, it would be good to consider partnerships with other heat pump manufacturers as well as thermostat vendors to try to make the control strategy embedded in smart devices, rather than relying on people to run the systems properly.

- They could expand their direct stakeholder involvement. Currently, stakeholder involvement appears to be largely through other projects.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining work logically flows from work to date and is expected to be achieved within the project timeline and budget.
- They are clearly defining the problem and plan and coordinating buildings with both mini-splits and central systems.
- The remaining work seems logically planned, but there is a fair amount of effort remaining in the short time until the project is scheduled to be completed.
- It appears that the team is on track to accomplish the project goals.
- The project seems on track to finish all tasks on time and on budget.
- The schedule and plans are sound and look like they will produce the desired results.

F. Additional Comments and Recommendations

1. Project Strengths

- The project's strengths are in the proof of concept to use a mini-split system to supplement and reduce central system air conditioning operation, the price point target for smart thermostats, the focus on system integration rather than solely focusing on system replacement, and the project team's track record.
- They have a clear problem they are attempting to solve. They are using existing on-market thermostats (Nest, Sensibo). They are building off previous data that shows installing mini-splits saves energy, to fine tune an approach for additional savings. It is good that they are working with NYSERDA for heating climates, which has even greater savings potential.
- This is a good project to encourage an innovative approach towards achieving the BA goal of effective air distribution in low energy homes.
- They have a well-thought-out test plan, with the range of test sites being able to give a lot of insight into the operation of the control scheme.
- The idea of using this approach as a bridge to more widespread use of mini-splits when appropriate is good.
- This project seeks to respond to an urgent market need that is not currently being pursued aggressively by the manufacturers.
- This project is not overly ambitious. It has clearly defined a problem and has done a good job of figuring out a practical solution using existing technology. It has been performed on time and on budget and could yield savings if the results are adopted by the marketplace.
- There is some potential traction to the "incremental HVAC retrofit" or "phased deep retrofit" idea. This mini-split is the first in a series of measures to get a building to a much higher level of performance, or in a case where an existing system is getting old, and so this adds in some redundancy.

- They have an excellent research plan and researcher competency.

2. Project Weaknesses

- The project's application appears limited to a relatively small subset of systems.
- It is not clear what the long-term plan is for mini-splits in existing homes, nor how significant the potential is (how many homes will have a mini-split plus central HVAC).
- No major weaknesses were found. Perhaps the team could eventually think about the best way to transition this early stage research into a usable product.
- It just needs to be expanded to cover more use cases and engage more market actors (OEMs) to accelerate deployment of these solutions in markets that are in greatest need.
- It is unclear if homeowners are going to be interested in buying a new AC unit just for the hallway in order to save energy. Generally, people make buying decisions for reasons other than energy savings. This solution seems to be only really about energy savings. When people buy a supplemental mini-split, generally it is because a room is too hot, or they want different rooms at different temperatures. They are trying to solve a comfort problem.
- A future implementation plan and market size would benefit from more detail.

3. Recommendations

- It would be good to see an assessment of the market size and variables that could affect market size positively or negatively. Price point, ease of installation, and resolving the night time comfort issues appear to be key drivers to the ultimate success of the project.
- Clearly define the end-result. What homes would benefit from installing a mini-split and why?
- When reporting, give some focus to RH and moisture removal comparisons to assess the effectiveness of the control scheme.
- It appears that one of the key benefits of such a control scheme will lie in demand response. The wattage decrease is impressive in using the mini-split versus the central system, and some degree of comfort would be maintained. Perhaps utilities would be interested in supporting such solutions.
- Response is the same as noted under the prior question.
- Perhaps there is a comfort problem you are solving with this solution too. If so, focus on that. Otherwise, it could be a nice piece of research that doesn't gain any traction in the market.
- Spend more time with contractors and see if this is a solution they think they can really sell, and how they might go about selling it. You might need to do more than just the minimum needed for energy savings in order to make the solution popular in the market.
- It would be good to see some system cost and payback analysis.

Project #1114: Advanced HVAC Equipment Design Strategies for Optimal Efficiency and Humidity Control

Presenter: Vladimir Kochkin, Home Innovation Research Labs
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Overall, the reviewers agreed the project contributes to overcoming barriers to energy efficiency and moisture control, and that the project's approach is valid. In addition, one reviewer noted that some reported results did not meet ASHRAE standards and another reviewer felt more information about the level of interest of manufacturers and homebuilders, as well as pre-market testing, is needed.

Reviewers stated that the project will contribute to program technical goals, but also emphasized that adoption of the technical advances that result from the project will need to be supported by measures ranging from educating homeowners to utility incentives to standards and codes. One reviewer questioned the value of enhanced dehumidification and noted that the benefits of ventilation extend beyond dehumidification.

The reviewers found the project is progressing well towards its goals, and two reviewers specifically highlighted that the project should produce results that can impact the market. One reviewer felt that work related to control protocols is scheduled too late in the project timeline.

The reviewers all rated the project highly for its collaboration efforts, which range across private sector, industry association, and government entities. Three reviewers agreed the project was on track to meet its goals, but one reviewer felt the modelling work should have been done first. Lastly, one other reviewer felt the project plan does not support project results that will impact the market.

Weighted Average: 3.20   # of Reviewers: 6
Approach: 3.30   Impact: 2.80   Progress: 3.20   Collaboration/Coordination: 3.50   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.30** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach is squarely aimed at addressing potential interior moisture problems in low load homes. The priority on providing ventilation and latent load control is essential to right-sizing HVAC equipment and addressing concerns of HVAC installers and manufacturers, who seem to lack the equipment and knowledge to appropriately size, install, and operate residential HVAC systems for latent load and sensible temperature control.
- The project's approach seems reasonable in the sense that it focuses on changing the rate of ventilation as a function of season.
- The approach is well-planned and logical. Using industry stakeholders and equipment manufacturers to help inform the metrics, control strategies, and test protocols is a smart approach. Maintaining a multi-pronged set of goals (e.g., standardized metrics and equipment labeling in addition to the control strategy itself) helps ensure maximum impact and reach.
- The principal investigator's research plan is reasonable and he recruited industry partners to carry out the work.
- The project approach is very succinct and closely followed: "Develop and validate a coordinated humidity and ventilation control strategy for central ducted systems that improves comfort and energy performance in hot-humid climates."
- The project approach is probably optimum for an early real-world approach. That is, get as close as possible with minimum cost and additional equipment (introduce outside air using a carefully controlled strategy, adding only an outside air duct and efficient ventilation fan). Measure the results by focusing on key variables, such as humidity control, 2-stage ventilation, and similar items.
- However, the project can only meet ASHRAE 62.2-2010 by employing a seasonal time shift. Performance is marginal at some hours (which were not specified) in the summer. However, this is a hard problem.
- Slide 12 is incomplete. It doesn't really represent results under standard conditions (Fed Test, AHRI 210/240), but at some arbitrary point which is then compared with the standard.
- I have lots of questions concerning this project. More information about the level of interest of heating, ventilation, and air conditioning (HVAC) manufacturers and home builders would have been very helpful. Where do they see this product fitting into their offerings? What information would be used to upsell this product's additional cost?
- I am concerned that in order to secure manufacturer warranty, this approach may require much broader field testing before being brought to market. More information about this would be helpful.
- Leveraging existing HVAC subcontractors as a delivery mechanism seems good.
- The main focus of the technical part of the presentation was moisture removal. Is the real benefit in the added ventilation?

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Project impact is targeted to provide the range of tools, equipment, and installation methods needed to facilitate adoption of optimized systems and technologies through normal supply and installation channels, which is key to providing the environment and market for this equipment. Utility incentives and homeowner education may also be needed to facilitate adoption. Impact is rated as "good" because markets are resistant to change and customers will need to be convinced or provided with sufficient incentives to persuade them to adopt this approach.

- Much of the project's impact is dependent on whether the builders will be willing to use the defined metrics for enhanced dehumidification in air conditioner dehumidification mode. The idea of using the central HVAC for dehumidification may need significant time to be accepted in practice. The developed and suggested metrics for standardizing dehumidification mode and control protocols may result in impacts after they have been accepted by the industry and adopted by standards and codes.

- This project seeks to offer a solution to one of Building America's priority research areas (controlling moisture in low load homes in humid climates). The approach focuses on technological solutions that are designed to overcome market barriers, including demystifying what is perceived as a complex and costly HVAC system design. As a result, this project stands a good chance of creating systems and standards that will be highly valued in the marketplace.

- I believe that most manufacturers of residential split systems already know that their systems can be set up to do more dehumidification. This project worked with Goodman to modify a system to do just that. They went from normal 75%-80% sensible heat ratio (SHR) down to 60% SHR by lowering the fan speed by reprogramming the Goodman air handler controller. The project is still a good project, but until manufacturers are forced to comply with some kind of dehumidification mandate, they will not implement a controller to dehumidify. I don't like mandates. I would use some kind of reward scheme to get manufacturers to promote better dehumidification techniques. Manufacturers must get some kind of reward for pushing their equipment to work at these lower evaporator saturation temperatures.

- The project demonstrates a real-world approach that is likely to be the least disliked by conservative builders in the Southeast, who seem to build in a way that results in outside air infiltration. This method uses the least equipment and assigns the least responsibility for control strategy. Is that responsibility to be assigned to the OEM or someone else?

- The valued added by enhanced dehumidification seems low given its modest impacts. Ventilation is discussed in the slides but I am not sure there was that much concerning ventilation in the presentation. Improved ventilation can have an impact much broader than just dehumidification. Is this something that could be installed as part of a retrofit? If so, understanding limitations would be helpful.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The project shows good progress toward meeting project specific goals and excellent promise to deliver optimized equipment and controls to the market.

- The project's progress seems reasonable. The following is reported to have been done: creation of an enhanced dehumidification and ventilation protocol, test house design reviews, and instrument readings in three test homes.

- The project progress to date seems to be going well. With additional time to refine the strategy and conduct additional field tests, the project should produce actionable results within the planned project period.

- The development of a working split system that can do 60% SHR is great. The modelling is lacking. Modelling would show the annual energy penalty due to this extra dehumidification, but it would also show that human comfort increased substantially. The number of hours above 60% relative humidity in the home should be substantially less with a unit that can do 60% SHR.
- Slide 16 showed that discussions with the Air Conditioning, Heating, and Refrigeration Institute (AHRI) and the manufacturers have been a significant part of the last two or three rounds of DOE rulemaking, as to what would be a desirable output for the "yellow label." In the first negotiated rulemaking, which established the regional standards, AHRI committed to further work. It has been difficult to find metrics that would be highly relevant and not impose large testing burdens. There are additional policy issues. If this task was important for this project, these discussions should have begun at or near the beginning of the project, to increase understanding of possibilities.
- "Control protocols for coordination" is a major issue by itself, with major independent (and somewhat competing) protocols being offered by various home automation groups, the consumer electronics trade association, and ASHRAE SPC 205. This issue is way too big to tuck into the end of the project, just for the purpose of learning what's happening. The maximum possible outcome would be the proposal of rating points (temperature, humidity) and what information needs to be shared among the controlling components.
- The project still seems to be in the early stages. The proof of concept installation is done. Initial testing has been completed and early manufacturer approval obtained.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination is excellent. The project has involved an appropriate and comprehensive cross section of private sector, industry association, and government entities.
- The stakeholders have been engaged at a reasonable level in various project stages, including design, installation, commissioning, and reviewing initial results, and will be involved in dissemination of the results.
- Engaging the manufacturers and the standard setting bodies in this project has been and will continue to be a key component to its success.
- The team has done a good job working with their main industry contact. I would have liked to see more industry partners modify their equipment to do the low SHR (high latent) cooling.
- The presentation documents deep and wide collaboration and coordination and successful industry participation.
- The project has assembled a good team. The presentation made it hard to tell how engaged and committed the stakeholders are.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project work logically builds on results to date and is expected to achieve project goals.

- The remaining work is well defined and consists mainly of continuing the work to date, including monitoring the three test homes, adding two more homes for testing, finalizing the standardized metrics for enhanced dehumidification mode and control protocols for coordination of equipment operation, and some outreach.
- The remaining work plan seems solid and should produce meaningful and actionable results.
- The majority of the remaining work is modelling to be done by NREL. I think the modelling should have been done first and the actual field work used to tune the model to give more realistic results for annual energy use and human comfort in different climate zones.
- Bringing this solution to the point where others will bring it to market will take more than what is described in the remaining work. Who is interested enough to make this happen and what research support do they need? For example, is a market potential study being done?

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include the depth and breadth of the project team and the focus on directly addressing humidity and ventilation problems in high performance homes.
- The project is strong in developing metrics for employing enhanced dehumidification mode through air conditioners.
- The project has a well thought out approach to develop the experimental parameters and execute them in a logical set of steps. The project makes good use of stakeholders' resources. The project is focused on bringing direct value to the market by eliminating perceived barriers identified by the stakeholders.
- The team has developed a good representative system that uses low SHR. They are in contact with industry people, and they seem to have further contacts in the HVAC manufacturing industry. For the money spent, this project has been a very good success; I would just have liked to see more manufacturers get on board. I am sure the principal investigators would have liked that as well.
- The team has strong qualifications and are supported by very complete facility.
- The project has an excellent concept, plan, and execution. In particular, making the goal getting the best possible results by controlling technologies already on the market, as opposed to exploring development and application of novel concepts. The project results won't be a panacea but will be a very large step for a very important problem.
- The project has excellent industry stakeholder engagement, with stakeholders providing equipment and technical effort.
- The project has the potential to deliver a cost-effective, year-round ventilation solution without adding significant equipment.

2. Project Weaknesses

- The project's weakness most likely lies in implementation; that is, the extent to which the market can be penetrated, and the likelihood systems will be installed correctly. Both these issues can be addressed with good planning and forethought.
- The project states that one main objective is to focus on hot and humid climates. The presentation did not discuss this aspect enough.

- The project has no weaknesses. The only possible drawback is the reliance on the air handler fan, but the project is meant to optimize the control strategy based on that specific ventilation system type, so it's not really a weakness of the project. I guess it would just be nice to see more projects offering alternative ventilation system designs that also address the humidity issue. That could be a future project.

- The project has not involved manufacturers enough, and modelling work should have been done first or at least in parallel with the system modification and development work.

- The team apparently has less understanding of software (e.g, protocols and equipment communications) than of the traditional HVAC hardware.

- The team seems to have a less sophisticated understanding of metrics for success than I might like. It's not just about performance at one temperature and humidity point indoors and outdoors, but the fraction of the time that the resulting envelope satisfies ASHRAE 55 comfort criteria, or other relevant metrics. People remember a relatively small number of times when they are uncomfortable and forget the vast majority of the time when the equipment is delivering comfort.

- Is there a strong enough value proposition to change what market actors are doing now? Is production of a new control required? Changing equipment operation may also have risks that may not be uncovered in a pilot that only includes three sites. The project does not quantify moisture removal impacts in a way that can be compared to other options.

3. Recommendations

- It would be good to use more test homes and more testing to further validate the project concept and the installation requirements and parameters.

- It seems the project has not disseminated results very much. It would be better to share outcomes as the project progresses.

- The project should use larger set of field test sites and assess system performance under varying household and occupancy conditions.

- This project is almost complete. I think the team did a good job in developing the 60% relative humidity Goodman split system. I would like to see a thorough modelling effort that draws solid conclusions about energy use and human comfort on an annual basis for regions that need the hot-humid dehumidifying systems.

- Disseminate the results in ways that motivate the project participants to offer appropriate solutions to the large hot-humid climate market.

- The project should increase its focus on what would support more investment by stakeholders. It should clarify the value proposition to the end customer as compared to other options. The project should define the added costs for installation. The project should conduct a market potential study to better define market opportunity.

Project #1115: Integrated Zero Energy Ready Retrofit Solution for Multifamily Renovations

Presenter: Martha Campbell, Rocky Mountain Institute
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

The reviewers were divided on the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks, but multiple reviewers agreed that there will be challenges in preparing this technology for the market. The team did a good job realizing that the timeline needed to be extended, but they still have more work to do with further development of project plans and implementation and more demonstrations that build on the lessons learned from the first pilots. Two reviewers expressed concern that these deep energy efficiency retrofits may be cost prohibitive.

Overall, the reviewers were cautiously optimistic about the project's impact, with multiple reviewers questioning the specific segment of the market that this project addresses. The impact is potentially massive, assuming cost is on par or less than conventional over-cladding options, as a revolutionary way to retrofit existing multifamily buildings. The project is ambitious, but one reviewer highlighted that the project may not achieve the stated impact owing to (a) complexities in system integration, sizing, optimal location, and how this integrated system works in conjunction with existing systems (controls) and (b) an integrated system that is/may not be zero-energy.

Multiple reviewers agreed that the project has made progress on specific tasks such as gaining partners and finding gap funding. However, they have not yet fully secured a construction project, the lack of an integrated MEP system is concerning, and there is a challenge of "at what cost" when at such a small scale today. One reviewer determined that, given the progress to date, it is too early to tell the degree to which the project has met project goals.

The reviewers all agreed that the project has a strong team of partnerships, with good collaboration and coordination. The project has well-rounded stakeholder involvement, particularly with the European manufacturers, since they have already figured out how to achieve scale on many of these products. One reviewer suggested improving the coordination to complete the project within the timeframe and within the budget allotted.

Many reviewers approved of the project's remaining work, but multiple reviewers were critical of the timeline and noted the lack of time to monitor adequately to truly gauge the effectiveness of the process. The plan is reasonable, with two pilot projects selected, but remaining project work hinges on successful fulfillment of two RFPs for panelized wall assemblies and a factory zero integrated climate energy module. Reviewers highlighted additional issues such as there is an identified need for gap financing for the initial projects, when manufacturing and installation are not yet at scale, the integrated system may not be zero energy ready, and the project is currently running over-budget.

Weighted Average: 3.01   # of Reviewers: 7
Approach: 3.00   Impact: 3.43   Progress: 2.57   Collaboration/Coordination: 3.29   Remaining Work: 2.57

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- It's too early to tell whether the project approach will contribute to overcoming barriers, technical challenges, and mitigating project risks. Further development of project plans and implementation is necessary to comment more confidently on the approach to date.
- They are thinking big and taking the time to get the market set up. The Reviewer likes the approach.
- The team has spent a fair amount of time lining up collaborators to make the panels and to conduct other aspects of the retrofits. They have identified pilot buildings. The approach involves demonstration of the techniques on these pilot buildings. There are a good number of similar buildings that could be retrofitted if these demos are successful. The team will be able to publish lessons learned from these installations. It would probably require substantially more funding to conduct more demonstrations that build on the lessons learned from these first pilots, and, hence, to get to a point where the approach is more consistent. Use of the Energiesprong idea will hopefully help to leverage lessons learned in Europe to American applications.
- This is a difficult technology/innovation to test in the market and will be similarly difficult to deploy beyond the initial research. For those reasons, it makes sense for DOE to support the initial market testing as it is unlikely to happen on its own, but there is significant risk that this technology will not be scalable in U.S. markets, despite its success in Belgium. The research protocol seems sound, but the procurement of willing partners with suitable project sites and the capital to invest in these projects is a serious challenge. The Reviewer hopes to see them succeed in getting to construction so we can learn from the experience.
- This project is all about the big goal - deep energy efficiency retrofits. The question is can we get there cost-effectively in a way that will scale.
- 1) This integrated zero energy-ready retrofit solution for multi-family renovations may be cost prohibitive / unaffordable.
- 2) This integrated solution may not accomplish the zero-energy goal.
- The team did a good job realizing that the timeline needed to be extended.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.43** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Over-cladding existing buildings with panelized systems represents a novel approach and adaptation of a method of improving existing buildings in Europe. The requirements for over-cladding are highly dependent on the building being over-clad. Assuming project goals will be met, it is expected that some early adopters and owners of projects suitable for panelized over-cladding will take a serious look at this method, assuming cost is on par or less than conventional over-cladding options.
- The impact is potentially massive, if/when the economics work.
- This approach, if successful, would be a revolutionary way to retrofit existing multifamily buildings. There are likely many, many opportunities to save energy and improve the indoor environment in such buildings. Minimizing the hassle and effort required to conduct envelope retrofits is critical in deep retrofits of any building. This approach, if successful, should make great strides towards minimizing those challenges.

- This technology holds promise as a solution for what is currently a fairly specific segment of the market (hence the difficulty in finding appropriate projects for demonstration). There are many very large market challenges that will need to be overcome before we are likely to see significant impact from the deployment of this technology, but that doesn't mean we shouldn't continue to push the envelope. We just need to be realistically cautious about over-projecting the scalability and potential for wide-scale impact.
- The project is ambitious. But if it succeeds in catalyzing kitted high-performance envelope retrofits and high-performance mechanical systems, at a reasonable price, then it could be game-changing.
- The project may not achieve the stated impact owing to (a) complexities in system integration, sizing, optimal location, and how this integrated system works in conjunction with existing systems (controls) and (b) an integrated system that is / may not be zero energy. The use of 'zero energy' may be catchphrase. However, the project team must prove that they achieve zero energy, in this case.
- This project is critical as it addresses the existing home retrofit market.

C. Progress

Based on current project efforts, the project was rated **2.57** for the degree to which the project has met ***project-specific goals***.

- Given the progress to date, it is too early to tell the degree to which the project has met project goals. Further refinement of the systems chosen is necessary to make this determination beyond the "fair" rating.
- They spent a year doing RFP to gain partners and increase impact, adding time to the work plan. They have clear next steps, gap funding, an integrated MEP system, and pilot owner commitments.
- The project seems to be behind schedule and has already asked for a two-year extension. The team has put a lot of effort to date into lining up partners. They appear to have made good progress on the envelope side, though it is not clear whether the collaborators have made significant progress towards panelized retrofits. There is still work to be done in lining up the appropriate vendor to provide mechanical solutions.
- This project ranked as only a two for progress because they have not yet fully secured a construction project. The background work completed to date and the efforts to procure willing partners and identify demo sites is non-trivial, but the big impact won't come until there is an actual construction contract in place and we can learn from the actual design and construction process.
- They seem to have made more progress on the modularized envelope retrofit than on the mechanical system "pod." There is a challenge of "at what cost" when at such a small scale today (even if there is a chance of a much larger scale in the future).
- Among the technical issues, the most critical component is identifying gap funding for actual implementation. Based on the presentation by the project team, there is more work to be done to figure out the gap funding issues. Moreover, in order for this project to have a lasting impact, the project should develop mechanisms for gap funding and stipulate / work with public-private partnerships.
- Progress is good, but the lack of an integrated MEP system is concerning.

D. Collaboration and Coordination

This project was rated **3.29** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination are good. A good cross section of private, public, and governmental stakeholders is engaged, representing cold climate jurisdictions.
- They are a strong team with lots of partners.
- The team has lined up two pilot projects, which is always challenging. The challenge is likely magnified with a multifamily building. They appear to have lined up good collaborations with state and local housing authorities and government agencies. The challenge will be in lining up the key contractors to provide the actual building solutions.
- The project team and partnerships are strong, and the team appears to have done a good job in identifying property owners with two project sites for demonstration, which is no small feat. Additional stakeholder and partner engagement are expected to emerge as the construction projects progress (e.g., local community groups, contractors, building management and residents, etc.) to obtain further learnings from the construction process and occupancy of the buildings post-retrofit.
- They seem to have all the right players on their team. Working with the European manufacturers seems to be especially important (can they modify something for the US market?), since they have already figured out how to achieve scale on many of these products.
- The project team has identified and collaborated with stakeholders (industry, organizations). However, the coordination needs to be improved to complete the project within the timeframe and within the budget allotted.
- The project has extremely complete and well-rounded stakeholder involvement.

E. Remaining Project Work

This project was rated **2.57** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work hinges on successful fulfillment of two RFPs for panelized wall assemblies and a factory zero integrated climate energy module. The RFP process, while creatively engaging the marketplace to develop potential solutions, may ultimately lead to a lack of options when solutions through the RFP process are based on a single technology, or family of technologies. Further development of the project is required to improve this rating.
- They increased their scope, with two pilot projects selected. They are undergoing capital improvements, so there is a realistic delta (not entire cost). This was selected based on common typology, which the Reviewer really likes.
- There is still a good deal of work to do, but the Reviewer is confident that the plan provided by the contractor will lead to successful findings from the research project. There is a bit of concern still with the timeline. Will there be sufficient time to monitor adequately to truly gauge the effectiveness of the process?
- The plan is reasonable, but the project is dependent upon market participation which is not entirely within their control.
- Actually, getting the materials, both envelope but especially for the mechanical systems, is likely to be harder than you think. Also, there is an identified need for gap financing for the initial projects, when manufacturing and installation are not yet at scale. This could also be tough to raise.
- There are two issues discussed previously.

- (a) The integrated system may not be zero energy ready (the project team must prove otherwise).
- (b) The integrated system and installation may be cost prohibitive and too complex for one industry partner to work on (e.g., this system needs coordination of builders and mechanical contractors as a team and the cost may increase significantly).
- (c) The project is currently running over-budget / over-cost and, if not controlled, it may fail.

- The timeline has been extended once, and there is still uncertainty around the critical items (integrated MEP).

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths lie in that it is an adaptation of a proven European model and involves factory-assembled components to limit site lay down area constraints.
- They have partners and stakeholder engagement. They are selecting projects that are similar in specifics to most common MF project types. They have a comprehensive understanding of the challenges, including gap funding and financing mechanisms.
- It could be a game-changing approach to improving energy efficiency of multifamily buildings.
- Selection of pilot sites is challenging, and they have lined up two good ones.
- The project seeks to support the deployment of a technology that offers an attractive solution for a challenging market segment to pursue net-zero goals. The track record of this technology (and availability of proven design and manufacturing processes) in Europe is promising. The partnerships the team has developed are good.
- This project is ambitious. They are trying to solve a big problem.
- The first pilot sites seem to be well chosen to at least get some demonstration projects done.
- Conceptually, the integrated system is a good solution.
- The project has goals of addressing existing home retrofits. They have broad stakeholder involvement.

2. Project Weaknesses

- Bespoke over-cladding solutions are not necessarily bad on their own as they offer building owners a wide variety of options to freshen up the look of their building. Accordingly, insulated metal panel options are design-limiting and may not be welcome in some cities/jurisdictions. Determining how and where windows will be placed in the panelized over-cladding assembly can also be a significant system weakness depending on how it is all put together.
- Have they tackled zoning/code issues (lot coverage percentage, setback distance) due to thicker envelope and, therefore, footprint of the building? $50,000 per unit installed cost of system is not commercially viable (which is not surprising considering it’s a prototype).
- A bit behind schedule, and a solution is still needed for the mechanical systems.
- With this fall in schedule, it is hoped that there will be sufficient time to adequately assess benefits and risks of this technology.

- Uncertainty related to key elements could make or break the project. Getting to construction and finding a viable mechanical system solution are not small tasks. Assuming the planned construction projects proceed and are successful, there is still significant risk that the technology is not really market-ready in the U.S and additional work will be needed to get it there.
- It is hard to "will" a market for these products/practices into existence. There are many barriers here, including the low cost of energy and lack of inexpensive long-term financing for this sort of thing, that make it much harder to make a market for these products/practices than in Europe. You need to bring the cost down in order to get to scale, but you need to get to scale in order to bring the cost down.
- 1) The cost of integrated systems may be unaffordable.
- 2) A potential weakness is cost / budget overrun.
- 3) The project team has a lack of expertise in the mechanical systems' integration.
- It may have been somewhat over ambitious for the required timeline. They are dependent on finding manufacturers ready to collaborate on technology development.

3. Recommendations

- Be careful about placing all eggs in one basket with one manufacturer and one panelized enclosure system. Systems should be selected and tailored based on the building being retrofitted. Don't overlook bespoke options that can be fabricated in a panelized fashion either onsite or in a factory.
- Continue to look at addressing financial challenges and consider adding policy recommendations to deal with a bigger building footprint (especially relevant in cities).
- It is unclear if a thorough monitoring plan existed that will adequately assess technologies. "Monitoring" probably needs to incorporate challenges faced in the factory as well as on-site operations.
- Work to line up collaborators who could implement these solutions if successful.
- When results are evaluated, make sure to compare them to prior deep energy retrofit projects. Particularly, the Winn project in Boston is of significant interest as it offers an opportunity to compare costs, experience, and results to that of Winn's prior DER in the same region.
- The concept is new enough that just getting deep energy retrofits done to prove that we can has value, even without the modularization and scalability.
- If we truly want to get these technologies to exist at scale, we need to create a market for them here. The harder part is to create an environment where a project like this (deep energy retrofit of both envelope and mechanicals) is cost-effective, with some sort of long-term, creative financing instrument (like Energiesprong has). Once there is a demonstrated market, getting companies to make the products should be easy.
- 1) Identify more stakeholders (to sort out technical issues related to integration) and reach out to state / city officials for help.
- 2) Needless to say, reduce cost / budget overrun and re-organize your team and optimize / reduce expenses.
- The adjustments already made in the timeline will improve the project.

Project #1116: Building America Indoor Air Quality (IAQ) Field Study in Occupied New US Homes: Hot Humid and Mixed Humid Climates

Presenter: Eric Martin, University of Central Florida
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Overall, the reviewers agreed that the project has a sound approach and research plan. The project's approach, going out and measuring real homes with extensive instrumentation, is straightforward, on-track, and the best way to see how real homes are performing. The information gathered will significantly add to the building science community's knowledge base of the current state of IAQ and ventilation in newer homes, but one reviewer highlighted that it is unclear that the short-term field monitoring will translate accurately as a proxy for long-term performance of these systems over the course of a year.

In general, the reviewers agreed that the project is critical in helping to understand how homes are performing and ensuring that very tight, energy efficient homes have good IAQ and critical in collecting data to achieve overall program goals. Developing a field-validated moisture balance model that ventilation standards can reference for hot-humid climates is an important step toward enhancing our current standards to make them more relevant for humid climates. The impact is significant, and the project team's effort is commendable, but one reviewer emphasized that the link between project goals and program goals is not direct, but it is no less important.

Reviewers unanimously agreed that project progress is on-track. The team has made good progress and they are likely to achieve project-specific goals. However, one reviewer noted that they still have a good amount of work to do in the locations outside of Florida and hopefully they will be able to find enough homes in other states as well.

Multiple reviewers suggested additional communities that the project team can include outreach to: HERS rater community, Gainesville community (Gainesville, Alachua County is Radon zone 2), and builder community. Reviewers generally agreed that project collaboration and coordination are good, and the team has been coordinating with the right entities. They have additional funding from ASRHAE for lab validation of more homes and researchers are working with other national labs (LBNL, PNNL) to build up the database nationwide on this important topic.

Reviewers agree that, despite the early delay with getting started and working with IBR, remaining project work is on-track and will lead to the desired results, once analyzed. One reviewer commented that remaining project work is expected to truly round out the pool of data gathered to be able to see various trends and to prove the data gathering protocols, and the validated data can then be used to inform future standards and technology development. The project team will achieve the project-specific goals within the time frame.

Weighted Average: 3.45   # of Reviewers: 7
Approach: 3.57   Impact: 3.57   Progress: 3.29   Collaboration/Coordination: 3.29   Remaining Work: 3.43

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.57** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Knowledge is power and so is commissioning apparently. The approach to gather information to address the common tirade against requiring mechanical ventilation is genius - gather data to fill in the knowledge gaps! Though it is a bit facetious, it is important to recognize the power of the information being gathered from a good cross section of single-family residential buildings recently constructed. The information gathered will significantly add to the building science community's knowledge base of the current state of IAQ and ventilation in newer homes.
- This is a simple project, with a straightforward approach.
- This project tackles a key question with low energy buildings and is one piece in trying to capture baseline data that is critically important. The approach taken to date appears to be sound. One question is whether the sample selected is truly representative of the housing stock in the southeast, but the Reviewer understands the limitations that the team has faced in acquiring homes. There will also be challenges going forward in analyzing the data given that it was very difficult to conduct a sound design of experiments given the challenges in acquiring test homes. In collaboration with the PNNL project, this work will add to the missing knowledge of the effectiveness of ventilation.
- Field data to support validated IAQ and moisture models for ventilation standards is something we have needed for a long time. It is good to see this work being supported by DOE. However, it is unclear that the short-term field monitoring will translate accurately as a proxy for long-term performance of these systems over the course of a year.
- This is important research for understanding IAQ in homes. Actually, going out and measuring real homes with extensive instrumentation is the best way to see how real homes are performing.
- The project's approach to program goals is commendable and on track.
- They have a sound research plan and are asking the right questions.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.57** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The link between project goals and program goals is not direct, but it is no less important. Progress towards program goals cannot readily be measured without understanding the state of the art today, or where we are now with respect to system installation, operation, and effectiveness. Granted, assumptions can be made, but there's nothing like solidly produced data based on consensus protocols.
- The impact is significant. We need to demonstrate that air sealing won't negatively impact IAQ, but first, a baseline of IAQ is needed.
- This project addresses one of the key challenges in low energy homes, namely the need for mechanical ventilation. It is great that DOE is putting funds towards capturing this critical data.
- Having a field-validated moisture balance model that ventilation standards can point to for hot-humid climates is an important step toward enhancing our current standards to make them more relevant for humid climates.

- This research is critical for understanding how homes are performing and ensuring that very tight, energy efficient homes have good IAQ.
- The project will achieve the program goals. The study is thorough, and the project team's effort is commendable.
- The study addresses critical questions to achievement of program goals.

C. Progress

Based on current project efforts, the project was rated **3.29** for the degree to which the project has met ***project-specific goals***.

- Progress to date is good and expected to trend to outstanding as more data is gathered and information developed regarding internal moisture generation. The Reviewer is looking forward to next year's update.
- The project is on track to meeting pilot project numbers.
- The team appears to be making solid progress, though they still have a good amount of work to do in the locations outside of Florida. For them, getting homes in Florida should be easier. It is hoped that they will be able to find sufficient homes in the other states as well.
- The team seems to be on track to produce the moisture model intended by the project. It is good to see the additional funding from ASHRAE will allow for expanded field testing to further refine the model.
- The project seems to be on track, at least with the number of homes tested, though there are more issues with the ventilation systems in the homes themselves than anticipated (also a useful finding).
- The project's progress is likely to achieve project-specific goals.
- They have made very good progress.

D. Collaboration and Coordination

This project was rated **3.29** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination are good, drawing upon the expertise of industry organizations, national labs, and similar academic institutions concerned with discovering similar information regarding interior moisture generation and IAQ. Understanding that this is a purely research and data gathering exercise that covers multiple climate zones, it would be nice to see a manufacturer of HVAC equipment participating, just so they can see how poorly their products are installed.
- A large team isn't needed for a field validation study. They have additional funding from ASRHAE for lab validation of more homes. There are no other partners.
- Researchers are working with other national labs (LBNL, PNNL) to build up the database nationwide on this important topic. Collaboration appears to be solid.
- Given the goals of the project, the team has been coordinating with the right entities. The strategic partners and stakeholder engagement employed by the project should ensure the findings are well-positioned to inform future standards revisions.
- They seem to be well coordinated across the whole project, with different groups doing the testing.

- An area of collaboration to consider adding would be feedback to homebuilder and HERS rater community with the deficiencies that you are finding in the ventilation systems in the homes.
- The collaboration efforts with stakeholders are excellent. They may want to reach out to the Gainesville community as well (Gainesville, Alachua County is Radon zone 2).
- It would be nice to do outreach to more code adoption entities and to more of the builder community.

E. Remaining Project Work

This project was rated **3.43** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work is expected to truly round out the pool of data gathered to be able to see various trends and to prove the data gathering protocols. The validated data can then be used to inform future standards and technology development.
- They are not yet analyzing results. The project is solid and on track.
- If the effort continues as it has, the approach will lead to the desired results. There will certainly be challenges in recruiting homes in the other states, and it is hoped that those homes will be able to give broad results that are typical of the housing stock. In other words, the selected houses won't be unique.
- Despite delays in getting started and working with IBR, the progress to date is good and should be continued, including expanded field testing as planned to further develop and refine the model.
- They seem on track to complete the project on time. The challenge is to get enough homes with working ventilation systems.
- The project team will achieve the project-specific goals within the time frame.
- The short delay not-withstanding, the project is on track to completion.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength of the project lies in the commitment to gathering data to fill gaps in our knowledge about how recently constructed buildings are performing operationally and on delivering good IAQ.
- They are adding data to a larger study. They have received additional funding from ASRHAE for lab validation of more homes and they are thinking of contractors/builders as stakeholders.
- They are addressing a critical problem in a thorough manner.
- They have very good collaboration.
- It seeks to address a gap in ventilation standards that has been a problem for this climate zone for a long time. In addition to providing a basis for the moisture balance model as intended by the project scope, the field work has turned up valuable findings illustrating the current state of practice and common failure modes (design, installation, and operation) of ventilation systems in southeast homes. Those findings could support a whole separate paper on their own.
- This is very important work in order to assess IAQ in homes as they are operating, in the way they are currently being built. It seems that best results are being seen with ERVs, which is also an important finding.

- The focus on hot and humid climates' data collection is important.
- Project strengths are the detailed data collection and the project team's expertise in IAQ.
- The project strengths are the research plan and approach.

2. Project Weaknesses

- The main project weakness lies in the leap from taking the data gathered and using it effectively to inform future standards and technology development. Data can be used as a sword or scalpel depending on the hands that wield it.
- The project has selection bias of volunteers. The project includes only Florida homes, but they are working on additional states.
- Will the data be representative, and will the results be broadly applicable given the number of homes and short testing time?
- The short-term monitoring could be limited in its ability to fully capture the performance of these systems and homes. The small sample set could be similarly limiting, but the team is attempting to mitigate that with the added funding from ASHRAE.
- It is hard to work in real buildings in the real world, but the findings are valuable, nonetheless.
- They could potentially include more homes in Radon Zone 2.
- Describe how occupants were surveyed to obtain their perceptions.
- Discuss location of sensors (height from floor, distance from opening, etc.), and sensor calibration.
- Can the project team complete a total of 64 homes by October 2019? This may be an aggressive schedule. At this time, only 18 homes have been completed.
- It would be good to have a more detailed plan which describes the use and implementation of the data.

3. Recommendations

- It would be good to tie the IAQ piece tighter to public health outcomes. This may be difficult given the valid potential Institutional Review Board concerns around what actions may need to be taken when gathering data in homes people live in, but the integration of the two in some fashion would be useful information moving forward, assuming it can be ethically gathered and developed.
- Find a way to handle selection bias and expand to a wider geographic area.
- Continue this effort and build up the data set available to 62.2 members. Identify ways to make sense of the data given the large number of factors at play.
- They should have longer term field monitoring over the course of a full year. Also, measurements indicated elevated levels of pollutants in some cases but did not identify the sources of those pollutants. Hopefully, the final report will address that in more detail to allow us to better understand what the measurements are telling us.
- Perhaps the most actionable near-term results are the fact that so many of the ventilation systems in these new homes are not working properly/as designed. It sounds like the issue is partly education of residents but also often due to poor construction. Work with HERS raters to better understand how to test these systems and

ensure they are working properly. Develop educational materials both for residents and contractors. The best design does not matter if execution is poor. We need to ensure that ventilation systems are working properly if we make tighter buildings that rely on that ventilation system working to maintain IAQ.

- Overall, they have a good approach. The PIs may want to review issues listed in the weaknesses section.
- The project is quite complete. There are no recommended improvements.

Project #1222: Baseline Indoor Air Quality (IAQ) Field Study in Occupied New US Homes

Presenter: Cheryn Metzger, Pacific Northwest National Laboratory
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

The reviewers agreed that the approach is significant in adding to the building science and HVAC communities' knowledge base of the current state of the IAQ and ventilation effectiveness in newer homes. This project has an excellent approach design and will overcome technical challenges related to IAQ. Reviewers praised the team's approach for testing a large number of homes and actually going out and measuring real homes with extensive instrumentation.

Overall, reviewers agreed that this project is critical for understanding how homes are performing and ensuring that very tight, energy efficient homes have good IAQ. The project will likely contribute to program goals, but first, as one reviewer pointed out, a baseline of IAQ is needed. However, one reviewer argued that the link between project goals and program goals is not direct because it seems assumptions are made that systems are generally installed and functioning correctly, but that is clearly not the case, so the assumptions need to be adjusted based on the reality of the data being gathered and other measures need to be implemented to ultimately achieve program goals.

Reviewers generally agreed that the project is on-track. Progress to-date is good and the project is expected to achieve project-specific goals. One reviewer highlighted that there is still a good deal of homes to cover and work will need to be done to determine the best ways to analyze the data and present the results.

In general, reviewers praised the project for being a well-coordinated effort. The project team has excellent collaboration and coordination with stakeholders and a large group of expert partners. Three reviewers suggested additional stakeholders and partners to involve: manufacturers of HVAC equipment, homebuilders, the HERS rater community, more code adoption groups, and the builder industry.

Most of the reviewers agreed that the remaining project work is on track. The project will meet the project-specific goals within the timeframe and the validated data from this project can eventually be used to inform future standards and technology development. One reviewer expressed concerns that the team still has a fair amount of homes on which to capture data and they will need a broad set of data to get meaningful results.

Weighted Average: 3.52 # of Reviewers: 6
Approach: 3.67 Impact: 3.67 Progress: 3.33 Collaboration/Coordination: 3.33 Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.67** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Similar to the FSEC study, knowledge is power, and so is commissioning. The power of the information gathered cannot be overstated and significantly adds to the building science and HVAC communities' knowledge base of the current state of the IAQ and ventilation effectiveness in newer homes.
- The project approach is significant. They will demonstrate that air sealing won't negatively impact IAQ, but first a baseline of IAQ is needed.
- The problem of benchmarking the effectiveness of ventilation is an important one, and the approach taken by this team and the one at FSEC is a good one. By focusing on cold and marine climates, this project will assist in building up the knowledge of IAQ in homes. There is always a concern when trying to select correct homes that the selection is not representative of the housing stock as a whole. It is acknowledged that developing a statistically sound sample is challenging, but the large number of homes will be a good step. It is also hoped that the relatively short duration of tests in each home will yield representative results for the entire year.
- This is important research for understanding IAQ in homes. Actually, going out and measuring real homes with extensive instrumentation is the best way to see how real homes are performing.
- The project's approach is commendable and will overcome technical challenges related to IAQ.
- This project has an excellent approach design.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.67** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The link between project goals and program goals is not direct, but it is no less important. Progress towards program goals cannot readily be measured without understanding the state of the industry today. It seems assumptions are made that systems are generally installed and functioning correctly, but that is clearly not the case. Our assumptions need to be adjusted based on the reality of the data being gathered and other measures need to be implemented to ultimately achieve program goals.
- The impact is significant. They will demonstrate that air sealing won't negatively impact IAQ, but first a baseline of IAQ is needed.
- This project addresses one of the critical questions in energy efficient homes, namely the IAQ performance. Standard 62.2 can greatly benefit from authoritative data on the status of new homes and the impact of mechanical ventilation. It is good to see DOE funding this much needed research.
- This research is critical for understanding how homes are performing and ensuring that very tight, energy efficient homes have good IAQ.
- The project will likely contribute to program goals to an extent.
- This project answers a critical question to overall program goals.

C. Progress

Based on current project efforts, the project was rated **3.33** for the degree to which the project has met ***project-specific goals***.

- Progress to date is good and expected to trend to outstanding as more data is gathered.
- The project is on track.
- The team has made good progress to date, with 14 homes completed in the Boulder area and 8 homes in the Portland area. That still leaves a good deal of homes to get, but the team appears to have made good progress. No specific data was presented, so some work will need to be done to determine the best ways to analyze the data and present the results.
- Despite some initial delays, the project seems to be on track.
- The project is expected to achieve project-specific goals.
- The project is on track.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination are good, drawing upon the expertise of industry organizations, national labs, and similar academic institutions concerned with discovering similar information regarding interior moisture generation, ventilation system installation and effectiveness, and IAQ. Understanding that this is a purely research and data gathering exercise, it would be nice to see a manufacturer of HVAC equipment participating just so they can see how poorly systems are installed.
- They have a large group of expert partners.
- The team has worked closely with other contractors (LBNL, FSEC) to run a coordinated effort. They have enlisted leaders in IAQ and Building Science on their team.
- It seems to be well coordinated across the whole project, with different groups doing the testing.
- An area of collaboration to consider adding would be to provide feedback to the homebuilder and HERS rater community with the deficiencies that you are finding in the ventilation systems in the homes.
- The project team has excellent collaboration and coordination with stakeholders. This is commendable.
- It would be good to involve more code adoption groups and builder industry to help with future implementation of results.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work is expected to truly round out the pool of data gathered to be able to see various trends and to prove the data gathering protocols. The validated data can then be used to inform future standards and technology development.

- They are not yet analyzing results, but they are solid and on track.
- The approach for the remaining work is appropriate. They have a fair amount of homes on which to capture data, and it is hoped that they will truly have a broad set of data to get meaningful results. Data analysis needs to be finalized, probably before all data is collected.
- They seem on track to complete the project on time. The challenge is to get enough homes with working ventilation systems!
- The project will meet the project-specific goals within the timeframe.
- It looks on track to finish on time.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength of the project lies in the commitment to gathering data to fill gaps in our knowledge about how recently constructed buildings are performing operationally and on delivering good IAQ.
- They are adding data to a larger study.
- They are addressing a key gap in the knowledge of energy efficient homes, namely the IAQ and the impact of ventilation on that IAQ.
- They have well-designed tests, and good effort has been taken to date to identify test homes. That's not an easy process.
- They have a strong team and collaboration.
- This is very important work in order to assess IAQ in homes as they are operating, in the way they are currently being built.
- They focus on cold and marine climate zones.
- They understand the potential health risks.
- Their strength is their project approach.

2. Project Weaknesses

- The main project weakness lies in the leap from taking the data gathered and using it effectively to inform future standards and technology development.
- One project weakness is selection bias of volunteers. They are using Thrive as the above code home partner for half the homes (all their homes won’t be representative of new construction).
- It would be good to start analyzing data before getting much further into the data collection to make sure that nothing is missing or should be done differently in the monitoring effort.
- It is unclear whether one week of data collection is sufficient.
- Doing data collection in the real world is hard, and you must deal with the world as it is. It would be good to figure out a way to test those "untestable" supply ventilation systems in Portland. Are there no other ways of testing?

- These are suggestions.
- On slide ten, there are a few "NP" (owing to wildfires / forest fires). Will these be eliminated in the study? One related question is—was location of the home (near school, traffic-prone area, etc.) considered as a factor?
- Are the protocols for measurements shared between PNNL and FSEC?
- Are the reports shared between the organizations for consistency?
- There is a lack of plan to affect the building industry beyond incorporation in 62.2. What about using this to increase adoption of 62.2?

3. Recommendations

- It would be good to tie the IAQ piece tighter to public health outcomes.
- There are none. Keep up the good work
- Consider longer tests in a couple homes if feasible.
- Find ways to focus in on the key factors that impact IAQ in a statistically defensible way.
- Perhaps the most actionable near-term results are the fact that so many of the ventilation systems in these new homes are not working properly/as designed. It sounds like the issue is partly education of residents but also often due to poor construction. Work with HERS raters to better understand how to test these systems and ensure they are working properly. Develop educational materials both for residents and contractors. The best design does not matter if execution is poor. We need to ensure that ventilation systems are working properly if we make tighter buildings that rely on that ventilation system working to maintain IAQ.
- The recommendations are listed in the previous section. Overall, this is a good project. Kudos to the team.
- There are no improvements to offer.

Project #11119: Healthy Efficient Homes Research & Standards Support

Presenter: Ian Walker, Lawrence Berkeley National Laboratory
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Reviewers were overall very supportive of this project's approach to overcoming barriers, technical challenges, and mitigating project risks. Two reviewers lauded the long-term, ongoing approach taken by this project team and the supplemental role this team plays in supporting other Building America teams. Most reviewers believed this project serves key functions in both the collection and dissemination of information on indoor air quality (IAQ) in homes and the development of standards for the IAQ industry. One reviewer also commended the team for taking on a leadership role in establishment IAQ codes and standards. Most reviewers also agreed that this project has been impactful in its contribution to meeting program goals, with two reviewers highlighting the project team's role in developing low-cost sensors for IAQ measurement. However, one reviewer was keen on understanding what approaches the team uses to achieve such a low cost of implementation.

Regarding progress on project-specific goals, reviewers were impressed with the work done to date. Two reviewers specifically called out the studies completed on developing smart ventilation systems. However, one reviewer expressed concern that the remaining FY19 workload would not allow appropriate evaluation time for the smart ventilation algorithms being developed. Overall, the sentiment was strong among reviewers that the project had made significant progress, with the theme of IAQ standards development cropping up again, specifically as it relates to RESNET 380 and the ASHRAE IAQ section.

There was near unanimous agreement among reviewers that the project team has been extremely effective at achieving strategic collaboration and coordination with relevant stakeholders. Reviewers commended the team for working with industry partners, and two reviewers specifically called out the collaboration as "exemplary". Most reviewers also believed that that remaining work for this project team was reasonable. However, one reviewer was again concerned that the current timeline did not leave enough time for evaluation.

Weighted Average: 3.80   # of Reviewers: 7
Approach: 4.00   Impact: 3.60   Progress: 3.60   Collaboration/Coordination: 4.00   Remaining Work: 3.60

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will leverage the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **4.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Given the paucity of information on indoor air quality (IAQ) in homes, this project's combined and comprehensive approach to develop information in field and lab studies, test system performance, develop test methods, and compare results is unprecedented. Development of information on IAQ in homes is critical to efforts to make buildings more airtight and energy efficient. Because it takes energy to have good IAQ, development of information about indoor IAQ and the tools and systems to optimize ventilation to limit wasting energy, i.e., to limit over-ventilating, this project's scale and approach, coupled with concurrently funded projects, has the most potential to change the course of the ventilation and IAQ field since the advent of ASHRAE Standard 62.2.

- The project aims to produce technologies, guidelines, and standards to reduce IAQ-related energy use and costs (it should not cost too much to have good IAQ). It also seeks to help industry by producing innovative technologies for homes that achieve 40% energy savings in existing homes and 60% in new construction. The approach is based on smart ventilation systems that control IAQ fans and filters to achieve the goal of lower energy consumption. Field testing is done to gauge the performance of the technologies. The approach seems reasonable and provides opportunities to revise the control parameters if performance is not on target.

- This is not so much a specific project, but a necessary on-going support function to supplement the work of the Building America teams and fill in gaps.

- The approach of working with IAQ standards and standards organizations is very effective. The involvement of stakeholders is important, and the investigators seem to be involving the stakeholders to the point that they feel like a part of the team working to solve the problem.

- An exemplary program in the DOE portfolio. Targets the barriers and challenges well. The project is very diverse, with different risks to different sub-projects. Overall, I consider it very robust.

- The project's approach is solid in (a) developing new tools and algorithms for healthy homes, and (b) knowledge dissemination.

- The approach here is less direct than the other projects. This is good. A national lab has the national standing and funding continuity to take a longer-term approach that focuses less on specific technologies. Investments in improving measurement quality and standards development create increased accountability in the IAQ industry. This is a very appropriate role for the lab and DOE. These investments create stronger private sector opportunities for solutions that meet standards and are measurably more effective. Strong and cost-effective IAQ solutions are key to continued reduction of energy use in residential buildings.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.60** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- To say that it would be nearly impossible to achieve program goals without the successful completion of this project is not saying too much. Optimized, demand-based ventilation strategies are essential to achieving net zero energy homes that also exhibit good indoor IAQ; one cannot happen without the other.

- The project has had good impacts in the following areas: a) contributing to industry consensus standards, publications and workshops, b) helping several HVAC industries to develop new products, c) contributing to development of low-cost sensors for IAQ measurement, d) contributing to BA new home IAQ data generation as well as creating a labeling system for ventilation for homeowners, and e) testing range hood and kitchen ventilation.

- Lab support of BA projects helps ensure experimental designs are sound and leverages DOE's prior investments in lab facilities, modeling tools, and testing protocols. One of the most impactful roles of LBNL's work is carrying the results of BA research across the finish line by actively taking on a leadership role in the committees that establish codes and standards.
- This project has been working on cheaper and better sensors for IAQ and energy monitoring. This will directly benefit and impact the programs goals of lowering energy use. This is an extremely important part of the push to lower energy use; we must have better and cheaper sensors.
- The project advances the state of the art in understanding a real problem (ventilation).
- It is not clear that the non-government health community is engaged enough to feel some ownership.
- The project will probably contribute to BTO’s goals, but the distribution of over-ventilated versus under-ventilated existing housing units is not yet clear enough to me to know if society will aim for more or less net ventilation. Health should be considered first, and this requires much more field research into which housing types and occupancies are associated with specific ventilation issues and which health effects are caused by those issues.
- The project's innovative technologies, including using big data (obtained from sensors from homes in California, for example) are commendable. However, the principal investigators need to discuss how their work reduces the cost of implementing energy-saving IAQ strategies. In other words, what approaches does the project use to lower the cost of implementation? Additional information would be helpful for reviewers. Low cost of implementation is one of the outcome measures of this project.
- While hard to measure directly, the impacts seem high and the project focus correct. This is because of the leverage created when focusing on improving measurement and standards development.

C. Progress

Based on current project efforts, the project was rated **3.60** for the degree to which the project has met ***project-specific goals*.**

- Progress towards achieving project targets is impressive. Despite industry resistance, the project team's approach to lean in to fill in the data gaps and develop tools the whole industry can use based on sound scientific principles and data will be key to further improvements in the ventilation and IAQ space. While it is tempting to claim to be near the finish line, the progress and completion of this project sets up future studies for further characterization and refinement of the data gathered, as well as development of tools and equipment designed to respond to local IAQ conditions in logical, meaningful, and impactful ways.
- The project has made good progress in the following areas: revising RESNET 380; adding multifamily building requirements to the ASHRAE IAQ section; adding range hood test method to HVI testing procedure (can significantly reduce kitchen ventilation energy required); low-cost IAQ sensors and monitoring devices; measurement of formaldehyde; temperature controls sensitive to seasonal shifts; and creating a measuring stick for acceptability of home IAQ when ventilation causes particulates and contaminants to enter the home.
- The work supporting the development of smart ventilation systems, low cost sensors and control strategies, range hood standards, and better understanding of the effectiveness of our current ventilation requirements is promising. We need a better understanding of how ventilation systems really work in homes (i.e., are they effective?), as well as affordable solutions that are easier to install as we continue to adopt codes and programs supporting tighter building envelopes.

- The studies performed on smart ventilation equipment and contaminants in residential buildings are very useful and needed. The measurements of actual IAQ will help industry develop better IAQ products; therefore, this project has succeeded already.
- The remaining FY19 project workload feels high, but reviewers do not have complete information. The project might meet the goal of "developing" (additional?) smart ventilation algorithms, but it is hard to see how these can be evaluated in the time remaining (re: slide 17).
- Excellent progress! Kudos to the team. Please discuss how lower implementation cost is achieved.
- Progress seems strong in both research and dissemination. Support for the FOA grantees was not called out.

D. Collaboration and Coordination

This project was rated **4.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- A project of this scale and importance would be difficult to imagine without the collaboration and coordination of academic and industry partners. The project team and effort is exemplary.
- There is an impressive list (over 30) of companies and organizations that are engaged in the study.
- The work the lab is doing to gain consensus among key industry stakeholders is vital to gain buy-in for standards and test methods, as well as building awareness of the issues so manufacturers and other industry players can work on addressing them.
- This project has been very successful at recruiting industry partners. I think the main reason is that the project seeks to answer fundamental questions by doing field measurements that are really difficult for industry, but easy for government-funded (neutral) third parties. Industry wants to participate when they see value in the measurements, as it pertains to their being able to create new products that can differentiate them in the marketplace.
- There is great emphasis on working with others and with industry on new products and new strategies.
- This project is definitely a massive undertaking! The project team has done an excellent, outstanding job in collaboration and coordination. This is truly a lead-by-example project.
- As noted, the connection to industry and the impact on industry is high.

E. Remaining Project Work

This project was rated **3.60** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- The remaining project goals logically follow from the work that has been completed to date. Furthermore, the remaining project work seeks to bring the results of the project to date into the realm of standards, tools, and test methods.
- The projected project work consists of developing ventilation algorithms for multi-zone and multifamily buildings; continue work on range hood efficiency and IAQ study for BA teams; integration of grid expansion of smart ventilation system to other than residential buildings; and low-cost IAQ and energy retrofits for low-income housing.
- The planned tasks for completion in 2019-20 are reasonable goals.

- The future work is more of the same good work already done. I would like to see more focus on the cheaper and better sensors., Otherwise, the project future work is logical and an efficient use of time.
- The FY19 project workload feels high. The project might meet goal of “developing” (additional?) smart ventilation algorithms, but it is hard to see how the evaluation can take place in the remaining time (re: slide 17).
- The project team’s schedule indicates it will complete the remaining work within the project timeline.
- The remaining workload seems reasonable.

F. Additional Comments and Recommendations

1. Project Strengths

- The project’s strengths flow primarily from the data collection necessary to make informed decisions about ventilation rather than guessing as the industry has done for so many years. Other strengths include the wide engagement with the industry, and the broad reach to spread the word about the project's progress and achievements.
- The project’s strengths are developing standards and codes for IAQ measurement and acceptability, as well as low cost sensors.
- The project’s strengths are the technical expertise of the lab staff, the use of lab-based resources in a variety of applications, and the heavy emphasis on industry engagement.
- The personalities of the lead principal investigator and his team shape the dynamics of their interactions with their industry contacts. The results show that strong relationships have been developed and this fact cannot be underrated. Good work.
- The project has an excellent team that has deep institutional knowledge and broad connections within the research community and an outstanding facility.
- The large research program provides opportunities for synergies among participants.
- The team has a long history of collaboration with and contributions to ASHRAE ventilation work. This is a significant force multiplier for DOE, as it enables wide dissemination of information. The project also is directly supporting key standards work (62.2).
- The project strengths are: 1) stakeholder collaboration (industry, state governments, laboratories, universities); 2) the use of data science and big data analysis to extend results beyond field and lab conditions (however, please discuss issues related to prediction accuracies in the report); and
  3) the development of test methods.
- IAQ is a tough area for research and validation. An investment by DOE in this area creates a high amount of leverage in this industry, moving the industry towards more effective solutions for real problems.

2. Project Weaknesses

- None that readily come to mind. Perhaps the breadth of the project's goals, but ultimately the project appears to have broken all pieces down into achievable chunks that build on each other and the work of other Building America and industry teams.
- None stand out.

- The work has mostly focused on ventilation-related issues and supporting better IAQ control in homes. That is all good, but under the umbrella of "healthy efficient homes" there are issues beyond ventilation that should also be explored. Pollutant source control (or elimination) strategies, better appliance designs (say, vented smart ovens), construction methods to reduce pollutants entering the home (such as radon), efficient air filtering and purification when outdoor air is bad, and similar issues are all examples of projects that might fall under this general topic. I'm sure there are many others. Just throwing some ideas out there. Not really weaknesses.

- If this project has any real weakness, it may be that the investigators are trying to do too much and not focusing more on important areas. This is an opinion and is not obvious in view of the success they have had and the industry involvement they have solicited. I would like to see more universities involved with them, especially if they could involve universities in taking more field measurements and developing cheaper and better sensors.

- The project shows little recognition that the human sensory system is very good, but sometimes not sensitive to airborne insults that can affect health at levels that are not detected by the nose (e.g., formaldehyde in some populations). One might think that slide 11 illustrates an important point: "Big % errors at low concentrations." This will be a huge issue for those pollutants that exhibit short-term exposure threats to sensitive populations (times of exposures of less than 8 hours, or less than 1 hour). It may be very challenging to develop more sensitive, low-cost, sensors for those pollutants.

- When considering "seasonal shifting" of ventilation for energy savings, it is critical to differentiate between pollutants for which short-term exposures are key (e.g., formaldehyde, some criteria pollutants) versus those for which very long-term cumulative exposure is the issue (e.g., radon). Seasonal shifting is appropriate for the latter, although in the case of radon probably not preferable to source control by sub-slab ventilation. Seasonal shifting can't be appropriate for challenges associated with short exposures, such as formaldehyde. Without a deep understanding of lung clearing mechanisms as a function of particle concentration, seasonal shifting would not be appropriate for PM2.5.

- Make the smart ventilation algorithms public for university researchers and others so that they can use them in applications and test and validate them.

- Defining concrete deliverables for this type of project is difficult. Many of the best outcomes are byproducts of the process of creating the deliverables and not the deliverables themselves.

3. Recommendations

- Keep leaning in to answer the unanswered questions and fill in the data gaps.

- The team and the work presented is very high quality. Keep up the good work. Explain more clearly how the project assists manufacturers in developing new products. Is the project licensing or does the project provide manufacturers with technical knowledge so that they can develop new technologies?

- Get more university participation in any area that involves IAQ, cheaper/better sensors, field measurements, ventilation, and grid interactions.

- Strengthen further work with industry (e.g., Broan, Aereco), as well as interaction with trade associations (e.g., HVI). The current work is best characterized as a predominantly upstream research project.

- 1) Most of the field study is focused in California. With the increase in traffic-related air pollution in cities across the U.S. (e.g., Jacksonville, Florida), field tests in other cities may be helpful and will extend the work considerably. 2) This comment is general. I noticed there were inconsistencies in the contaminants measured by the other project teams, although all of you focused on IAQ. Maybe, you (Iain and Brett) can mandate the minimum contaminants that needs to be analyzed and studied so there is some consistency in measurements.

- Is there a better way to define deliverables such that the broader impacts are enhanced while maintaining accountability in performance?

Project #12204: Energy Savings with Acceptable Indoor Air Quality Through Improved Air Flow Control

Presenter: Jason LaFleur, Gas Technology Institute
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most of the reviewers approved of the project approach and stated that it establishes a good initial step at addressing the relationship between IAQ, air flows, and the air sealing/weatherization program and the project's approach is likely to achieve program goals through validation of acceptable airflow rates/quantity/quality. However, one reviewer highlighted that this is too small of a sample size, over too long of a time period. Another reviewer suggested putting some thought into ways to tease out the difference, if any, between the control homes and the treatment homes.

In general, reviewers agreed that if successful, this project will shed light on the most cost-effective way to save energy in most homes: air-sealing. The goal is to show that homes with deeper levels of air sealing and ventilation can be just as healthy, if not healthier, than homes with less air sealing and air sealing with good IAQ is critical to program goals. However, two reviewers disagreed and noted that the sample size is so small that it's hard to see how results could be extrapolated to the larger community and the impact on program goals remains to be firmly established.

Many reviewers agreed that project progress appears to have been somewhat hampered by the unexpected difficulty of finding target homes. Reviewers expressed disappointment that the team has only managed to cover fifteen homes in three years. Although it was noted that they appear to have a good deal of data analysis remaining in the short time left in the project, two reviewers stated that the project is on-track for completion to deliver expected results.

The reviewers were split on the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders. Some reviewers praised that the project has excellent stakeholder engagement and collaboration with a variety of industry associations and academic and home performance contracting partners. Other reviewers expressed uncertainty regarding how they are relying on a larger stakeholder community and how results of the research will be disseminated.

Once again, the reviewers were divided on their opinions regarding the remaining planned work to meet the project-specific goals. Some reviewers expressed that the project will meet the project-specific goals and remaining work logically includes a significant amount of data analysis and promulgation of the results. However, other reviewers expressed concern about recruiting and testing out another 17 homes by September 2019. One reviewer suggested an extension to complete the planned number of field evaluations.

Weighted Average: 2.94 # of Reviewers: 6
Approach: 3.00 Impact: 3.33 Progress: 2.67 Collaboration/Coordination: 3.00 Remaining Work: 2.50

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.00** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach establishes a good initial step at addressing the relationship between IAQ, air flows, and the air sealing/weatherization program. If a customer is going to make the investment in weatherization, it's only a small step to look at air flows and IAQ from the homeowner perspective but a bigger step from the perspective of the weatherization contractor in terms of training and implementation.
- This is too small of a sample size, over too long of a time period.
- They are struggling with finding projects (who are going through an HP retrofit). How will they get the final homes? What are they going to do differently?
- The team is taking a good approach to assessing the impact of good air sealing in homes. This problem is an important one to explore. The use of an equal number of control homes and test homes is very good. A technical challenge that still needs to be addressed is the analysis of the data, as the team has grouped all results together for the review presentation. They will need to put some thought into ways to tease out the difference, if any, between the control homes and the treatment homes.
- The concept is good, and the attempted rigor to control variables by selecting only homes that met certain standardized criteria is appreciated.
- The project's approach is likely to achieve program goals through validation of acceptable airflow rates / quantity / quality.
- The project has a sound technical approach.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The project specific goals seem too focused on a specific single-family building type, which is understandable to establish comparable data points, but it seems simple before and after testing between control houses and houses with airflow improvements could work just as well. The impact on program goals remains to be firmly established, but it is certainly leaning in the direction of supporting program goals. This reviewer feels that further monitoring and data gathering should continue to trend in the direction of more clearly defined levels of progress towards meeting program goals and providing valuable information to the industry.
- The sample size is so small that it's hard to see how results could be extrapolated to the larger community.
- If successful, this project will shed light on the most cost-effective way to save energy in most homes, air-sealing. One concern is always that you may end up doing more damage to the home and its occupants if done incorrectly, so this work will hopefully bring light to those challenges and help in developing best practices.
- The goal is to show that homes with deeper levels of air sealing and ventilation can be just as healthy, if not healthier, than homes with less air sealing. This would eliminate some of the concerns about making homes "too tight" and achieving greater levels of energy performance.
- The project will influence retrofit IAQ guidelines.
- Air sealing with good IAQ is critical to program goals. It also deals with existing building retrofits.

C. Progress

Based on current project efforts, the project was rated **2.67** for the degree to which the project has met ***project-specific goals***.

- Project progress appears to have been somewhat hampered by the unexpected difficulty of finding target homes. Adjustments are being made and progress is expected to accelerate.
- They aren't able to locate enough projects.
- The team appears to have identified and started testing in 40 homes, which is no small feat. They appear to have a good deal of data analysis remaining in the short time left in the project. In particular, as noted earlier, finding ways to tease out the differences between the control homes and the treatment homes with some degree of statistical significance remains to be completed.
- Preliminary results are encouraging. But it is disappointing that they have only managed to do fifteen homes in three years. There must be more homes in Illinois that would fit the criteria, and if not, there are other homes around the country that would have been good candidates. Recruitment may be harder than you anticipated, but it shouldn't have been that hard to get 40 homes.
- At this time, the project is on track for completion by 09/2019.
- The approach seems to be delivering expected results.

D. Collaboration and Coordination

This project was rated **3.00** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination are good amongst a variety of industry associations and academic and home performance contracting partners. Close collaboration and coordination with retrofit contractors are key to the ultimate success of the project to achieve buy in and implementation effectiveness and efficiencies.
- It is unclear how they are relying on a larger stakeholder community.
- The team includes some world experts on indoor air quality and building sciences. It is not clear that there is a good avenue to disseminate the results of the research, e.g., through BPI or other organizations that could include the work into best practices.
- The team is good and brings together a good set of partners.
- However, if you were better at collaborating/coordinating with incentive programs, contractors, and others, you would have been able to recruit the number of homes you needed by now.
- The project has excellent stakeholder engagement and collaboration.
- The project has excellent and well-rounded stakeholder involvement.

E. Remaining Project Work

This project was rated **2.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work is logical and expected to add a significant amount of data to the early data sets gathered thus far. Additional data and homes monitored will begin to paint a clearer and more comprehensive picture of the efficacy of the air flow improvements, IAQ impact, and energy savings potential achieved. Ultimately, this project coupled with the smart thermostat project would be a powerful tool for targeting marketing efforts and incentives and retrofit measures.

- How will they get the final homes? What are they going to do differently?
- The team appears to have managed the hard part, identifying and instrumenting the 40 homes. There is still some thought needed regarding data analysis and promulgation of the results.
- Given the (lack of) success recruiting candidate homes to date, it seems like a stretch to recruit and test out another 17 homes by September 2019. It is certainly not impossible, but you will have to do things differently to get there.
- The project will meet the project-specific goals.
- They may need an extension to complete the planned number of field evaluations.

F. Additional Comments and Recommendations

1. Project Strengths

- The project strength is that it builds on a weatherization and retrofit infrastructure that already exists and it is a logical and minimally invasive extension of that work.
- Pre-post retrofit testing is a good idea.
- The project is addressing an important problem that could lead to solutions to save large amounts of energy with lower risk to occupants and the structure.
- The project is a well-designed field study, and the team has managed to line up a large number of homes despite many constraints.
- Proving that weatherization and deeper energy efficiency methods don't hurt (and can help!) IAQ is definitely important. This project has the ability to contribute to this.
- One project strength is the elaborate study (40 homes) and elaborate data collection.
- Another strength is the critical topic – IAQ versus energy efficiency.
- The project strengths are the experimental approach and the stakeholder involvement.

2. Project Weaknesses

- The project weakness lies in the change required to retrofit contractor's processes. A clear correlation will need to be established to direct more utility incentive dollars and to entice retrofit contractors, all of them, to change the way they do business to add on air flow improvements, which may be in a realm beyond some of their capabilities.
- The requirements for participation are too specific and it is unlikely they will find enough projects.
- Improved approaches to analyzing the data may be needed to isolate factors of importance.
- Poor recruitment equals a small sample size which equals less statistically significant results (the and original proposal of twenty and twenty was already not a large sample).

- If recruiting really is as hard as it has been, perhaps what was thought to be a "typical" home isn't really typical. Maybe they have too many finished basements? What are the reasons why recruitment has been so tough? It could mean that for greater impact, the researchers should be looking for a different type of proto-typical home.
- The project needed tighter protocols so for example, loggers didn't get thrown out with old HVAC equipment.
- 1) The control study (40 homes) is commendable. However, the inclusion/exclusion criteria selection of homes should be identified such that they represent homes in various locations (e.g., close or not close to traffic-prone roads, etc.).
- 2) The plot over time shows outliers. These can be removed if the reason is known, such as New Year's Eve, game day, etc. This would improve results.
- 3) The project focuses on ASHRAE climate zone 5 only!
- 4) On slide twelve, CO_2 data shoots above 1,100 at certain times. It is an anomaly. Was there a party inside the house or is it a sensor drift/issue?
- 5) Is there outdoor air quality monitoring conducted at all? This outdoor air quality can be related to IAQ and airflow ventilation, etc.
- They may not have understood the difficulties / time involved in homeowner recruitment.

3. Recommendations

- Be sure to stay tuned in to retrofit contractor and homeowner feedback and make adjustments accordingly while maintaining the overall goal of improving IAQ and reducing energy use. Any barriers to implementation should be carefully considered and addressed in the program design moving forward.
- Consider re-evaluation test procedures, so they can close out the project.
- Identify ways to disseminate the research results in the best possible manner.
- Think about limitations, if any, of the results given the small geographical footprint of the test houses and convey those limitations in the report.
- They need to show scatter plots of performance, so there is a range of performance and error bars on the results.
- Gather qualitative data (surveys) about comfort, smells, pests, etc. Did the retrofits with ventilation make the homes better/more comfortable? That could be a bigger selling point than just energy savings.
- Overall, this is a good project. Refer to the weaknesses section for recommendations.
- The project would benefit from a more detailed listing/analysis of confounding variables.

Project #11150a: Structural Support of Windows in Walls with Continuous Insulation

Presenter: Vladimir Kochkin, Home Innovation Research Labs
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

In general, reviewers agreed that the project approach is targeted, acceptable, and focused, with one reviewer praising the project for its excellent (consensus) experimental design. The project is well-designed to ensure research results translate into market-based practices and the approach to stakeholder engagement is a key element to the project's success and it appears to have been well-executed. However, one reviewer expressed concerns that it seems that continuous insulation (CI) will require custom details at the window interaction because of the many varieties of window-wall interfaces and it is not clear whether the detail at such interface has been the cause of lower than desirable levels of the use of CI.

Most of the reviewers agreed that the project will contribute to program goals, with an immediate and solid impact, because this project is targeted directly at solving a problem that could hinder the wide-scale deployment of high-R walls if left unresolved. The consensus process and excellent experimental design are likely to lead to a test procedure adequate for code adoption, which is demonstrably required for market acceptance and expansion. However, two reviewers disagreed on the extent of the project impact, stating that leaving out the air barrier connection in the testing protocol is a critical mistake that doesn't further DOE BTO program goals and because the result of the work will be mainly test data from tests for selected window-wall interface details, the impact will be very limited.

Overall, reviewers agreed that the project is progressing as expected and they have done good work on this complicated problem. The project is on track and the team has made strong progress working with multiple stakeholders to identify concerns and test accordingly to address those concerns. One reviewer highlighted that there is still major outstanding work to be completed, such as (a) proposed construction solutions after consensus from industry (this is a major task and contractors may not rely on instruction manuals) and (b) development of standardized testing (another formidable task that takes considerable time).

Most of the reviewers agreed that project staff demonstrated strategic collaboration or coordination with relevant stakeholders, with one reviewer stating that the stakeholder engagement process, including the impacted manufacturers from the beginning of the project, is a key strategy to the project's overall success in achieving real market impact. Another reviewer praised this project for being a model of proper collaboration, bringing together all the stakeholders and spending enough time (one year) just working out the appropriate test methods and test points. However, two reviewers pointed out gaps in the collaboration and coordination, including air barrier continuity testing, the manufactured home industry, and the National Fenestration Rating Council (NFRC).

In general, the reviewers agreed that the remaining work in the project plan is logical and on-track, and they are substantially finished with the project. They have a clear path forward and mechanisms for industry to follow up with the development of testing framework. Two reviewers highlighted that important, time-consuming work remains to be done, including phase II testing and evaluation of results and developing a best practices manual (after consensus with industry/contractors).

Weighted Average: 3.41 # of Reviewers: 7
Approach: 3.29 Impact: 3.29 Progress: 3.57 Collaboration/Coordination: 3.57 Remaining Work: 3.43

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.29** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach squarely addresses what has become a mess of an issue in the industry with regard to installation of flanged windows in CI applications. The approach logically addresses almost all important aspects of window installation, leaving out one important aspect - tie in of window to the air barrier.
- The project involves testing several types of windows for wind-driven rain, thermal cycling, and long-term deformation in order to show the performance of the window so that the industry will have better understanding in developing details for continuous insulation. It seems that CI will have to have custom details at window interaction because of the many varieties of window-wall interface. One other issue is that it is not clear whether the detail at such interface has been the cause of lower than desirable levels of the use of CI.
- The project is well-designed to ensure research results translate into market-based practices. The approach to stakeholder engagement is a key element to the project's success and it appears to have been well-executed. The testing protocols are well-designed to cover a lot of ground in a short amount of time and for relatively small investment.
- This project was focused from the very beginning. It solves a problem that builders have with their window suppliers. How do we best install in homes with thick walls and foam insulation on the outside? The PI and his team defined the problem well and got industry involvement. The approach is great.
- Continuous exterior sheet foam insulation can be an effective component for excellent control of air movement, vapor control, and insulation.
- Market share requires application standards that are simpler (less expensive) to use reliably in the field.
- Slide 4 beautifully illustrates two critical field challenges: (a) there is no code-approved method for installation of flange windows and (b) no participant in the disaggregated industry has had enough incentive to solve the codes problem by developing, testing, and demonstrating the benefits of its method, to assure performance and durability. This project and its approach directly attack this “cryptic barrier” to progress toward industry and DOE goals. The approach deserves kudos.
- The project has an excellent (consensus) experimental design (slide 11).
- The project's approach is acceptable and on-track to achieve the project-specific goals.
- The project has a very targeted approach to addressing a key window installation risk factor for window manufacturers and builders. They also have a high level of stakeholder engagement.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.29** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Assuming the project goals are met, leaving out the air barrier connection in the testing protocol is a critical mistake that doesn't further DOE BTO program goals. In terms of critical barrier continuity, air barrier continuity is the second most important behind moisture barrier continuity. It is a given that windows need to be structurally supported and stay in the openings in which they are installed, but not addressing all aspects of window installation in the test protocol leaves a large and confusing data gap in the installation instructions that will leave the industry in the same position it was in before the project - without information and guessing on the best methods to address the data gap. Fortunately, with some minor tweaking to the project and testing protocols, this gap can be easily overcome.

- Because the result of the work will be mainly test data from tests for selected window-wall interface details, the impact will be very limited, as the beneficiary will be mainly the specific window suppliers. The result if properly disseminated can show examples of good detail for CI to be used. However, such details can be developed by professionals with proper building science training, and since most projects have custom details, the results from this project cannot be expected to have significant impact.

- This project is targeted directly at solving a problem that could hinder the wide-scale deployment of high-R walls if left unresolved. Bringing the industry together to scope the problem and using independent third-party testing to performance test the issues should be a very effective way of getting to consensus on the necessary standards quickly. Since this construction detail will need to be addressed in virtually every home in the country to pursue deeper energy efficiency, carbon neutrality, and/or net zero, there is a very large market this could impact.

- The level of industry involvement with the formulation of testing and the actual testing will ensure the results get put into their installation instructions. This is a big impact that really helps low energy home (zero energy ready) builders.

- This project is a winner. Consensus process and excellent experimental design are likely to lead to a test procedure adequate for code adoption, which is demonstrably required for market acceptance and expansion. This project deserves kudos.

- Perhaps to the surprise of the collaborative group, testing revealed weak points in window design that manufacturers should be able to address at low cost (e.g., hardware failures). This is better now than when there is high wind stress in the field!

- Stakeholders/advisors have strong incentives to propagate results and work toward code acceptance. They will profit in sales and reduce field failures. It is a win-win-win situation. The nation will save energy and reduce call-backs.

- Continuous insulation is a critical component of thwarting thermal bridging effects and this project will definitely contribute to the program goals.

- The impact is immediate and solid. Concerns about installation practices and warranty can be a significant blocker for builders.

C. Progress

Based on current project efforts, the project was rated **3.57** for the degree to which the project has met ***project-specific goals***.

- Project specific goals are on track to be achieved.

- The progress of developing the test procedures and carrying out the first set of ten specimens has been good. It seems the project is moving along as expected.

- The project seems to be moving along mostly as planned and the progress to date is promising.

- The project is wrapping up and they have shown that they have met goals and will meet the final goals. They have done good work on this complicated problem.

- The project is on track, and they seem to have allowed time in 2020 for write-ups, dissemination, and close-out.
- Although the project team has completed some major work as of April 2019, there is still major outstanding work to be completed, such as (a) proposed construction solutions after consensus from industry (this is a major task given and contractors may not rely on instruction manuals) and (b) development of standardized testing is a formidable task and takes considerable time.
- The team has made strong progress working with multiple stakeholders to identify concerns and test accordingly to address those concerns.

D. Collaboration and Coordination

This project was rated **3.57** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Strategic collaboration and coordination with relevant stakeholders are impressive and, as noted in the presentation, full of opinions on every detail of the testing program. The lack of air barrier continuity testing, for whatever reason, represents a significant gap in the overall program that should be addressed.
- The project has engaged stakeholders from the beginning and the plan seems to be that the stakeholders help disseminate the results.
- In addition to the partnerships needed to execute the project, the stakeholder engagement process, including the impacted manufacturers from the beginning of the project, is a key strategy to the project's overall success in achieving real market impact. Well done on the project collaboration and coordination.
- The testing formulation and the actual testing had industry involvement. You can't get any better. The team was forced to be efficient and share results immediately with their partners. They did good work.
- Intensive industry involvement shaped the research plan through consensus. It took time, but it will lead to earlier and better application of results (e.g., through standards and outreach).
- The project has an excellent (consensus) experimental design (slide 11), which is a direct result of the upfront negotiations and consensus building with stakeholders. They had a great process.
- The project is a model of proper collaboration, bringing together all the stakeholders and spending enough time (one year!) just working out the appropriate test methods and test points. With this consensus, rapid progress could be made with assurance that each stakeholder “owns” the results, all would work together to get the results that industry needs, and DOE needs failure-resistant methods coordinated between windows and envelope to meet its own goals.
- The project team should have stakeholder engagement with the manufactured home industry, among others. Also, the National Fenestration Rating Council (NFRC) was not listed as a stakeholder.
- They have shown strong progress with a tough crowd.

E. Remaining Project Work

This project was rated **3.43** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work flows logically and is expected to fully satisfy the project specific goals.

- The remaining work seems to be doable during the next period, as only 25% of testing seems to be left to do. However, the more time-consuming work that remains would be documenting the results including developing recommendations, proposing construction solutions, guidelines for future testing of this type of details, and dissemination through various media. Such activities may take more time than the remaining period.
- The remaining work in the project plan is logical and appears to be on a realistic timeline.
- The team has a few more tests to perform and some test results to explain, but they are substantially finished with this project. It is a success.
- The project is on track, and they seem to have allowed time in 2020 for write-ups, dissemination, and close-out.
- Slide 16 is a model for other projects, showing how far they have come and what remains to do. They are on track and will produce model work products.
- There are still a few important tasks to be completed within the timeframe, such as (a) phase II testing and evaluation of results and (b) developing a best practices manual (after consensus with industry/contractors).
- They have a clear path forward and mechanisms for industry to follow up with the development of testing framework.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include the broad depth and breadth of the project team and stakeholder group and the project itself being aimed squarely at addressing an endemic issue.
- They are generating new test results.
- A project strength is their use of stakeholder engagement. Also, they are scoping to address a very specific, but critical efficient wall construction detail.
- They have had great industry involvement from beginning to the almost end (now).
- They have an excellent team and facility.
- They have a great work plan.
- They have a willingness to spend all the time required to establish a solid foundation for developing the test method and making it something that all the stakeholders ‘own’ and will help to get implemented. This supports the quickest possible achievement of DOE goals to save energy reliably.
- They are focusing on continuous insulation.
- The project team has expertise in testing envelopes.
- This is a very clean intervention to address a discrete barrier to adoption of tight high R insulation strategies. Stakeholder engagement is high and potential for industry adoption is strong.

2. Project Weaknesses

- There is a lack of inclusion of air barrier continuity in the testing program.

- There is a limited scope and applicability due to many varieties of details for window-wall interface. Also, there is no solid evidence that such results will impact and improve the use of CI in practice.
- No comment.
- There are no real weaknesses with this project.
- The test method is the larger half of the solution. What the project left out (but is needed if not available) is an industry-standard framework for code-acceptable flanges. These might, for example, be telescoping (in-out) L-shaped flanges that attach to structural sheathing, marking a precise "rough-cut" for the window location, and supporting the installed window. This concept might not be the best, in that it would have to be done before sheet foam installation, but it is one approach that might work.
- They need to identify appropriate stakeholders (e.g., manufactured home industry, NFRC, AERC).
- No comment.

3. Recommendations

- Add air barrier continuity testing to the testing protocol.
- The barriers for more use of CI should be identified through more in-depth study. A better developed plan for dissemination is needed. Having the stakeholders engaged to tell the story does not sound like a reasonable and fair approach for the rest of the industry.
- Just keep going and make sure the findings make it across the finish line by being integrated into industry standard practice.
- The only thing that would improve the project would be more testing, but that would not be possible with the current funding.
- Next, work on flanging standards.
- Focus on code acceptance.
- Work on market development to move conforming windows into the field.
- With a good system, we should be able to reduce labor content and improve reliability/durability of window attachments with continuous insulation.
- They have shown good progress and they have a great project team (kudos!).
- The development of construction solutions (manual/instructions) is critical for the success of the program goal (not just the project-specific goals). Therefore, they should bring appropriate stakeholders to the table and disseminate the technical knowledge.
- No comment.

Project #11150b: Aerosol Sealing in New Construction

Presenter: David Bohac, Center for Energy and the Environment
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Overall, reviewers approved of the project approach to demonstrate how to seal a building using aerosol sprayer with the potential to impact new construction approaches, particularly for larger production builders. Reviewers praised the approach for successfully demonstrating the viability and effectiveness of the technology and that it can be applied at a variety of logical stages in the construction of a home and achieve successful results, as well as establishing a good plan of recruiting home builders to test this new technology. This is a solid opportunity to simplify (e.g., eliminate poly-sheet air barrier at the ceiling) and potentially save construction time with improved performance.

Most of the reviewers agreed that the impact on helping create more airtight homes is clear and there is good potential that the results of this research will lead to the adoption of this technology by leading edge production builders. The impact will be significant when it is seen that the project produces a tighter, more energy efficient home with little effort. However, one reviewer highlighted that the impact is not expected to be significant as builders and home-owners will have many questions about the effectiveness and soundness of the approach. Another reviewer expressed uncertainty whether the key contractor (Aeroseal) can control the market (i.e., secure intellectual property) and whether it has the capacity to keep both costs and scheduling competitive with other approaches and capitalize the scale up to meet potential demand.

Reviewers unanimously agreed that the project team has shown great progress. They have made excellent progress in testing two houses in California and two in Minnesota, and they have successfully proven the concept from a technical perspective. The team has maintained excellent control of the schedule, including field work (with multiple cooperating builders), analysis, and outreach, and there has been adoption by a builder. Next, they will finish and have a document that illustrates good practice and recommended procedures for this Aeroseal technology.

All reviewers praised the project for its exemplary collaboration and coordination in the industry. The reviewers provided many examples of this collaboration and coordination, including bringing non-participating builders to construction sites to witness implementation of the aerosealing process, giving presentations about the method and product at several national conferences, and getting all testing and blower door measurements for so many homes. One reviewer commented that the primary go-to-market strategy will be driven by the manufacturer and their franchisees leveraging research conducted in this project.

Overall, reviewers recognized the success of the project, while also noting that there is still remaining project work to be done. The team has done a nice job in laying out a well-defined, bounded set of goals to test this cutting-edge technology and they have gone beyond tasks in some cases for better outreach and more field house testing. Reviewers also noted the remaining work: end of construction testing, generating best practice documents, getting feedback from builders about this method as compared to the conventional approach, preparing installation guidelines, performing energy analysis, and disseminating the results.

Weighted Average: 3.46 # of Reviewers: 6
Approach: 3.33 Impact: 3.33 Progress: 3.67 Collaboration/Coordination: 3.33 Remaining Work: 3.83

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach has successfully demonstrated the viability and effectiveness of the technology and that it can be applied at a variety of logical stages in the construction of a home and achieve successful results. Few technologies have been shown to be this effective this simply.
- The project is mainly to demonstrate how to seal a building using aerosol sprayer. This may be like a proof of concept for this product. If the project was funded for this objective, then the approach is reasonable. If the barrier for better airtight homes is the cost, this approach is promising to have a more affordable way to seal the house. Of course, currently, the approaches we have do work, but they also require considerable labor time.
- This is an interesting re-purposing of the Aeroseal technology with the potential to impact new construction approaches, particularly for larger production builders. The technical concept is innovative with the potential to reduce labor costs and ensure builders are meeting their whole building air tightness goals. The research approach seems sound as a proof of concept.
- The team performed well and had a good plan of recruiting home builders to test this new technology.
- They have a well-controlled experimental design, well-implemented for two very different climates and (presumably) construction ‘cultures’ and practices.
- The project tests doing the heavy lifting (labor) of envelope sealing with single intervention and any of several construction phases. All were evaluated.
- This is an opportunity to simplify (e.g., eliminate poly sheet air barrier at ceiling) and potentially save construction time with improved performance.
- They took advantage of multiple opportunities for outreach to real builders on real sites.
- This project is helping a manufacturer demonstrate the value of trading off foam or extensive air sealing for a proprietary sealing approach. The opportunity seems solid. The impact will be determined by builders willing to make this change.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.33** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The impact on helping create more airtight homes is clear, well-documented, and highly repeatable, allowing for more reliability in achieving air tightness targets.
- The impact is not expected to be significant as builders and home owners will have many questions about the effectiveness and soundness of the approach. In particular, since there is no record of the performance of homes sealed using this technology, this will be a deterrent for people to start using a product. Home owners may be concerned about health issues.
- There is good potential that the results of this research will lead to the adoption of this technology by leading edge production builders. That market segment alone is significant enough to merit further development of this technology to get it into the market.

- Some of these results are amazing and should illicit a positive response from builders in other parts of the country. This should produce a big impact when it is seen to produce a tighter, more energy efficient home with this little effort. This is a huge benefit for a fairly simple technology.

- If their unbiased and well-founded report(s) and outreach do their jobs, then this approach could better assure high performance air sealing for new construction at very competitive costs.

- One of the more elegant aspects of their approach is that aerosealing can be done at any of several phases of construction. It’s adaptable to the process flow that a particular builder prefers.

- It has the potential to eliminate one or more steps (with attendant quality control required) in conventional practice, for cost savings. Beyond that, this sealing process could be carried out at night, with no interruption of construction schedule at all, possibly with a price premium to cover second shift labor costs for the work.

- It is not known whether the key contractor (Aeroseal) can control the market (IP) and whether it has the capacity to keep both costs and scheduling competitive with other approaches and capitalize the scale up to meet potential demand.

- Are there potential “killers” for the application, such as long-term emissions that “seem” to penetrate to the interior with “nasty” volatiles? Aeroseal must get ahead of potential challenges to meet fears of conservative builders and developers, to avoid downstream problems (e.g., urea-formaldehyde foam, bad Chinese dry-wall in Florida). The next project phase should consider participation by public health collaborators for some lab and field studies.

- They show validation of reduced cost options for reducing envelope loads. The technology does not require major changes to the construction process.

C. Progress

Based on current project efforts, the project was rated **3.67** for the degree to which the project has met ***project-specific goals***.

- Project progress is on target and has been overwhelmingly positive in terms of effectiveness and sequencing flexibility.

- The project has made excellent progress in testing two houses in California and two in Minnesota. The data obtained after the blower door test shows the effectiveness of the product in sealing intended gaps, holes, and small openings. Generated data has been plotted and available for study.

- The project is close to completion and seems to have successfully proven the concept from a technical perspective, i.e., the technology works. It will be interesting to see how the economics pencil out from the builder's perspective.

- The team has done a lot in hundreds of new homes. They have made great progress. They will finish and have a document that illustrates good practice and recommended procedures for this Aeroseal technology.

- It appears from the presentation that the contractor has maintained excellent control of the schedule, including field work (with multiple cooperating builders), analysis, and outreach.

- There has been solid progress, including adoption by a builder.

D. Collaboration and Coordination

This project was rated **3.33** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination in the industry are exemplary and are already paying off well beyond the investment in the project as evidenced by one builder already adopting the technology for all their projects. Future growth is expected to be exponential.
- The local builders have been invited to observe how the product works in sealing the house. Presentations about the method and product have also been made at several national conferences to make them aware. Furthermore, the main stakeholder (AeroBarrier) has already started to promote its application.
- The team has been successful in establishing the necessary partnerships to execute the project.
- They show evidence of good coordination by getting all of this testing and blower door measurements for this many homes. Mandalay has decided to use this technology in all their new homes. This will be a common reaction once other builders see how much the aeroseal can improve tightness.
- This project seems to be an excellent example of collaboration and coordination (builders, two university groups, private sector technology firm), all wrapped into a whole that demonstrated excellent results that could improve construction quality and might even modestly reduce costs in a production environment.
- The team has done great outreach, such as bringing non-participating builders to construction sites to witness implementation of the aerosealing process. If "seeing is believing" and "data rule," then (a) this is ready for YouTube and (b) it could spread as quickly as Aeroseal can safely expand (partner or franchisee recruitment, training, and control).
- Primary go to market will be driven by the manufacturer and their franchisees leveraging research conducted in this project. Efforts by the project seem solid.

E. Remaining Project Work

This project was rated **3.83** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work logically flows from the results of testing conducted thus far and will lead to further and exponential adoption and implementation.
- The project is nearly over, with end of construction testing remaining. Aside from testing, the main parts to complete include getting feedback from builders about this method as compared to the conventional approach, preparing installation guidelines, performing energy analysis, and disseminating the results, which all seem doable, although dissemination may continue beyond the end of the project.
- The team has done a nice job in laying out a well-defined, bounded set of goals to test this cutting-edge technology. While more work will be needed to get the product into the market, this research will provide a sound basis for continuing efforts and future market adoption.
- The team has a few more homes to test and documents on best practices to generate from this testing. They seem to be highly capable and will develop and distribute the best practices documents/reports to builders.
- As noted above, the contractor seems to have maintained excellent control of budget and time, to assure that the remaining work to meet its goals will be accomplished, and they have gone beyond tasks in some cases, for better outreach and more field house testing.

- The project is closing in on success.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include good, reliable demonstrated results with minimal effort and sequencing flexibility.
- This is a new idea for air sealing homes using aerosol spray.
- They have a well-defined, contained scope of work for a project that might have suffered from scope creep. The innovation of re-purposing a proven technology with limited market penetration could help increase market adoption of the aerosol sealant approach for both ducts and building envelopes, which would in turn help with cost-compression (at least in theory). The variations in application scenarios were well thought out to cover a good range of construction approaches without getting overly complicated.
- The team did great work taking so many measurements.
- The project has a great team, highly experienced in field work.
- This is a relatively large field study, with more than fourteen houses.
- They received strong support from Aeroseal developers and from the contractor.
- Deep team connections helped drive selection of the right houses for multiple benefits from the work.
- Aeroseal is almost unique in offering validated interventions for air-sealing at multiple alternative work stages (slide 8). Multiple options (perhaps doing the sealing at night) minimizes the need to interrupt other construction for air sealing.
- They have a very effective process that really pulls down air infiltration.
- They had strong third-party testing of a solution. They demonstrated adoption by a builder. The technology has performance testing integrated, verifying success.

2. Project Weaknesses

- The main weakness lies in potential replacement of good air sealing construction practices with an over reliance on aerosol sealing for air tightness.
- The issue is that this product may not work if the gaps are large and the long-term bond issue is unknown. So, under infiltration, the seal may break. There is not test data yet. Also, with forced air going through the wall, whether this material may become airborne is not known.
- There are no real weaknesses. Perhaps they could beef up the stakeholder engagement by working with a wider range of builders/contractors to better understand their value proposition and how this technology may or may not work for them.
- It would be good to have seen more builders involved, but this may not have been practical given the newness of this technology.
- It is not clear how this method will compete on cost with its alternatives that achieve “enough” air infiltration control. For example, what construction steps would make it unnecessary? Does it remove the cost of ceiling poly barriers? Even a rough cost comparison for mature application would have been a good add.

- Looking beyond this project, intellectual property raises its head. Presumably, there is some intellectual property involved (latex formulation, application method, etc.). Will competitors emerge doing a worse job with worse materials at a lower price point, ruining the reputation of aerosealing? This was the nightmare of urea-formaldehyde wall insulation in the early 1980s.
- More information is needed on economic trade-offs, such as install labor, interruption of workflow during installation, and cost reduction in moving away from foam or moving from air sealing labor to subcontract. These will be what a builder will want to understand.

3. Recommendations

- The technology should be viewed and marketed as a complement to good air sealing construction practices rather than a replacement for such practices.
- Perhaps additional research is needed to address the issues mentioned under weaknesses.
- Collecting additional feedback on the concept from a wider range of builders and contractors would be helpful to give insight into the market potential for this technology. It would also be good to see the installed product stress-tested in a lab to see how the seals will hold up over time under varying weather conditions when sealing various types of building products and assemblies (i.e., do the seals hold up just as well when sealing sheetrock, wood, wires, and plumbing as they do in ductwork?).
- The team plans to test this next in existing homes, which is an interesting next step. There is a potential market for this technology to be used to compartmentalize apartments in multifamily buildings, which can often be difficult to do using traditional manual sealing methods.
- The team should make sure that the results are well published (before and after performance of these envelopes should be fully advertised). The best practices documents should be circulated all over the country through associations and trade shows to reach the biggest audience possible.
- Get the word out while continuing field demonstrations.
- Do more economic analysis.

Project #11150c: Monitoring of Unvented Roofs with Diffusion Vents and Interior Vapor Control in a Cold Climate

Presenter: Joe Lstiburek, Building Science Corporation
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most reviewers were satisfied with the project team's approach to demonstrate that unvented roofs with fibrous insulation are ineffective in cold climates and that unvented roofs with diffusion vents and interior vapor control may address this moisture issue. Two reviewers specifically commended the test hut approach for its excellent experimental design. However, at least one reviewer preferred that data be collected from actual homes that were experiencing the problems that this project seeks to understand and correct. Regarding the project's impact, most reviewers were similarly optimistic that this project would have a significant impact on program goals. These reviewers highlighted the cheaper insulation option and lower costs when compared to foam insulation as reasons for the potential positive impact on the market. One reviewer pointed to the potential to use this cheaper insulation method in retrofit projects. However, another reviewer cautioned that this impact will ultimately be driven by whether builders are willing to add insulation at roofline.

All reviewers commended the project team for its well-planned and thorough progress date, noting the high-quality tests that had been performed and the actionable results that had been documented. Reviewers called out at least three findings that had already proved significant, including demonstrating that: 1) diffusion vents help control and prevent condensation, 2) fibrous insulation with unvented attics is calamitous, and 3) moisture cycling in blown in cellulose causes a lot of settling.

Almost all reviewers lauded the project team for engaging and collaborating with relevant stakeholders, including major insulation manufacturers and leaders in the insulation industry. Reviewers also praised the project team for sharing the results broadly through annual meetings, conference presentations, and trade associations. However, one reviewer was unclear how the advisory group was composed and advised the project team to include code enforcement officials and subcontractors affected by the results.

Most reviewers also believed that the project has been logically planned such that the remaining work will meet the project-specific goals. Some reviewers pondered whether the project goals have already been met and that whatever minimal testing remained would not reveal drastically different results (e.g., that spray foam is the best solution for this kind of roof). Other reviewers believed that despite the data already collected, important work remained to be completed, including analysis and recommendation. However, reviewers were unanimous in their belief that the project would be completed with the scheduled timeframe.

Weighted Average: 3.58   # of Reviewers: 6
Approach: 3.50   Impact: 3.50   Progress: 3.83   Collaboration/Coordination: 3.67   Remaining Work: 3.50

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Project approach is squarely aimed at attempting to advance the state-of-the-art science in roof insulation strategies. Theory and practice meet to shed light on what some in the industry have observed in terms of problematic installations and how they have been addressed. The project fills a gap in the community's knowledge that is needed to move on to other solutions.

- The project intends to demonstrate that the unvented attics with fibrous insulation in cold climates may have moisture issues; these can be handled with diffusion vents that allow vapor to pass through but not air. The main motivation for this work seems to be to find a way to make the more-affordable unconditioned attic with fibrous insulation as opposed to a vented or unconditioned attic with foam or rigid board insulation work without moisture problems. It is stated that about 5% of homes may have this issue. The approach taken to address the issue is to use a test house that uses the suggested diffusion vents to prove the concept. It seems that, initially, data should be collected from actual homes that may be experiencing this problem. Furthermore, the suggested concept would be better gaged on an actual home. Nonetheless, using a small test house is also acceptable to generate initial preliminary data.

- The project seeks to understand the potential impact on moisture management in high-R celling assemblies with lower construction costs than those requiring foam (rigid or sprayed) insulation products. Cost-reduction and simplified assemblies are necessary now as code compliance is increasingly challenging for builders and comes at a premium to the customer. Easier, cheaper, more scalable solutions are needed. The team was creative in conceptualizing a testing rig (hut with bay-by-bay variations) and protocol that allows for the testing of a good variety of assembly configurations (combinations of insulation, vapor barrier, and ventilation). We could argue over the selection of relative humidity and air pressure configurations, but for research purposes, we have to start somewhere and this project does that effectively.

- This team has a broad depth of experience and designed a good experiment for determining the efficacy of using this new type of roof design. Good approach. Test hut method is always the best.

- Test hut is the basis for an excellent experimental design, with excellent step-wise actions and great documentation of dramatic results.

- This may be the most important negative result in the field in years: The team has shown that fibrous insulation should not be used in unvented attics in cold climates (or even in unvented attics with diffusion venting and interior vapor control) using the best-available technologies for both.

- The second result is almost as important: blown-in fibrous insulation for unvented attics is going to settle and sacrifice its efficacy. Don't go there, builders, because the near-peak uninsulated space that results will have high likelihood of mold on the ceiling drywall from cold surface there.

- Together, these findings are the best possible shot across the bow, to enable OEMs to warn builders, and for builders to avoid the next construction disaster of the scale of the "[foreign] Drywall" example.

- Documentation that ASHRAE 160, the relevant standard, is not stringent enough for cold climates. This is particularly important because the current best practice uses spray or sheet foam, and is 2 – 3x more expensive than fibrous and vapor barrier. That, and anti-foam 'prejudice' among builders, require strong demonstrations of risks to move the builders away from this application.

- Next Research Question: For which warmer climates are non-settling fibrous and vapor diffusion vents good enough?

- Concrete, focused approach to resolving questions about an energy related building detail. Very solid project.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.50** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- Project impact is significant and solidifies the community's understanding of how these roof assemblies perform under almost real-world conditions and provide enough information to extrapolate performance expectations and options for addressing the issues addressed.

- The impact is dependent on whether builders will be willing to add insulation at roofline and a membrane to allow vapor to pass through. The incentive can be the lower cost associated with the method. There is also potential for its use in retrofit projects.

- Lower cost, easier to access moisture-managed high-R assemblies are among the holy grails of what we need to enable the construction (and retrofit) of homes that are low load enough to meet aggressive national and state level goals for carbon neutrality and zero net energy. If the project successfully identifies assemblies that are easier and cheaper to construct than those that require foam insulations and still maintain acceptable moisture performance in cold climates, it would have a significant impact on the market in terms of improved code compliance and reduced costs.

- This project was done to see if cheaper insulation options could be used to replace blown foam in a non-vented roof application. If nothing else, the work has shown us that the spray foam is a solid solution, and we need to work to lower its cost. This work will prevent some builders from making bad decisions on using cellulose in an unvented roof application. Now we know. Good work and impactful.

- This negative result (cold climates) could make a huge difference in demonstrating that high-performance need not imply higher risk – a result that should greatly improve market acceptance of better approaches, including those that have somewhat higher costs.

- Perhaps as important, it may help save the industry from major liability from mis-applying unvented roofs with fibrous insulation on a large scale, a repeat of the ugly problems associated with foreign drywall example in Florida and stucco-over-foam in the Southeast United States.

- Solid research investment with strong potential of adoption of results by industry. Durability of energy efficient buildings needs to be maintained for market adoption of low energy buildings to occur.

C. Progress

Based on current project efforts, the project was rated **3.83** for the degree to which the project has met ***project-specific goals.***

- Progress thus far has produced actionable results and significantly added to the building science community's understanding of unvented roof assembly performance.

- The tests on the test house have been done, and data has been collected with good results. The concept seems to have been proven in the sense that diffusion vents help to control and prevent condensation. But if low perm diffusion perm is used, the result is not good. So, it seems the project has generated some good results to move to the next step.

- The project seems to be progressing mostly as planned with the team making appropriate results-driven adjustments between phases.

- The experimental work in the test hut have been very thorough. This work showed that moisture cycling in the blown in cellulose causes lots of settling; this was unexpected. They have made great progress and have substantially completed all project goals.
- Well thought-out. Three winter experimental design has kept on track, with adaptation of measures to reflect prior winter results. Well done.
- Nice interim 'socializations' with sponsors and advisors.
- Excellent progress in demonstrating that combining fibrous insulation with unvented attics is going to be a disaster in cold climates.
- It remains to see which – if any – climates will be safe for this construction.
- Almost as important was documentation of full-depth settling of cellulose insulation near attic peaks. This is quite likely to lead to condensate on drywall near peaks, and thus to mold infestation as a chronic problem.
- Team is working through the research plan with concrete progress.

D. Collaboration and Coordination

This project was rated **3.67** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination with industry and stakeholders is significant and exemplary. Results are shared broadly and the community engaged to review, digest, and make comments, recommendations, and adjustments. The project team is responsive to the findings and allowing the data to speak for itself and make adjustments based on the data observed and collected.
- The stakeholders have been engaged or informed during the project through annual meetings, manufacturers' participation, conference presentations, and consultation with the industry.
- It wasn't entirely clear from the presentation how the advisory group is comprised. It appears that a wide range of manufacturers were included and some builders, but it would also be good to get feedback from code enforcement and the affected sub-contracting trades (maybe they were included?).
- The team involved the major insulation manufacturers and people in the know about insulation. The work was performed efficiently and produced some really good and unexpected results. The results will force insulation manufacturers to seek other options for non-vented roofs; we need other options, other than spray foam.
- Very strong collaborators, who are leaders in the insulation industry, and their trade association to reach the rest of the manufacturers (slide 3). A tribute to the track record of the contractor, BSC.
- Key fiber insulation players represented. Results may not be what they are looking for but this will help them avoid failures and liability.

E. Remaining Project Work

This project was rated **3.50** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- It seems as though project specific goals have already been met, and I am not clear that remaining project work will significantly add to the knowledge already gained. Remaining project work is indeed valuable, just not sure it will reveal anything new.

- The experimental part of the projects seems to be near completion, but data collection will continue followed by analysis and recommendation. The project then intends to share the results with industry and stakeholders.
- The planned remaining testing phase is a logical progression from the initial phases.
- The team still has one more winter of higher humidity test conditions to complete. I don't think they will find much difference for this set of conditions. Spray foam is by far the best solution for this kind of roof. They will not have any difficulty completing this work.
- Project plan and schedule indicate ample time for the remaining tasks.
- On track, and well done.
- Closing in on successful completion.

F. Additional Comments and Recommendations

1. Project Strengths

- The strength of the project lies in the data gaps being filled between theoretical and actual performance. A lot of good data that has been gathered, demonstrating the sensitivity of the assemblies and hence the increased risks.
- Developing the new idea of using diffusion vents in unvented attic. As always, the generation of test data is valuable.
- The testing protocol is well-designed to enable testing of a wide range of configurations and conditions at relatively low cost. The phasing of the test and inspection periods allow for informed adjustments between phases, which is a smart approach. The project targets a critical issue as codes and environmental goals drive accelerated adoption of the construction and retrofit of very low-load homes.
- Great team of researchers who have involved all the major insulation manufacturers. This is the kind of research that produces most for our investment. Good work.
- Excellent team with outstanding track record.
- Excellent experimental design and multi-year, multi-variable use of the facility.
- Fine 'dissection' after each winter with appropriate inferences from visual evidence and some surprises.
- Experienced building scientists with sharp minds 'get it' when they carefully observe, even the surprises. Good documentation.
- Solid research in resolving an envelope performance issue that has arisen from other DOE BA recommendation (conditioned attic). Strong research design. Good connection to market.

2. Project Weaknesses

- The simplicity of the project could be a weakness where the project might show certain assemblies perform better than others without including typical penetrations and air leakage points in those assemblies. It is expected that the results from the year-3 testing should address this area in sufficient detail to allow for reasonable and useful extrapolation of the data.
- Lack of test data from actual homes that has motivated the study.

- It is not clear what the team's work plan is to socialize its findings with the codes and standards communities. Confirmation that diffusion vents are effective at mitigating moisture in these assemblies is important and should be translated into code. Beyond that, it is not entirely clear how well this research translates to actual occupied buildings with varying leakage paths into these ceiling cavities.

- I would like to have seen even more insulation options for the roof; other types of blown in insulation, thin spray foam layer then cellulose, etc. More permutations would have been better.

- It's a pity that the project doesn't explicitly consider the underlying question: Even if there is "proper" construction QI/QA, is post-occupancy control (relative humidity, penetrations, failure warnings) even feasible, or should this construction be banned until we establish which climates are robust enough to use?

- Sometimes things don't work as hoped, and that is important to know also. No real weaknesses.

3. Recommendations

- Further testing of assemblies to mitigate the sensitivity of the assemblies tested would be beneficial to lead the building science community toward better consensus of how to construct durable, resilient, high R-value roof assemblies in cold climates.

- A thorough report on how the existing homes with different attic details and unvented attic have performed will be very useful. Also, if the solution is actually implemented to an actual home and its performance monitored, it will help to prove the effectiveness of the approach in real life situations.

- Think about ways to better simulate the performance of an entire roof system. How well does the single bay testing configuration simulate whole ceiling performance? The proposal to continue this research in existing homes is good, but additional hut testing could also be useful with simulated occupancy (varying temperature and relative humidity conditions on daily and seasonal cycles) instead of a single constant set of conditions.

- No comment.

- Keep the team busy. Next steps would seem to be:

    - Repeat experiment in a carefully chosen, milder climate, preferably climate zones 1 or 2, to examine resiliency.

    - Is it feasible to install cellulose and similar materials in thick blankets in ways that assure that there will not be way too much settling, including full-depth near peak?

- No comment.

Project #11150d: Physics-Based Interval Data Models to Automate and Scale Home Energy Performance Evaluations

Presenter: Kurt Roth, Fraunhofer CSE
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most of the reviewers approved of the project approach to use smart thermostat data in a smart way to target utility incentive program outreach, circumventing traditional outreach methods in what is hoped to be a more targeted and accurate way. There is a clear challenge and the team has a promising method, that is technically sound, to leverage a technology that is already on its way to scaled deployment in the market (communicating thermostats) to target consumers with meaningful opportunities to improve their homes. However, two reviewers expressed concerns about the approach: success and final steps of the project assume that the targeting will increase energy audit uptakes, but there is no back-up plan if this is not found in the market test – the sparse data used for modeling is worrisome; and this project may not be applicable to all American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climatic zones.

In general, reviewers agreed that the project is expected to contribute to program goals. Assuming the project-specific goals are met, this could ultimately lead to achievement of the program goal of improving existing building energy efficiency. One reviewer commented that a tool that enables program administrators and contractors to get a "peek under the hood" without going to the house is invaluable for reducing acquisition costs and project cycle times while increasing close rates, achievement of savings, and overall cost-effectiveness. However, reviewers highlighted that the project doesn't help overcome the challenge of why (besides energy savings) the buildings might want this benefit and this project is only specific to ASHRAE climate zones 4, 5, and 6.

Overall, reviewers agreed that the project is on-track and showing excellent progress. The team has made significant progress on the technical aspects of their algorithms, have obtained preliminary data to check those algorithms, they are providing useful and accurate data to target utility energy efficiency marketing programs for less cost, and they are well on their way to producing a tool that can be used in the broader market. One reviewer pointed out that there is concern on the validity of the statistical analysis of the R-value predicted versus CT R-value.

Reviewers unanimously agreed that the project has excellent stakeholder engagement, particularly with utilities. The strategic partnership with Eversource and National Grid is one of the key strengths of this project, and with more validation, they could seek other utility partners too. One reviewer highlighted that strategic collaboration and coordination to use private utility data is critical to maintaining confidence in the use of such data and will be essential moving forward.

The reviewers were divided on the degree to which the project has logically planned remaining work to meet the project-specific goals. Three reviewers agreed with the remaining project work, stating that remaining project work is well-planned and thoughtful in tying the project goals to program goals and the team seems on track to successfully complete the project and bring it to market. One reviewer highlighted that the team plans to spend the remainder of its time validating the approach through its partners. However, two reviewers voiced concern regarding the remaining work and noted that there are still several questions that need the attention of the project team prior to finalizing the modified grey-box model and there is no back-up plan if the hypothesis of targeting increasing energy audit uptake is not proven.

Weighted Average: 3.31 # of Reviewers: 7
Approach: 3.14 Impact: 3.29 Progress: 3.43 Collaboration/Coordination: 3.43 Remaining Work: 3.43

Program Response

The Building Technologies Office recognizes the peer review as an effective tool for program management and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.14** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach is unique in that it appears to be one of the first to use smart thermostat data in a smart way to target utility incentive program outreach, circumventing traditional outreach methods in what is hoped to be a more targeted and accurate way. Through better targeting and reducing the cost to acquire leads, it is hoped that incentive program conversion to actual projects will increase. The early results are promising, but ultimately it remains to be seen whether achieving project goals will lead to the conversion of leads into projects.
- There is a clear challenge they are trying to address. They understand how this could be used.
- The approach appears to be technically sound. The partnership with utilities will enable them to evaluate how well their algorithms work. The challenge will be in predicting the marketing impact of this idea. Hopefully they will improve on the high costs of customer acquisition.
- Reducing the soft costs associated with the deployment of energy efficiency is vital to enabling scalable solutions for the retrofit market. This project seeks to leverage a technology that is already on its way to scaled deployment in the market (communicating thermostats) to target consumers with meaningful opportunities to improve their homes. The ability to segment the market and target high impact services remotely is both timely and necessary. We look forward to seeing these tools continue to be refined and find more applications in the market.
- This seems like a very promising method for identifying homes with major attic/wall insulation or air sealing opportunities (provided that they have a communicating thermostat).
- The project team's approach to characterize R values for major insulation retrofit opportunities is novel and commendable. However, the sparse data used for modeling is worrisome. Moreover, this project may not be applicable to all ASHRAE climatic zones.
- Success and final steps of the project are based on the assumption that the targeting will increase energy audit uptakes. There is no back-up plan if this is not found in the market test.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.29** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Project impact is primarily focused on market uptake of utility energy efficiency program dollars, which is expected to ultimately lead to achievement of the program goal of improving existing building energy efficiency. Project goals are indirectly linked to program goals due to the intervening steps between project goals and program goals, thus execution of intervening steps will be critical to achievement of program goals.
- This project has a well-articulated market opportunity and market impact.
- It is very important to look at solutions for existing buildings, and this project directly addresses the key energy consumer in existing buildings. It seems to be focused on heating climates, particularly houses that use boilers or furnaces. Tools to target marketing should hopefully improve the uptake of energy retrofits.
- The potential impact of this type of tool is very large. There is a growing need for us to become smarter about how customers are targeted and how energy savings are measured. We know how to fix the houses but not how to get into them at scale. A tool that enables program administrators and contractors to get a "peek under

the hood" without actually going to the house is invaluable for reducing acquisition costs and project cycle times while increasing close rates, achievement of savings, and overall cost-effectiveness.

- This seems like it can contribute to identifying the buildings that need help. However, it doesn't help overcome the challenge of why (besides energy savings) they might want the help. This needs to be paired with outreach strategies to actually solve the problem.
- The project-specific goals will contribute to the program goals in a considerable manner if the characterization of R values is accurate.
- This project is specific to ASHRAE climate zones 4, 5, and 6. What about other climate zones?
- Provided that the hypotheses on which the project are based are proved true, this could increase energy efficiency in a sizable number of existing homes.

C. Progress

Based on current project efforts, the project was rated **3.43** for the degree to which the project has met ***project-specific goals***.

- The progress on achievement of project goals is impressive and they are providing useful and accurate data to target utility energy efficiency marketing programs for less cost.
- The project is on track. Ideally, they would eventually look at cooling loads in warm climates too.
- The team appears to have made significant progress on the technical aspects of their algorithms and they have preliminary data to check those algorithms. The next steps involve more work with their utility partners. The team appears to be well on its way to meeting the goals of the project.
- The team is well on their way to producing a tool that can be used in the broader market. It will be great to seeing how the tool is further refined in the coming months/years.
- There is excellent validation thus far that the algorithm works. Taking it to scale and testing at scale is the next step.
- There is good project progress as per project-specific goals.
- There is concern on the validity of the statistical analysis of the R-value predicted versus CT R-value.

D. Collaboration and Coordination

This project was rated **3.43** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Strategic collaboration and coordination to use private utility data is critical to maintaining confidence in the use of such data and will be essential moving forward. Collaboration and coordination with stakeholders and utilities to date is excellent. Testing of the assumptions made and leads generated will be critical to achieving program goals.
- They have key partners in place (local utilities).
- One of the key strengths of this project is the close ties with organizations (e.g., utilities) who will ultimately use the results of the research.

- The strategic partnerships with Eversource and National Grid, and in turn with the thermostat manufacturers, have been vital to the success of this project.
- They seem to have excellent collaboration, particularly with Eversource and National Grid. With more validation, they could seek other utility partners too.
- For the given project-specific goals, the project has developed significant stakeholder engagement.
- There is excellent stakeholder involvement.

E. Remaining Project Work

This project was rated **3.43** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work to validate to scale follows logically from the work to date and is necessary to establish the validity and usefulness of the data and tools to target EE outreach and incentives to customers. Remaining project work is well planned and thoughtful in tying the project goals to program goals through the intervening steps required to move from project goals to meeting program goals.
- The reviewer has no comment.
- As noted earlier, the first draft of the technical work appears to be complete and the team plans to spend the remainder of its time validating the approach through its partners.
- The team seems to have a solid plan for finishing up the project and bringing it to the market.
- They seem on track to successfully complete the project.
- There are several questions that need the attention of the project team prior to finalizing the modified grey-box model. A few are listed below.
- 1. How will the spare data be used (n=29)?
- 2. How are internal equipment loads considered (BeOPT has assumptions for q_int)?
- 3. What is the impact of occupancy (time versus heat generation)?
- 4. The randomized controlled design includes a large number of homes. Does the timeframe allow this survey?
- There is no back-up plan if the hypothesis of targeting increasing energy audit uptake is not proven. There may be other factors which could contribute to energy audit uptake.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include realizing the promise of data collected by communicating thermostats and the internet of things to cost effectively target utility energy efficiency dollars, and increase uptake/conversion of outreach to projects that will ultimately save consumers money and significantly reduce energy use. Other strengths include creating licensable algorithms that relatively accurately predict effective R-value and air tightness to target marketing and energy efficiency upgrade programs.
- They clearly articulated the challenge of locating under-insulated homes in order to approach the customer (from energy-efficiency program).

- Demonstrating post-retrofit savings is likely the most beneficial use.
- They are addressing a key problem, namely finding ways to improve the efficiency of existing homes.
- Should the data be available, it appears that the approach is robust in targeting homes with high leakage rates and low insulation levels. The clever algorithms allow for differentiation of those two issues.
- The project will hopefully help improve the very low numbers of people being willing to undergo home retrofits.
- They have good collaboration with end users.
- It addresses a timely need in the market and offers a novel application for the use of data generated by connected thermostats. The selection of utility partners in Massachusetts was a smart one which enabled the team to access a robust data set for building and training the model.
- It is an elegant, low cost way to identify homes that can likely use significant insulation and air sealing.
- 1) The project team's expertise is a strength.
- 2) Another strength is the project's objective of identifying homes with the largest retrofit opportunities.
- 3) They have excellent stakeholder engagement.
- The project deals with existing building envelope retrofits.

2. Project Weaknesses

- A project weakness is that it is indirectly linked to program goals rather than directly linked and will require constant attention and marketing efforts by utilities and home energy performance contractors to realize program goals.
- They need to better refine the business model.
- It is always challenging to apply technical solutions to improve sales. Hopefully this work will help out.
- There seems to be a challenge in not seeming like "Big Brother" when using customer data from communicating thermostats.
- Are Communicating Thermostats, which are needed for these algorithms, biasing the samples to those homes that may not actually be in need of a retrofit? E.g., are CT's mostly in better homes?
- The need for long term fuel consumption data is a potential challenge for broad-scale deployment of this tool. Strategies that allow for analysis based on shorter term data with or without actual fuel consumption would increase the marketability of the tool.
- Homes must have a communicating thermostat. Some of the worst homes (low income, etc.) may not have CTs.
- More importantly, most homes that get energy audits don't actually do retrofits. This seems to be a bigger problem than identifying which buildings can use air sealing/insulation. Potentially this project can help with a solution. One of the biggest issues with utility programs is that they try to sell people energy savings, when energy savings often aren't that compelling of a sale. Comfort, draft reduction, and health impacts are much more compelling. Potentially, you can infer that homes that lose heat quickly are drafty. But if you are also

getting information on how often people are changing thermostat setpoints, then that is an indication of discomfort, which might be a better selling point than just that the homes are losing energy.

- 1) The simple approach of using the modified grey-box model may lead to overfitting and may not estimate accurately. This may lead to cost overruns / waste and discouraging ROIs.
- 2) Field testing of the model is crucial. Relying on the sparse data-based grey box model is worrisome. Hopefully, the next phase of this project will help remove this issue.
- The project focuses on consumer choice without analysis of complicated consumer behavior factors.

3. Recommendations

- It will be great to see the validation to scale work to be completed and testing of utility outreach and uptake/conversion success rates.
- Look at how algorithms could be used to track post-retrofit savings, not just in insulated/air sealed projects.
- Assess the subset of existing homes in which communicating thermostats are installed. Does this subset of the housing stock provide the best targets for retrofits?
- Extend algorithms in future work to heat pump heating systems.
- This is the same as the prior question.
- As discussed at the end of the discussion, don't just throw away the buildings that are not good candidates for air sealing/insulation. If those buildings are high natural gas users, then you can infer that there may be something going on with their water heating system (or perhaps a gas leak somewhere). But it would still be an opportunity!
- Also, try to align analysis with compelling messaging (comfort) so that buildings that get targeted using the algorithm can be given more compelling pitches than "you can save some money on your utility bill."
- 1) With adequate data (new home surveys), you can improve your model without overfitting.
- Add a method to obtain more information on the reasons for consumer choice in this area.

Project #11150e: Development of the Industry's First Smart Range Hood

Presenter: Mike Moore, Newport Partners
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

In general, reviewers agreed that the project approach is sound. The project, which provides a way to help eliminate contaminants in a home from cooking in order to enable homes to be constructed more tightly for energy savings, has an approach that builds on and exploits the work of other Building America projects to identify and develop low cost and reliable sensors and range hood capture efficiency. However, reviewers expressed concerns about the complexity of the control scheme and the assumption that the most viable answer is a control strategy that relies on sensing specific pollutant concentrations instead of a simpler control solution.

Reviewers were divided on the degree to which the project is expected to contribute to program goals, with two reviewers agreeing that the project addresses Building America's goals of improving indoor air quality in energy efficient homes. The other reviewers were skeptical, stating that there is only an indirect link to the overall energy efficiency goals and the proposed solution is overly complex. Reviewers were critical about a higher failure rate (working when needed and not turning on when not needed) and more energy expenditure from the fan running more.

Overall, reviewers agreed that the project has shown great progress, and next steps will include testing and commercialization. Reviewers mostly agreed that the project is on-track, but one reviewer stated that it is difficult to assess the project’s progress because most information on the prototype was held as proprietary information. One reviewer critiqued the project that it seems like the project team came into the project with a pre-conceived notion of what the answer would be and it is limiting their creativity in exploring alternative solutions to the control strategy.

The reviewers unanimously approved of the project’s collaboration, particularly with Broan, a major range hood manufacturer that will give them an avenue to making their development readily available in the marketplace. Collaboration and coordination are comprehensive and well-designed to achieve project goals working with and through project team members and stakeholders. One reviewer suggested future collaboration with ANSI because of their role as the standard setting body for oven performance.

Most of the reviewers approved of the remaining project work, with many reviewers pointing out that field testing will be the next step, and two reviewers expressing optimism that the field tests will successfully mirror the performance from laboratory findings. The project is on track to commercialization and creating a marketable product. The only critique provided for remaining project work is that the time for customer field studies seems a little short.

Weighted Average: 3.33 # of Reviewers: 6
Approach: 3.33 Impact: 2.67 Progress: 3.67 Collaboration/Coordination: 3.83 Remaining Work: 3.17

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will leverage the feedback provided by the reviewers to inform potential updates to this project as appropriate.

A. Approach

This project was rated **3.33** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The approach is solid and logically flows to address key issues and functionality leading to development and commercialization of smart range hood products. The approach builds on and exploits the work of other BA projects to identify and develop low cost and reliable sensors and range hood capture efficiency.
- The problem statement and plan to address key challenges are spot on.
- While many of the details of the approach had to be withheld due to their proprietary nature, it seems like the team is taking a good approach to succeed. They are trying to find ways to get range hoods to turn on automatically in response to contaminants arising from cooking. They have identified key issues with range hoods to make more widespread use occur. They have completed lab tests that have shown the promise; it is logical to next evaluate these range hoods in the field to identify unforeseen issues.
- The one concern relates to the complexity of the control scheme. It is hoped that these range hoods will work when needed and will not turn on when not needed.
- The general approach seems sound. The market research identifying barriers (noise level, capture efficiency, etc.) is valuable and the lab testing will provide valuable learnings regarding the efficacy of removing pollutants from the air. There is skepticism of the assumption that the most viable answer is a control strategy that relies on sensing specific pollutant concentrations instead of a simpler control solution.
- It seems like a way to help eliminate contaminants in a home from cooking in order to enable homes to be constructed more tightly for energy savings.
- The project approach is sound.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.67** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- The importance of exhausting pollutants from the kitchen is well known and understood in the building science community, but it is apparently less well understood by the general public as evidenced by the overall lack of use of kitchen range hoods and lack of accountability in the manufacturing industry for capture efficiency and quiet operation. All of that is changing, creating a market and opportunity that is ripe for implementation of smart range hood technology that doesn't require much user knowledge or interface - it just has to work. Program goals to improve IAQ in tight homes is directly linked to having functional and reliable equipment like smart range hoods to capture and remove pollutants when needed with minimal user intervention. The project goals squarely and positively impact program goals.
- The project has quantified impact (1.4 quads), but it's a stretch.
- With cooking leading to a good number of contaminants in homes, it addresses BA's goals of improving IAQ in energy efficient homes.
- There is a very large market for a range hood that actually removes pollutants automatically with operation that is minimally noticeable to the occupants. However, the proposed solution is overly complex, potentially prone to high failure rates, and likely to come at a high price point. It is anticipated that the potential for high failure rates due to the reliance on specific pollutant sensors (how robust are they?), which may or may not be reliable in a wide range of home/appliance configurations and occupant behaviors (e.g., will the same sensor

strategy that works for cooking bacon on the front burner of the stovetop be just as effective at removing the CO surge at light-off that some ovens experience?).

- This solution definitely makes a contribution, but how much of a contribution is unclear. There are some other "smart range hoods" out there that at least use just temperature sensing to turn on and off, and this technology would need to be much better than those. And regardless, how much of indoor contaminants are from cooking? The product seems well on its way to commercialization, regardless. The energy savings impact in unclear. And if it causes the fan to run a lot more, it could cause more energy expenditure.
- There is only an indirect link to the overall energy efficiency goals.

C. Progress

Based on current project efforts, the project was rated **3.67** for the degree to which the project has met ***project-specific goals***.

- Project progress to date is outstanding and expected to lead to product commercialization in 2020. Testing and effectiveness of 1st and 2nd generation prototypes is impressive, very promising, and demonstrates the significant progress that has been made.
- The Reviewer has no comments and the project is on track.
- Initial prototype development and evaluation in a laboratory is complete, with good results. Next step is field testing, which will occur in the remaining months of the contract.
- As noted in the comments on the overall approach, the team is making good progress on chasing down answers to the project specific challenges. It seems like they came into the project with a pre-conceived notion of what the answer would be and it is limiting their creativity in exploring alternative solutions to the control strategy.
- The project seems right on target and is getting to the final phase before commercialization.
- It is difficult to assess because most information on the prototype was held as proprietary information.

D. Collaboration and Coordination

This project was rated **3.83** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination are comprehensive and well-designed to achieve project goals working with and through project team members and stakeholders.
- It doesn’t get better than working with Broan and LBNL.
- The team has engaged with leading researchers in the residential IAQ field. Additionally, they have collaborated with a major range hood manufacturer that will give them an avenue to making their development readily available in the marketplace.
- The team is tapping into a good base of partners. However, the oven/stove manufacturers should also be in the mix, as well as ANSI in their role as the standard setting body for oven performance. Addressing the venting issue is a great step forward, but the source of the problem is really the oven/stove itself and the problem is entirely solvable. An integrated control that marries the appliance to the fan operation would be worth exploring, as would separating the issue of pollutants generated from cooking versus those generated from burning fuel – the latter being something that could be vented outside at the point of combustion. Getting the range hood to work is a good start, but it's only part of the problem.

- The project seems tightly coordinated with Broan, with a clear path to commercialization.
- They have excellent stakeholder involvement, including a manufacturer who appears ready to go to market.

E. Remaining Project Work

This project was rated **3.17** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The remaining project work is logical and necessary to prove the performance and effectiveness of the smart range hood technology that has been developed through this project. While remaining project work is expected to mirror laboratory findings, it is never a given that will be the case. The best one can say at this stage before final field trials is that it is likely to meet project specific goals based on the test results to date.
- The project is on track and almost complete.
- Remaining work will focus on field tests. After successfully proving the performance in laboratory tests, it will be important to conduct field evaluations to uncover any unforeseen issues.
- The team will be successful in creating a marketable product based on their selected strategy.
- Testing with homeowners is the next big step before commercialization.
- The time for customer field studies seems a little short.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include the automated nature of the product and the focus on quiet operation and capture efficiency.
- The team is working with Broan and LBNL. They have a clearly defined current state and expected outcomes. The product is needed.
- They have good collaboration with leading researchers and a manufacturer who can bring the product to market.
- They have an innovative technology that could improve IAQ.
- They have a good test plan to date.
- The market research results are interesting and useful. The lab testing to understand which pollutants are being produced and how to control them is invaluable. Refining the fan/hood design to minimize noise, optimize capture rates, and improve overall efficacy is also very valuable.
- Clearly, this is a problem that Broan thinks is worth solving. The solution seems to work. It has a high likelihood of resulting in a commercial product.
- The project has a good test methodology.

2. Project Weaknesses

- The main project weakness lies in the reliability and longevity of smart range hood sensors.

- Is it over-engineered (better defined cost of sensors versus energy/IAQ benefit)? What are the energy benefits versus a system that turned on when it sensed heat? How much more would this system cost? How long will IAQ monitors last versus a thermometer in the hood?
- There are questions on the complexity of the control scheme and its robustness. You don't want the product to be introduced and not perform as desired, thereby putting a black eye on the prospects of smart range hoods (e.g., see heat pump water heaters).
- The assumption that a complicated pollutant-specific control strategy is the best solution is too limiting. We need solutions that are viable to the mass market and robust enough to manage IAQ in a wide range of house/appliance/consumer scenarios at an affordable price point. It is difficult to see this solution fitting that set of criteria.
- Field testing with homeowners will tell a lot. Ultimately, do people want to pay for the technology and will they realize/value benefits from it?
- It is difficult to assess because of information held as proprietary, but it is unclear if this is an over-complicated approach and whether a simpler solution could be found.

3. Recommendations

- Though it wasn't addressed in the project presentation, care and maintenance of sensors and ease of replacement of sensors seem to be keys aspects of assuring proper operation and long-term achievement of program IAQ goals.
- The Reviewer’s favorite aspect is the focus on efficacy, sound, and capture efficiency. Automatic control based on IAQ sensors is less valuable (see previous comment on temperature control).
- Think about the control schemes that will be available to the customer. Assuming that there will be some sort of option for manual override, what will motivate the customer to keep the unit in the smart mode?
- Include stove/oven manufacturers and ANSI in the stakeholder engagement process. Be open to the possibility that a simpler solution might be just as effective (possibly better) and more affordable.
- You could potentially run comparisons of this hood against not just no hood (or a hood not turned on), but also against a temperature-sensing only hood. What is the benefit versus the additional complexity/cost?
- Evaluate heat control rather than using complicated sensor technology. Or explain why heat does not work.

Project #11150f: Achieving Affordable Zero Energy via Zero Energy Ready Homes

Presenter: Pat Huelman, University of Minnesota
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most reviewers agreed that the project approach was thoughtful and well-designed. At least three reviewers believed that the project offered a fresh and unique approach to designed-in building construction that would prove foundational in future work in this field. Furthermore, most reviewers were optimistic that the project could prove impactful in contributing to program goals, with two reviewers highlighting the reduction in labor costs. However, some reviewers expressed concern that the current level of funding and industry cost share committed to this concept would not be enough to move the dial forward and that current economies of scale would not make this viable for smaller scale builders. One reviewer suggested that the project needs to demonstrate adoption outside of the pilot in order to expand the impact of this project.

Most reviewers agreed that the project has made significant progress despite the novel approach to building construction being implemented and the inherent complexities of new home construction. However, one reviewer implied that this project will not be completed when funding runs out. Another reviewer suggested that this project could lead to a follow-up project that engaged more builders in the industry.

The reviewers commended this project for its overall collaboration and coordination with key stakeholders, citing the strong partnerships that were formed with large home builders and the wider building community. Two reviewers were particularly impressed with the level of buy-in that was achieved to enable builders to accept significant changes to their construction techniques. However, two different reviewers suggested that the project – having demonstrated proof of concept – should be expanded to even more builders, specifically those in the manufactured homes industry. Overall, most reviewers believed the remaining project work was on-track to be completed within the timeframe. However, one reviewer expressed concern that it would be “impossible” to complete the plan in the given timeframe.

Weighted Average: 3.50   # of Reviewers: 6
Approach: 3.50   Impact: 3.70   Progress: 3.30   Collaboration/Coordination: 3.50   Remaining Work: 3.70

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will use the feedback provided by the reviewers to inform potential updates to this project as deemed appropriate.

A. Approach

This project was rated **3.50** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach is thoughtful, thorough, and unique, bringing to fruition a fresh look at a decades-old technology that serendipitously addresses current challenges related to construction labor, commodity pricing, and speed of dry-in.
- The novel approach to building construction being demonstrated in this project is of great interest. This early stage proof of concept should lay the foundation for continued work to further explore the true market potential for this technology.
- The project was well designed and very aggressive considering the unknowns of this new design and no knowledge of construction hurdles that would be seen.
- This approach is a new and plausible route to designed-in higher quality construction (thermal, infiltration, etc.), because there are fewer places where on-site labor can make mistakes.
- Beyond the initial application to single-family, 2-story, moderate-income housing, housing lots of extensions are conceivable. Examples include: 1) townhouses for seniors, with enough linked to justify the cost of an elevator to serve the units on the second floor; 2) regular-market townhouses, where shared (fire)walls might become acceptable with package of OSB-drywall-OSB.
- Crane time is undoubtedly a significant expense. As the market develops, pre-assembled modules (kitchen, baths) could be lifted, dropped in, and located for hook-up before close-in (e.g., the second-floor work performed between floor installations and ceiling/roof trusses).
- How does construction waste weight and volume compare across systems? Haulage/disposal costs and impacts matter, and may matter more with this type of construction.
- Still, the devil is in the details, such as:
    - Production-friendly ways to insert and seal windows and doors with continuous insulation.
    - Handling ceiling fans and other second-floor penetrations with assured sealing – just as for any other construction type.
    - Designs that accommodate supply and drain lines for second floor baths. (Could these be boxed-in? Or in partition walls?)
    - Making it “future-resistant.” For example, the extended baseboards and door frames must be accessible so that things can be changed as necessary. Think about the aesthetics, labor needed, and ways to move outlets and switches to surface locations on exterior walls.
        - Construction is likely to be easier with crawl spaces or basements than with slab-on-grade, just to allow for installation and servicing of the first-floor plumbing and other items. How do costs compare with slab on grade installed with proper cold-climate slab insulation?
- The project team's approach to develop, install, and validate the moisture-managed, site-fabricated building system is commendable.
- Taking a whole building construction concept to execution in real buildings is not easy. Impressive work has been done to date.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.70** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Project impact on achieving program goals is undeniable and is reliably and easily repeatable.
- With further technological development and lower costs, this approach to building construction could be highly impactful for production builders and some segments of the multifamily sector. It does not currently appear to be a viable option for smaller-scale builders or custom home construction, as it would require some economies of scale not available in its current form. However, with further development, the market for this technology could expand.
- I don't know if this project can have the needed impact to move homebuilders to this system. The level of funding needed to demonstrate more buildings and different assembly techniques doesn't seem to be available. The housing industry needs to commit more effort and cost share in order to push this concept forward. If this system were fully adopted, the measured energy savings and air tightness numbers would have a large impact on energy use.
- This is a very promising approach, because it addresses the decline of lumber quality and labor skills and availability. The approach would require a lower level of labor skills on average; the methodology itself can result in fewer errors; and the approach utilizes very low-quality timber to make the oriented strand board (OSB), which is the major building component. The methodology can dispense with the whole drywall step. In addition, the expected energy performance is higher: quality is designed in rather than inspected in.
- Production builders are probably the most likely to understand the single enclosure contractor model. It is important to show them how it can help them with both quality and cost by taking away nasty issues like inspections and blower doors tests for enclosure tightness, by establishing consistent performance records for RESNET and others.
- That said, the project's impact will depend strongly on external factors, such as market demand for higher quality construction that can be completed faster and cheaper; potential trade allies getting interested in the market for pre-fab kitchens and similar items that result in additional construction economies (such as items that can be dropped in by crane).
- The project's impact is expected to be outstanding considering labor savings, as well as the system's high performance in the areas of moisture management, air infiltration, and energy use.
- The project still needs to demonstrate adoption outside the pilot. A market potential study would be helpful. Key markets may be affordable housing developers and smaller new builders. Markets may also be stronger in regions where factories producing the required materials are accessible.

C. Progress

Based on current project efforts, the project was rated **3.30** for the degree to which the project has met ***project-specific goals***.

- Project progress clearly demonstrates proof of concept. Subsequent builds should improve on the efficiency of the solid panel system and its ability to speed up construction while at the same time reducing builder risk and delivering a high-performance building to owners and occupants.
- This project has progressed remarkably well, given the cutting-edge nature of this construction approach and the inherent complexity (and uncertainty) associated with any demonstration project that requires the construction of new homes using new techniques in multiple locations.

- The project will not be complete when its funding runs out. More time is needed to study the new homes being constructed and compare the different wall systems to the "perfect wall" system.
- It is possible that better planning would have identified potential building code issues earlier and enabled them to be resolved more quickly. But this statement may be 20/20 hindsight in that I do not know the details of what they did and tried to do.
- The project will substantially meet its goals. As is to be expected with projects that involve real construction in the field with real owners and real contractors, there have been delays and changes that the principal investigator could not control. That's the only critique I can make concerning progress, and it seems the team is handling it as well as possible.
- The project is in its final stages, namely: energy monitoring, enclosure and system commissioning, and analyses and reporting. With several moving parts (including stakeholder involvement), the project team has successfully kept the scheduled timeframe tight, which is commendable.
- Progress is strong for such a complex project as a new way to build a house. This could be worth a follow- up project that engaged more builders. Getting code approvals and construction scheduling in place would allow broader testing at a lower project cost.

D. Collaboration and Coordination

This project was rated **3.50** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Project collaboration and coordination with key partners and stakeholders is impressive and contributes to realizing the project goals. Without significant collaboration and coordination, getting a new and novel construction method off the ground would be nearly impossible. The project team has done an excellent job of interfacing with the building community and key stakeholders to achieve the buy-in necessary to prove the concept and realize all its benefits.
- The team has forged strong partnerships with key stakeholders to ensure this project could be executed as planned. Getting builders to accept a wholesale change out of their construction techniques, even on a demonstration basis, is no small feat. Ensuring these demonstration buildings made it through the permitting and code compliance process and keeping them on schedule is equally impressive.
- Several large home builders are participating in this study. The team has done good work in measuring and comparing performance. The aggressive goals of this project and the unforeseen hurdles have delayed overall completion and exhausted their main funding source. This may have been unavoidable due to the unknowns associated with this new construction technology.
- The team is doing the best job possible, given the challenges in working with builder schedules and their slippage, drop-outs, and other vagaries of the larger construction world. There was less outreach than might have been expected, such as inviting contractors to watch the process. Today, YouTube videos are a great way to reach important audiences and stimulate interest in emulation – or is that still premature?
- The project team has established excellent collaboration with stakeholders. The team may want to extend their collaboration to the manufactured homes industry. The project's approach may help optimize or improve overall cost savings as well as onsite construction related issues in that industry.
- Engaging with more builders now that the concept has been tested would be worthwhile.

E. Remaining Project Work

This project was rated **3.70** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- Remaining project work will only further solidify the benefits and viability of the SPS construction model and make a clear case for this construction method being more widely adopted, leading to greater realization of project and program goals.
- It appears the team has the project well on track to complete the remaining work, and we look forward to seeing the monitored results.
- The aggressive goals and unknowns of this new construction technology has made it almost impossible for the team to complete the entire research plan in the time remaining.
- The project seems to be under control as per the scope of work.
- The project will likely complete project-specific goals within the timeframe, based on the project's work schedule and the record of accomplishments.
- The project has provided good documentation regarding its accomplishments. More pilots need to be conducted now that the systems are more evolved. But that is for the next phase.

F. Additional Comments and Recommendations

1. Project Strengths

- All project strengths flow from the "perfect wall" assembly. Other strengths include the speed and efficiency the construction method affords, as well as less need for skilled labor and protection against commodity price fluctuations.
- The project is demonstrating a highly innovative technology. The project was well-planned with well-selected strategic partners and locations to ensure success in maintaining construction schedules and specifications. The overall approach, including building homes using other high-efficiency techniques for comparison purposes gives the project additional credibility.
- This work is great and pushes construction technology into some unknown territory. These are great projects for DOE to fund because no one else can justify the risk; everyone just does the "same old same old."
- The "big deal" is the use of very large, thick OSB panels as the principal structural elements, replacing both stud construction and the structural insulated panel approach. Using 8'x24' OSB panels as the structural shell was a risky step in the conservative world of residential construction. They took it, they have documented it, and largely persuaded an initial group of its viability. One production builder has already adopted it for all its projects!
- Other than the OSB panel approach, the basic elements are familiar to the industry: 'regular' windows; the crane is already on site to install roof trusses, so it can also place the OSB panels and perhaps interior pre-fab assemblies (baths); and there is no change in the foundation technologies usage, but these can be adapted as advanced methods are introduced.
- The project has the potential to greatly decrease time-to-enclosure, and hence compress the schedule for interior work. In addition, it can eliminate important steps like drywall and finish.
- Perhaps as important, this approach offers a challenge and opportunity for sole-source responsibility of all major construction steps for envelope completion.

- The approach is likely to become almost inherently result in low air leakage, holding out the possibility of certifying contractors in a much shorter time than that required for blower-doors or other certification methods.
- The project strengths are its development of a moisture-controlled, high-performance enclosure in a residential building, and its onsite analysis (energy usage, moisture management, air infiltration) used to study the impact of the novel enclosure.
- The project's strength is the strong and repeatable envelope performance from site-built alternative construction materials. A lot of good work was done to get these homes built.

2. Project Weaknesses

- The novelty of the construction method may be its weakness, until the novelty wears off. Structural capacity in high seismic zones is also a weakness.
- No specific weaknesses at this stage of development and testing. We look forward to seeing the final results.
- There are too many unknowns in the construction of a new technology house to meet the time schedule; this may be unavoidable.
- Greatest savings will come with economies of production scale, which will provide opportunities for learning-by-doing for all participants. Optimistically, one hopes that this demonstration will support that expansion. The single envelope contractor business model may be initially challenging for non-technical reasons: access to capital, the advantages and disadvantages of full-time contractor employees versus sub-contractors (which can be employed as needed), the risk model for insurers and bonders, and similar issues.
- The project has no weaknesses.
- This technology probably will need additional support to be more broadly adopted. The team will need to convince more builders to participate in pilots. Who will be the funder for these pilots, as this is more or less an "open source" design? More public funding may be needed.

3. Recommendations

- Continuing working with and expanding outreach to more production and low-income homebuilders.
- A closer look at the potential to lower costs would be helpful and help better quantify the potential market for this technology.
- Try to promote this building technique to more builders in different parts of the country. Are there areas where these new types of materials would be more readily available? If so, focus on builders in that area to get more uptake.
- There is LOTS more to do to continue exploring the limits to growth of the technology suite being introduced. Some of the work to be done after this project involves further integration of prefabricated "internals" such as bathrooms into the workflow so they can be installed by cranes. Other opportunities include extending the business model from single-family houses to townhouses, and the all-important issues of easy and reliable service connections (ceiling fans and lights, plumbing fixtures) to points of installation.
- The project team is encouraged to work with manufactured home industry. It would also be worthwhile to study the impact of this novel enclosure in other climatic zones.
- Fund another stage of pilots but require a greater percentage of co-funding.

Project #11150g: Performance-Based Indoor Air Quality (IAQ) and Optimized Ventilation

Presenter: Bryant Hains, Southface Institute
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Reviewers offered mixed opinions on this project's overall approach to overcoming barriers by using smart, low-cost sensors to measure humidity and optimize ventilation in homes located in hot-humid climates. Reviewer comments on the project team's approach ranged from "excellent and thoughtful" to "reasonable and sound" to one reviewer concluding that the approach "may not lead to overcoming the challenges." In addition, another reviewer expressed concern that the small sample size of buildings (four) made it difficult to draw conclusions regarding the approach. Similarly, most reviewers were hesitant to attribute this project as having a significant impact on program goals. Several reviewers described the impact as being limited because of several factors including: 1) perceived risk adoption by builders, 2) competition with other products, 3) limitation to ERV market, and 4) lack of direct links with manufacturers. However, despite the early stages and limited scope of the project, two other reviewers cited this project's impact – specifically its role in field validation – as being an important building block for larger-scale field studies in a potentially huge hot-humid builders' market. Another reviewer was optimistic that this project's improvements to BeOpt and collaboration with Senseware would also have a lasting impact.

The consensus among reviewers was that, although the project team had encountered initial setbacks, the team has made significant progress on its project-specific goals. Only one reviewer (out of seven) was concerned that the team had not made enough progress to complete all of the goals within schedule. Similarly, most reviewers commended the project team for engaging in a high degree of coordination and collaboration with relevant stakeholders. Reviewers were impressed with the selection of industry partners, including Broan/Venmar and Beazer, and the inclusion of a public health group. This robust degree of coordination combined to generate a diverse project team with different perspectives.

Most reviewers believed that the project team was on pace to complete the remaining project work. However, two reviewers remained apprehensive that remaining data acquisition would creep into the time available to complete reporting and develop outreach materials, including important guidance documents for builders. They also noted that significant and time-consuming analysis remained to be done. The other five reviewers expressed no such doubts, though some acknowledged that there was still a lot of work to be done.

Weighted Average: 2.92   # of Reviewers: 7
Approach: 2.86   Impact: 2.57   Progress: 3.14   Collaboration/Coordination: 3.14   Remaining Work: 3.00

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **2.86** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Project approach represents an excellent and thoughtful approach to squarely addressing builder concerns regarding the need to provide a ventilation system and consequently, the need to build tight and energy efficient homes.
- The issue to address in this project is to encourage the use of smart ventilation system that can control the humidity in low-load homes in climates with high humidity. The challenge is to convince builders that this system will not increase humidity, and therefore, the project uses low-cost sensors to measure humidity, temperature, CO_2, and PM2.5 and Radon levels in four Charlestown homes equipped with this type of smart ventilation systems. The data collected is hoped to show the acceptable level of the parameters.
- The research approach is reasonable and sound to test a novel low-cost option for ensuring proper operation of home ventilation systems. The context of proving the system works for risk-averse builders is important and needs to be addressed, so this early stage research is an appropriate investment for DOE.
- The team used four houses, equipped them with the different ventilation options, and began measurements. This is a good approach, and this reviewer liked that they worked with NREL to add the CFIS to BEopt. This is very good.
- The principal barrier is builder reluctance regarding costs and inadequate humidity control (mold damage).
- The project is well-designed to develop a lower-cost solution for hot-humid climates, by adopting a smart ventilation system that controls by pollutant level (including humidity) rather than minimum ventilation rate.
- The excellent experimental design will reassure those who influence builders.
- The principal technical challenges include the following: sensor sensitivity, stability, service life, and cost. The team can’t control most of these, but they will be critical to field acceptance. How will a device signal end of life? Are they within striking range of low-cost, commercialized sensors for formaldehyde, which affects many people below its detection limit?
- Significant fractions of the target region may not achieve adequate Rn control with living area ventilation area alone. On the other hand, Rn risk is cumulative, not acute, and the short-term fluctuations that will be picked up by real-time monitors are largely irrelevant. This project should not let builders infer that radon control strategies are unnecessary in some areas.
- User interface is what actually matters to residents. As with current carbon monoxide and smoke alarms, all sensors must signal both out-of-allowed-range and end of (expected) life. But, it gets complicated. The simplest example is the case of very high PM2.5 from outdoors (downwind of forest fire), which requires shutting down outside air. But, how can it differentiate from some transient indoor event (smoker visit)?
- The project can’t address some of the technical barriers within its scope, but is very well designed within it.
- The project team's approach, based on their presentation, may not lead to overcoming the challenges.
- The limited number of buildings makes conclusions hard to draw. However, improvements to BeOpt and collaboration with Senseware have impacts outside this project.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **2.57** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- The project impact on program goals, assuming program goals are met, still seem dependent on whether a builder is willing at accept some perceived risk of providing good IAQ to future purchasers by providing a system that provides less than a continuous exchange of air. The project is in its early stages yet, so this reviewer is looking forward to seeing results from a longer monitoring period.
- The impact is likely to be limited, as there are other competing products that may address the same issue. However, the cost may be the determining factor for the builders. It is not clear that if builders see the results and prices, they will surely use the suggested system.
- Given that this control solution is reliant upon ERV operation, the solution being tested will be limited to the ERV market, but the learnings are potentially transferable to other ventilation strategies. Low cost solutions that take the guesswork out of the operation of ventilation systems will go a long way toward winning over the confidence of the builder market.
- Homes must be tighter to provide more energy savings. This work will help hot/humid builders see that tight homes can be built and still be comfortable. This section of the country is a huge market and this project will help educate hot/humid builders.
- Impact of a single brick (project) to the entire industry is hard to estimate. This project is an important “brick”, doing field evaluation (and working with manufacturer and builder) of one strategy to provide acceptable ventilation for a very challenging region. Kudos! The likelihood of impact is maximized by effective collaboration of diverse partners, but they should have been encouraged to implement a more robust outreach activity. Developing “actionable guidance” is just one step on a long road, as Building America and the EnergyStar programs have shown.
- This is a good project. It is well worth building on in larger-scale field studies, multiple approaches, and more downstream (outreach) activity.
- Several questions remain at this time.
- Technology development projects such as this struggle with obtaining larger impacts without a more direct link with a manufacturer. Upgrades to BeOpt and Senseware IAQ offering will provide some continuing impacts.

C. Progress

Based on current project efforts, the project was rated **3.14** for the degree to which the project has met ***project-specific goals.***

- Project progress is on target and producing intended, if not expected, results.
- The progress has been good as collaboration with stakeholders such as LoT and Broan/Venmar companies on equipment & sensors, with NREL for modifying BEopt as needed, and with UL to use their Environment's chamber for comparison of sensor performances has been successful. In particular, the four homes were instrumented using the hardware needed to measure the IAQ parameters. Extensive data has been generated.
- After getting over a few startup hurdles, the team seems well on their way to completing the project on schedule with meaningful and actionable results.

- This project seemed to have a jerky start, but is running as expected finally at the end. Although it doesn't seem possible that all of the analysis and reporting goals can be completed by the fiscal end of the project. The team still needs to push this forward and double their efforts to educate builders.

- Despite early set-backs requiring no-cost extension, progress has been very good. It will make a significant contribution.

- Overall, the progress (to project-specific goals) is good.

- Progress seems to be being made after a delay.

D. Collaboration and Coordination

This project was rated **3.14** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination is good, with appropriate stakeholders and knowledgeable participants contributing to all aspects of the project. This reviewer especially appreciates the diversity of the team members and inclusion of public health expertise from a local university.

- Extensive collaboration with stakeholders has been shown, including the following: Beazer, Broan, NREL, LBNL, and UV Environment.

- The team did a good job selecting industry partners to ensure the project will produce a robust and meaningful set of outcomes. Given the nature of this early stage product development, it is not expected that broader stakeholder engagement is appropriate at this time.

- The involvement of a fairly high-volume, low-energy home builder (Beazer) was a key for the success of this project. The team seemed to work well with the builder, but they had trouble with sensors and instrumentation at the beginning. The team did a good job solving these issues and getting the four homes up and running with the different ventilation options provided by Broan/Venmar.

- Bringing together public health group, equipment OEM, controller OEM, and experienced field studies team to really work together has been unusual, and these folks seem to have “nailed it”. Kudos.

- The project team's collaboration with sensor manufacturers and other stakeholders is commendable.

- Senseware collaboration seems strong. It’s unclear what the impacts will be for builder and ERV manufacturer. Broader lessons will be limited by the number of test sites and the sensor error/drift. Ventilation control that relies on sensors with the potential for errors that could remain undetected by the homeowners seems risky.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals*.**

- The remaining project work is essential to proving or disproving the value of the smart ventilation premise.

- The remaining work seems reasonable, including collecting more data, analysis of the results, ending the testing, and dissemination of the results, including development of guidance for builders and designers.

- The team has a solid plan to complete the project for this early stage research.

- It does not appear that the team can complete the measurements and reporting before the end of the project. With the homes running and data being generated, the real work is the analysis. This reviewer hopes the team will complete this work and push their findings in presentations to hot/humid builders.
- The only concern is that the data acquisition and test-out phases might compress the time available for both reporting and for developing outreach materials, the all-important "actionable guidance for builders and designers."
- At this time, the project team can achieve their project-specific goals by 9/30/2019.
- The remaining plan seems strong given the available number of sites. But, there's a lot to do by September.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include taking advantage of smart ventilation strategies and IAQ tools that were heretofore not available to attempt to optimize ventilation in hot humid climates to squarely address builder concerns.
- Generation of field data is a project strength.
- It is a low-cost strategy aimed at resolving a specific market barrier (builder risk aversion). The inclusion of UL to validate the sensor reliability and Emory to assess IAQ impacts is smart, in spite of the timeline setbacks incurred as a result of the need for IBR approval. This reviewer is looking forward to seeing the final results.
- The field measurements in four similar homes with the different ventilation strategies are great. The results must be used to develop best practices for hot/humid builders.
- Someone had great vision in inventing this project. They found the right collaborators with the right skills and "chemistry" to do more than the sum of the parts might suggest.
- It is a fine formal experimental design. It's the best that could reasonably be expected with any budget limitations.
- The team had great success in getting co-funding from industry partners: they care about this project's potential.
- Field validation (using low cost sensors) of smart ventilation system is important. This will help assure that homes comply with ASHRAE 62.2 ventilation requirements.
- Providing input to Senseware on development of low cost IAQ sensor package is a project strength, as well as the expansion of modeling capabilities.

2. Project Weaknesses

- As of this early stage, the wide range of PM2.5 sensor readings and the knowledge that smart ventilation doesn't lower pollutant concentrations as much as continuous ventilation appear to be weaknesses.
- For the scope of the project and the objectives, the project seems to have met the target outcomes. However, comparison with a conventional condition to serve as baseline seems is missed.
- The ERV market is inherently limited, at least with current ERV technology. While it may be the technology of choice for humid climates, the price point may still be prohibitive even with low cost control strategies.

That is not necessarily a weakness, just context for the potential reach unless the sensor/control strategy is replicated for other ventilation strategies.

- The team changed some at the beginning, and they had a difficult time getting all of the sensors to operate and measure as intended. More of a focus on sensors was needed at the beginning.
- Initial delays in getting all the pieces pulled together, not surprisingly, have led to a lot to do to wrap things up and get the important messages out. This reviewer hopes there will be follow-on work.
- The following are discussion points that will potentially improve overall project-specific goals:
    - Multi-variate linear mixed regression modeling (slide 15)
    - Beta_6: how is this input?
    - Why is the location of the house not included (for example, house located in CBD may have a different characteristics / IAQ)?
    - Beta_3: how is this input?
    - Is this the centroid distance of the sensors?
    - If the sensors are low-cost, why not use more sensors for testing and validation?
    - Why restrict the use to only two spaces/zones?
    - Was collinearity tested prior to identify the variables?
- The project team used an existing sensor manufacturer and did not develop a new sensor system. Why weren't other sensors (low cost) attempted?
- It's uncertain where this project goes from here. Are the sensors reliable enough to use? Is the data actionable enough to stimulate partners to make further investments?

3. Recommendations

- It is recommended that the team should make sure there is a good correlation between safe pollutant levels and the pollution levels measured during smart ventilation operation and if not, the team should make adjustments to the ventilation algorithms as necessary to achieve the appropriate healthy correlation.
- While it is too late for this project, it would be useful to see comparison with other products and, also, if not, a ventilator could be used. In that case, for realistic data, the behavior of occupants in using fresh air needs to be considered.
- It's suggested to keep going. More testing is needed (the sample set is small). The team should consider replicating for other ventilation technologies.
- Care must be given to the data analysis and much thought must be given on the best way to present the results to builders. These results shouldn't just sit on a shelf.
- More funding for more fieldwork with the same team with different houses is recommended.
- It's recommended that there should be some mechanism to forward-fund follow-up after five years instead of immediately removing the field instrumentation. The only alternative is accelerated aging of the field gear, and that not nearly as good.

- The monitored homes could have been spread over the region (with the same builder).
- More low-cost sensors could have been used for monitoring, considering the entire project budget was $661,000. With more sensors, the project team could have studied/analyzed the data and suggested an optimal number of sensors required for such monitoring. This may have been a wasted opportunity (this is a big surprise!).
- The team should enhance the focus on sensor reliability issues.

Project #11150h: Ventilation Integrated Comfort System

Presenter: Srikanth Puttagunta, Steven Winter Associates
DOE Manager: Eric Werling

Brief Summary of Reviewer Comments

Most reviewers were satisfied with this project team's approach to overcoming barriers, technical challenges, and mitigating project risks. Reviewers were overall supportive of an integrated, whole-house system that combines heating, cooling, and ventilation into a single package for low-load homes. One reviewer believed that the limited scope of the project was important because early success would lead to wider industry acceptance down the road. Similarly, another reviewer was optimistic that successful pilot implementation of this project would be in line with the result from the prototypes. Some reviewers conceded that more development would be required beyond the project in order to determine market readiness but were confident that this project's approach and subsequent documentation would lay the groundwork in a growing market.

Most reviewers were confident that, if the project-specific goals were met, this project would contribute to program goals, including an overall improvement in indoor air quality and a reduction in energy usage. Two reviewers cited the affordable cost as a primary reason for this product's eventual success. However, reviewers offered some caveats that may affect the long-term impact of this project. Two reviewers noted that this product would need to be successfully commercialized and readily adopted by HVAC contractors. One of those reviewers also highlighted the need for building codes that require ventilation and HRVs. A different reviewer also noted that energy savings would be very dependent on the climate in which this technology is implemented, and thus significant percentages of residential energy may not be saved.

All reviewers commended the project team for its progress on project-specific goals and noted that "significant" progress had been made to date. One reviewer lauded the product's value proposition and believed it would prove useful for commercialization. Two reviewers believed that a significant amount of work remained to be done, including "non-trivial engineering tasks". Another reviewer would like to see cost studied in detail for actual implementation by contractors. However, the consensus among reviewers was that a lot of progress had been achieved on the prototype in a relatively short amount of time.

All reviewers believed that the project team had demonstrated a high degree of strategic collaboration and coordination with relevant stakeholders, including Mitsubishi and Therma-Stor. Reviewers were satisfied with the incorporation of key manufacturers on this project and lauded the team for its outreach with contractors, builders, and other industry groups. One reviewer specifically highlighted the different types of media employed by the team to achieve this high level of outreach. Similarly, most reviewers believed that the team had logically planned its remaining work for the remaining timeframe and that this would largely be focused on refining the prototype and reporting results. Only one reviewer expressed concern, noting that he/she was confused by the change of plans to install a unit in an office rather than a home.

Weighted Average: 3.39   # of Reviewers: 7
Approach: 3.43   Impact: 3.14   Progress: 3.57   Collaboration/Coordination: 3.43   Remaining Work: 3.43

Program Response

The Building Technologies Office recognizes peer review as an effective program management tool and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.43** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project approach is strong and aimed at reducing key barriers to implementation of HRV devices and associated separate ductwork systems. Success of the approach remains to be fully vetted through pilot implementation, but results are expected to be in line with results seen from prototypes.
- The issue the project aims to address is to provide an integrated system that will handle heating, cooling, and ventilation, all in one unit. The approach taken is to have in the first-place lower heating/cooling loads, small H/C equipment, and efficient VS fans. This is made possible in high performance homes as such homes use highly energy efficient building envelope and glazing systems, as well as roofing systems.
- The project seeks to develop a product that will solve the problem of providing efficient, reliable whole house heating, cooling, and ventilation in a single package to address the needs of low load homes. This is a critical gap in the market as we drive toward very low energy homes and there are currently no products commercially available at this time to meet that need.
- This is a small project that works directly with manufacturers and product developers. The limited scope of the project helps to ensure success, but also can limit industry acceptance. But, in this case, success is the most important factor, and they should, and did, do what it took to be successful.
- There are clear, well-stated goals and rationale (slide 2): install-ability, cost, and savings.
- The approach includes integration of commercial products (small ducted AC/HP, ERV/HRV, and lower cost low-capacity ECM), and adding physical and controls integration, without the need for new sensors.
- The project has a fine, manageable work plan.
- The project's approach will likely lead to contribute to overcoming technical challenges, however, there are a few questions that need to be addressed.
- This is a more complete product (compared to some of the other product development projects presented) being developed and tested in close coordination with a potential manufacturer of that product. This product will still require more development beyond this project before introduction but the value proposition and market potential seems strong and are being well documented by the project. This aligns well with other housing trends so it is a market that is growing.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.14** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- Assuming the project goals are met and the equipment is readily adopted by HVAC contractors, broad implementation of HRV can be achieved relatively easily, which plays an important part in achieving program goals. However, cost is not the only headwind – lack of code requirements for HRV or much less ventilation also mitigate against wide implementation until such codes are amended to require ventilation and HRVs.
- Given the clear energy savings this VICS system can bring, and also the more affordable cost, it is expected that this new innovative system will have great impact.
- If a product can be successfully developed and commercialized to provide all-in-one HVAC for low load homes, the potential impact is very large as many states have introduced policies supporting net zero-energy

new construction and carbon neutral existing buildings that are even more aggressive than DOE's goals. Heat pumps are on the table to be deployed at a rapid pace throughout the northeast in efforts to decarbonize homes and the currently available technology is sub-optimal to meet those goals.

- This type of device is not going to save substantial percentages of residential energy, but it does improve indoor air quality while saving some energy. The magnitude of the energy savings is very dependent on climate and restricts the universal application of this product given other options that may be more economical.
- There is good progress in demonstrating the value and feasibility of integrating an air-to-air heat exchanger (HX) with a heat pump air handler and coil. If the technical challenges can be met, this could have great impact on the market for efficient, low-risk, single-box mechanisms for providing adequate ventilation for high-performance, low-load homes. One of these challenges is just engineering a package that is short enough to allow space for plenum with good airflow in enclosures with 8 ft. ceilings.
- This is a significant contribution to project and DOE program goals, with an excellent path to market.
- There are non-trivial engineering tasks yet to be done (slide 16).
- There is a lot of outreach for input (surveys, etc.); much less obvious outreach effort for results, but that probably is more appropriate during the next phase.
- Overall, the project will contribute to the program goal.
- Reducing the cost of ERV installation and improving the performance and fresh air distribution are strong impacts that will support low energy home market development.

C. Progress

Based on current project efforts, the project was rated **3.57** for the degree to which the project has met ***project-specific goals.***

- The project has made significant progress toward meeting project goals and proving performance, and is fully expected to realize implementation.
- The project has made significant progress considering prototype design and testing, with quite encouraging test results.
- While there is still quite a bit of work to do before this product is fully commercialized, the team has succeeded in making it past some critical milestones to solve a complex set of problems in a short amount of time.
- The team has successfully developed a working system that has market potential. Some refinement is needed, but they have been very successful.
- It claims to be at 80% of completion after 80% of contract duration and 83% of budget. Good concordance!
- This is a significant contribution to project and DOE program goals, with an excellent path to market.
- There are non-trivial engineering tasks yet to be done (slide 16).
- There is a lot of outreach for input (surveys, etc.); much less obvious outreach effort for results, but that probably is more appropriate during the next phase.

- At this time, the project has demonstrated significant contribution to the project-specific goals. The issue of cost has to be studied in detail for actual implementation by contractors.
- There was concrete demonstration of strong flow control in the prototype. Project team has done strong work on developing a value proposition and market research. These will be key for deciding to make further investments.

D. Collaboration and Coordination

This project was rated **3.43** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination is excellent, drawing on a wide array of project team members and stakeholders. The project couldn't have come this far without significant support, collaboration, and coordination.
- The engagement of stakeholders consisting of mainly Mitsubishi, and also Therma-Stor and Core Energy Recovery Solutions have been key to the success of the project, as design and testing has benefitted from such collaboration. The project has also used different media to disseminate the results. Furthermore, surveys have been conducted of various professional groups (builders, developers, contractors, designers, etc.) to obtain market feedback.
- The partnerships the team has developed to make this project possible seem to be working well and the outreach to contractors should help provide some important insights into the market needs. I encourage the team to continue to seek input from stakeholders engaged in programs and with policy objectives to reach aggressive low carbon, low energy goals. These entities are actively seeking solutions to provide comfort management in high efficiency homes without causing undue strain on electric grid demand or adversely impacting indoor air quality (IAQ) and this product can help with both of those issues.
- The focus of this project has always been to develop the working prototype and, therefore, broad industry involvement could not be the goal. The partners that have worked together with SWA (Mitsu, Trane, and Therma-stor) have been very successful helping SWA meet their goals. What other manufacturers will have interest in this kind of hardware?
- The collaboration and coordination is very good. The team includes key manufacturers with deep involvement. These people want to get a product designed, built, and into the market.
- The team has made excellent efforts to survey the builders about needs and issues.
- The project team's collaboration with stakeholders is commendable.
- The team has done lots of market research. More industry outreach is expected as more results are available and the product offering is finalized.

E. Remaining Project Work

This project was rated **3.43** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- Remaining project work is headed to production of a new type of mechanical equipment that has the potential to significantly move the needle with respect to home ventilation and heat recovery.

- There seems to be a change of plan, in that instead of installing a unit in a home, a revised version is now planned to be installed in an office. It is not clear what has led to this change of plan. Other parts that continue include market assessment and survey, and working with Therma-Stor to optimize the unit design.
- It is not entirely clear how much more work will be needed to further refine the prototype to a commercially viable design, but having solved some key technical performance issues, the team should continue its work to bring this product to market.
- The remaining work is only to refine their prototype and report results. They will easily succeed in this.
- Project will be tight for time, but will meet its goals, and further work is already in the pipeline. It is very promising.
- The fully functioning prototype (II): the project team will achieve the project-specific goals within the timeframe.
- Remaining work seems focused on defining the actual product.

F. Additional Comments and Recommendations

1. Project Strengths

- Project strength lies in proving the concept that HRVs can be integrated within traditional HVAC equipment to avoid the expense of adding a separate duct system, thereby reducing a significant barrier to implementation.
- The new and innovative integrated heating/cooling/ventilation system unit is the strength.
- It addresses a critical need in the market that is only going to get bigger over the next several years. The manufacturer partnerships have been key to getting the product developed to the point it is at today. The team's experience in field monitoring HVAC system performance over the years has proven to be valuable in guiding the overall concept and defining specific goals for the project.
- The focus of the team and dedicated industry partners has led to success on this project. The prototype had a much better chance of meeting goals when the number of people on the team were limited, and those people were very capable of developing this kind of product.
- It is a strong concept with good design through two prototype iterations.
- The team has a deep understanding of the challenges and barriers in getting the product into the market
- The team has excellent industrial partners, who are strongly committed for their own business reasons.
- The project takes advantage of new, low-cost technology, especially small, affordable, permanent magnet motors for the ventilation side and the main air handler.
- Combined system – heating, cooling, and ventilation – is unique and will potentially maintain adequate IAQ.
- The reduced installation cost is a project strength.
- This is a product with a clear value proposition and a partnership with a manufacturer that could build and sell this system. The work being done seems to align well with the product development requirements that a manufacturer has.

2. Project Weaknesses

- Further study of pilot installations will be needed to build a stronger case for switching to a system of this type. Building and homeowner concerns regarding the reliability and effectiveness of HRVs, regardless of where they are installed or how well they are balanced is still a hurdle to overcome. Ventilation and HRV's are not required by code in all jurisdictions.
- A comparison with alternative systems (ERV/HRV) would be good.
- Additional design work is needed to get the components into a compact unit that will easily integrate with low load home construction.
- The product does not save substantial energy and could be replaced by other options in a thorough economic/IAQ analysis.
- The size constraint of the proposed product, specifically enclosure height in most dwellings is a weakness.
- It is unclear how to overcome builder reluctance regarding outside air.
- Since AC coil is much higher than condensate, if ERV section is used (it will be at floor level (in vertical installations), some installations would require condensate pump just for the ERV.
- The apparent reliance on seasonal shift of ventilation rates to meet 62.2 may not be appropriate in some jurisdictions, because of concerns about potential acute pollutants reaching higher levels during low-ventilation intervals.
- Overall energy savings of 10% may not be a selling factor considering that the cost of this integrated system may be high compared to two separate systems.
- The product is still under development – what are the maintenance issues that may arise in the future?
- It is a full product, not just an enhancement to an existing product, so the amount of testing and development is greater than would be required for an add-on.

3. Recommendations

- The team should consider offering a maintenance plan to ensure equipment is operating correctly and is achieving desired savings.
- The team should perhaps develop a plan for marketing and application of the system. For example, it would be good to know the plan to get this system used in new homes. They should explain the basic difference between units for home vs. office.
- The team should consider working with programs and entities pursuing deep energy retrofits (e.g., Energiesprong model) in addition to new construction. Integrating a domestic hot water option would make the package complete.
- This project is complete for the most part. The project should have had more serious simulation work performed to show the possible benefits of such an H/ERV hybrid is various climate zones.
- Support for this work should be continued. The next steps are monitored field demonstrations. The project is relatively low risk if they can meet cost and dimension targets.
- The final end-user price (system cost, installation, maintenance) is critical for the project success.

- Multiple manufacturers are contributing to this project by offering their efficient systems. The team should discuss how a warranty will be applied; who/which manufacturer will provide a warranty?
- The vertical size should be reduced.

Project #12203: Integrated Design: A High Performance Solution for Affordable Housing

Presenter: Emanuel Levy, The Levy Partnership
DOE Manager: Eric Werling

Brief Summary of Review Comments

The approach to this project received a wide-ranging collection of comments from reviewers. Many of the reviewers approved of the project approach with one describing the understanding of the issues as "outstanding and highly focused." It was noted that manufactured houses often have unnecessarily poor energy performance due to construction details being overlooked by some manufacturers. A reviewer explained that the project's integrated design approach would be a smart strategy to address these issues. However, one reviewer disapproved of the project's approach and stated that "the study is more of a design nature than offering innovative and new ideas." It was also mentioned that the presentation ignored practices that are required for proper indoor air quality and ventilation in tight, manufactured houses and, in turn, an accurate estimate of the costs was omitted.

In general, the project impact was well-received among reviewers, recognizing its alignment with both DOE goals and project-specific goals. Reviewers complimented the project's contribution to standardizing energy efficient design and construction practices within the manufactured housing industry. Since the project demonstrated existing technology as opposed to a new product, a reviewer predicted that market adoption would be more wide-spread. Several reviewers stressed the importance of informing both the building community and the consumer of the technology benefits. The positive impact on economically disadvantaged populations was also noted in relation to energy and cost savings in the homes. On the other hand, one reviewer was uncertain whether the impacts presented would be realized.

Reviewers approved of the current progress and applauded the team's successful implementation of its approach strategy. Many of the comments included reference to the significant results achieved during the project and the impact that the project would have moving forward. The team's attention to comfort and energy savings was highlighted as well as their stakeholder engagement. In terms of collaboration and coordination, reviewers were overwhelmingly positive with five out of the seven reviewers awarding the project an "Outstanding." The wide variety of partners including manufacturers, research laboratories, and other industry stakeholders was celebrated by most reviewers.

Weighted Average: 3.39 # of Reviewers: 7
Approach: 3.14 Impact: 3.29 Progress: 3.43 Collaboration/Coordination: 3.71 Remaining Work: 3.57

Program Response

The Building Technologies Office recognizes peer review as an effective tool for program management and will appropriately use the feedback provided by the reviewers to inform potential updates to this project.

A. Approach

This project was rated **3.14** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The clarity and understanding of the issues to be addressed by the approach are outstanding and highly focused.
- The main objective seems to be developing an integrated design approach for factory-built housing that will be high-performance. In that context, it seems that the issue is to show how such a design can also be affordable and high-performing, comfortable, build-able, and energy efficient. Accordingly, the project would involve selection for products for building envelope and HVAC using point-source space conditioning. So, the study is more of a design nature than offering innovative and new ideas.
- Applying an integrated design approach to the manufactured housing market is a smart strategy. The individual components of these homes are necessarily built to be strong and tight to survive the shipping process, however, they are notorious for critical construction details being overlooked resulting in unnecessarily poor energy performance. Providing validated performance data to mitigate risk-averse builders is also smart.
- The initial research plan was valid and they were successful in recruiting industry partners.
- Clear, well-stated goals and rationale (slide 2): install-ability, cost, and savings.
- Integration of commercial products (small-ducted AC/HP, ERV/HRV, and lower cost low-capacity ECM), adding physical and controls integration, without need for new sensors.
- But, the data presented (and the presentation as a whole) completely ignore any technologies or practices required for adequate ventilation/IAQ in tightly constructed houses. Thus, we don't have realistic first-cost or operating cost data.
- Fine, manageable work plan.
- The project's approach will overcome technical barriers particularly in the area of affordable housing. Excellent work!
- There are a lot of moving parts here so it will be hard to demonstrate outcomes and impacts. However, the concentration of manufacturing capacity in this industry means that fewer parties need to be convinced to have a large impact. So, increasing the comfort of these large players with integrated approaches will be helpful.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.29** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- Alignment of project goals and programs goals is exemplary and clearly builds on prior and current Building America work.
- It seems that the impact aspect is tied to the overall Building America goals. The project intends to show that if they can produce manufactured homes that are affordable and high performance, then they have supported the BA goals of reducing the energy consumption in homes by 60% by 2020. While the design presented is fine, it is not clear if the impact will actually be realized.

- Standardizing energy-efficient design and construction practices into the manufactured housing market will have significant impact on its own. In addition, much of the guidance developed as a result of this research, particularly in terms of mechanical system design, can be translated to site-built, low-load homes, as well.
- This project has shown what can be done in a factory-built manufactured home to lower energy use; now the results of this study must be passed on to builders and dealers to promote the idea to consumers. The implementation of these energy efficiency measures could save homeowners money and reduce energy use substantially. This is especially important for the low-income buyers; they can save thousands over the life of the home. Good impact for low-income homeowners.
- The work is impressive: it lights a candle to begin illuminating the dark of these housing sectors. It engages stakeholders on the housing side while remaining feasible rather impressively.
- The project has done the best possible job to offer and document an approach for these housing stocks, which are very much driven by first-costs and (for manufactured housing) financing obstacles for "chattel property."
- This implies that the ultimate impact of the project depends on exogenous factors (public policy, finance, land use, etc.). Impact likely to be more modest than for some projects, since there are so many and such strong non-technical barriers to "zero-energy" housing than in the two addressed sectors.
- One threat is that the easy part (single-point heat/cooling) will be applied unsuccessfully if envelope defects are not systematically controlled.
- Still, the project is most worthwhile in terms of showing what can be done with well-thought-out, incremental approaches.
- The project will achieve program goals.
- Tough to measure, but this is a demonstration of existing technologies deployed in combination, so the threshold to overcome to reach larger-scale adoption is lower than for a new product.

C. Progress

Based on current project efforts, the project was rated **3.43** for the degree to which the project has met ***project-specific goals.***

- The project team has done an excellent job of tackling the thorny first-cost issue. Progress is impressive and undeniable and is expected to reap significant results going forward.
- The progress seems to be good and on schedule, as a typical manufactured home per design has been constructed and occupied, and performance data (temp.) has been collected to show the success of the design.
- This project has been underway for longer than the average BA project, but the long timeline is understandable given the project design requiring construction of multiple phases of homes and occupied long-term monitoring. It is a very ambitious project that seems to be on track to finish up soon.
- The team has completed 95% of the project goals. The only remaining work is the habitat home measurements and reporting. Good work.
- Project has successfully implemented its strategy in houses and measured performance. It is good. This was the principal goal.
- Project has also had great involvement with industrial partners.

- Excellent attention to both comfort and energy in occupied instrumented house (slide 12), but surprisingly there is a wide temperature excursion envelope (slide 14).
- The project claims to be at 80% of completion after 80% of contract duration and 83% of budget. Good concordance.
- Significant contribution to DOE program goals, with an excellent path to market
- There are non-trivial engineering tasks yet to be done (slide 16).
- Lots of outreach for input (surveys, etc.); but there is much less obvious outreach efforts for results, but that probably is more appropriate during the next phase.
- The progress towards project-specific goals is excellent.
- It takes time to get a lot of players onboard, but having more players onboard expands the impact of the demonstration project.

D. Collaboration and Coordination

This project was rated **3.71** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- Collaboration and coordination with stakeholders and amongst the project team participants is essential when addressing first-cost issues vs. long term/operational costs. Being able to implement and demonstrate the viability of the project efforts and goals is evidence of this outstanding level of collaboration and coordination amongst a team with the knowledge base and know-how to get things done.
- Stakeholders such as SBRA, Clayton, and Champion, and well as Habitat for Humanity, have been engaged, besides the material manufacturers.
- A wide variety of partners were necessary to carry out the multiple phases of this work. It is impressive that the team was successful in moving from lab designs to two different site construction techniques and actually monitoring occupied performance of the homes.
- The team secured the help of Clayton, Champion, and Habitat affiliates; these are the major suppliers for low income, affordable housing. The team has performed well.
- Excellent palette of partners who are seriously involved in all the relevant aspects.
- Collaboration by important industry partners who want to get product designed, built, and into the market is impressive.
- Excellent collaboration and coordination with stakeholders, including research organizations (NREL), home manufacturers, etc.
- Lots of collaboration with key players. Would like to understand more what those players consider success for this project? What do they want to see in results to be convinced to take next steps?

E. Remaining Project Work

This project was rated **3.57** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- Remaining project work to analyze and report on the data from the subject homes and to complete industry guidelines provides the roadmap and fuel needed to reach RBI program destinations.
- Given the scope of the project, the progress has been very good. Remaining work is minimal, including analysis of the performance of two Habitat homes, and developing industry guidelines.
- The project seems on track to wrap up soon. We look forward to the final guidance being published.
- The project goals have been substantially met and completed; only data collection on the habitat house and reporting remains. I would like to see more efforts made to convince builders and especially dealers of the life-cycle savings of these new designs. I don't have a good idea of how to involve dealers, but they are the ones missing from this project, and they are extremely important. How can builders of manufactured homes get dealers to see the benefits of energy efficiency and pass those recommendations along to the final customer?
- Contractor asserts that he's well on the way to on-time completion of all deliverables.
- Project will be tight for time, but will meet its goals, and further work is already in the pipeline. Good promise.
- The project is on track for completion within the timeframe.
- Reports on the project will not be enough. What does industry need?

F. Additional Comments and Recommendations

1. Project Strengths

- Project strengths include the soundness and clarity of the results and the integration of prior and current Building America-funded projects.
- The strength of the project is developing guidelines for design and high-performance manufactured homes. Since these are expected to be more affordable in the total overall life cycle cost, this could encourage more demand for such homes.
- Well-designed to address a complex set of challenges. Coordination of a wide range of partners and stakeholders. The results will not only address a significant segment of the market, but should be transferable to other market segments as well.
- The project has been focused, and they have completed most of their goals. They did a great job involving builders and Habitat for Humanity, the main suppliers of low-income affordable housing. Good job.
- Strong concept and good design through two prototype iterations.
- Deep understanding of challenges and barriers in getting the product into the market.
- Excellent industrial partners who are strongly committed for their own business reasons.
- Take advantage of new, low-cost technology, especially small, affordable, permanent magnet motors for the ventilation side and the main air handler.
- Focus on home manufacturers / manufactured homes, energy-efficient practices (high-R wall systems), and field verification/validation.
- Engagement with industry. Reliance on integration of existing technologies.

2. Project Weaknesses

- Project weaknesses include who is going to monitor and promote transforming the manufactured home industry and Habitat for Humanity?
- It is not clear whether such designs will be appropriate for all climates. The other issue is that if the initial cost is more expensive, when the bottom line is the first cost, not sure how you can meet BA goals.
- No specific weaknesses to comment on.
- I think more has to be done to convince dealers and the final customer about the importance of lifecycle savings. One suggestion is to show them return-on-investment or other economic or comfort benefits to get them excited about energy efficiency technology.
- Size-constraints of the proposed integrated HVAC product, specifically the enclosure height of most dwellings.
- How to overcome builder reluctance regarding outside air?
- Since the AC coil is much higher than the condensate if the ERV section is used (it will be at floor level in vertical installations), some installations would require a condensate pump just for the ERV.
- Apparent reliance on seasonal shift of ventilation rates to meet ASHRAE Standard 62.2 may not be appropriate in some jurisdictions because of concerns about potential acute pollutants reaching higher levels during low-ventilation intervals.
- Suggest expanding the work beyond ASHRAE's Climate Zones 4 & 5.
- Lots of pieces in the puzzle means lots of things to measure. Are the right things being measured to convince industry players to adopt?

3. Recommendations

- Find and fund champions to monitor and push progress.
- It seems that dissemination about design and details has been limited. Without the proper awareness and educating designers, developers, and builders, it is not clear how the higher initial cost barrier will be overcome. Much more literature is needed to show side-by-side comparison between such a system and conventional systems.
- Keep going. Consider how findings might inform guidance that is universal to all low load home construction and/or retrofit and electrification scenarios.
- I would do some targeted presentations and literature mailings to dealers nationwide. Try to come up with some literature and mailings that people can understand. Direct presentations to the big dealers would be a good start.
- DOE must next turn its attention to catalytic financing to get the manufacturing processes transformed so that construction quality at-scale is baked in so there are minimal opportunities to do things wrong.
- None at this time. Good work.
- Get clear success metrics from industry partners.

Residential Buildings Integration

Other Residential Research

Project #12263: Integral Hi-R, Dynamic Window and Wall Panel

Presenter: Charlie Curcija, Lawrence Berkeley National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Most reviewers were generally supportive of the project team's approach, believing the concept of integrated window and wall panels to be a successful means for preventing infiltration and improving sealing. However, some of the reviewers outlined potential areas of concern including the high cost of integration into new construction and the overall accessibility of this market. One reviewer also recommended that more could have been done at the onset of this project to review existing literature on this subject or coordinate with manufacturers regarding potential barriers.

Reviewers were more mixed on the potential impact of this project to contribute to program goals, with responses ranging from a large impact to a mid-level impact to unclear. At least two reviewers believed there to be a high potential impact if the project can demonstrate feasibility and model flanking loss between window wall interfaces. Again, reviewers expressed concern with the potential market for this project. One reviewer believed the market will be limited to multi-family construction, while another reviewer held that the approach requires pre-fabrication construction and is thus limited in scope of buildings.

All reviewers noted that this project is in the early stages and thus were hesitant to measure its progress to-date. Yet two reviewers were confident that progress had already been demonstrated in this early stage. One reviewer recommended that this project be reviewed at the next Peer Review. In addition, most reviewers believed that the project team could do more to coordinate and collaborate with relevant stakeholders in the residential homebuilding sector. One reviewer commented that the team's composition leaned too heavily towards technical engineers while neglecting building construction experts. Another reviewer recommended that the team incorporate other window manufacturers, such as SAGE or View. Most reviewers did not comment on the degree to which the project has logically planned remaining work to meet the project-specific goals.

Weighted Average: 3.10   # of Reviewers: 4
Approach: 3.30   Impact: 3.00   Progress: 2.80   Collaboration/Coordination: 3.30   Remaining Work: 3.30

Program Response

The project team noted reviewer comments requesting more discussion on the techno-economic analysis (TEA), and although such analysis is being conducted throughout the project, they will better emphasize this in future project evaluations. Similarly, the project lead will also consider more technical advisory group (TAG) assessments during early R&D phases of the project.

The PI also noted that some comments were specific to building ventilation and thin glass triple glazing technology. While this particular project focuses on window air tightness and moisture resiliency, the project lead acknowledged that the results are expected to benefit other applications, and this will be emphasized in the conclusions of the project. Also, because the project can lead to modeling flanking loss between the window-wall interface – and because this is not accounted for in energy models – the team will consider and report on this as it would help more accurately model energy performance of buildings.

The project team also stressed that the work plan is continuously updated to reflect current project developments. In response to other reviewer comments, the PI added that there is large area VIG glazing ready for trial, and that frame adoption is being considered as well. Moreover, issues associated with the transportation of the system are being investigated.

A. Approach

This project was rated **3.30** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- Good to see this is using highly insulated windows and not current production.
- Would like to have seen TEA being conducted throughout development instead of only for Task 8 and 10. Cost could prove to be a large barrier to successful integration of the product into new construction.
- The concept of the integrated window-wall panel is a good approach to preventing infiltration and achieving good edge sealing.
- It is not clear what the accessible market is and how the integrated product will be introduced to that market.
- The intro indicated that vacuum insulated glass (VIG) and thin center triples might be tested, but the subsequent slides only showed Pella 3mm triples.
- Is the interior Pella shade considered part of the "dynamic" window?
- It would seem easier and cheaper to use an electrochromic triple.
- The team has well planned out approach for the project work. The team could have done some literature searches or worked with manufacturers (such as DuPont) that have done similar work to address these barriers earlier in the project.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.00** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- The potential impact is large, but will this approach make a structure too tight, as there is no consideration for air transfer?
- The project impact seems mid-level, considering these products are expected to be used in conjunction with high-R windows, which will likely provide most of the benefit.
- The market seems limited to multi-family construction; the team seems hesitant about adoption in other applications.
- It is not clear this approach will be utilized for most windows. The approach requires pre-fabrication construction and only a limited number of buildings will define the market.
- If the team successfully demonstrates the feasibility of manufacturing integrated panelized insulated wall and high efficiency windows, it will transform the market with highly efficient construction methods that will resolve several deficiencies that occur in the field and reduce assembly energy performance.
- The project can also lead to modeling flanking loss between window wall interfaces, and this would help more accurately to model energy performance of buildings. Currently, flanking loss is not accounted for in energy models.

C. Progress

Based on current project efforts, the project was rated **2.80** for the degree to which the project has met ***project-specific goals.***

- Very early in the project.
- Good progress, very early on in project.
- This project is new for 2019 and progress can be assessed at the next review.
- The project is in early stages, but the progress toward goals has been demonstrated. The project team has a good plan to achieve the project goals.

D. Collaboration and Coordination

This project was rated **3.30** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team may need to consult with someone in the residential homebuilding sector concerning the history of structural insulated panels.
- The team's diversity could be improved by adding more experts on building construction. The team is heavy on technical engineering experts, but light on experience with actual construction. The project has the potential to create a great product that will not be cost effective for full wall installation (plumbing, electrical, insulation).
- Need to bring other window manufacturers into the project. Is there a suitable VIG window available? Is there a manufacturer that will fabricate a thin glass triple glazing? The team should partner with SAGE or View for a dynamic thin glass triple.
- The project has excellent strategic collaboration or coordination with relevant stakeholders. The participating manufacturers are active and contributing to achieving the project goals.

E. Remaining Project Work

This project was rated **3.30** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals.***

- The team identified areas of concern such as integration of the window wall interface.
- I would like to see TEA and TAG group assessment take place during early research and development.
- The project is new. The work plan details need to be fleshed out.
- The team has a good work plans, active manufacturer participation and expertise, and are likely to meet project goals.

F. Additional Comments and Recommendations

1. Project Strengths

- Solid window and wall manufacturing. The integration of sensors into the wall.
- The project uses 3D printing, which speeds up manufacturing. The project improves high-R window performance and consistency. A successful product could boost high-R window marketing and integration.

- The project team consists of good LBNL and ORNL staff. The team proposes a viable solution to an important problem. The project uses good laboratory and field testing technologies and equipment.
- The project team has significant knowledge and expertise to achieve project goals. The project participants—Sto, Pella, ADL, and S.Wall—are well-known companies that can help deploy the technology.

2. Project Weaknesses

- The integration of other components into walls such as electrical and wall-to-wall connections.
- The cost of the final product. The product may not be practical due to issues with the wall installation and wiring process.
- A number of new technologies are proposed, some of which are very new or don't yet exist.
- There is not yet a clear path to a thin glass triple glazing.
- Is there a large area VIG glazing ready for trial? Is there a standardized frame?
- Wall unit development will depend on the window construction. Is Pella the only window?
- The transportation of the system will need to be well planned for the system to succeed.

3. Recommendations

- Investigate the history of why this approach did not work in residential construction in the past.
- Involve the TEA and TAG groups early on or alongside research and development to ensure proper design changes and that issues related to practicality are considered.
- Make sure new highly insulating window technologies and the 3D-printed wall panels are ready so the work can begin on schedule.
- The project should account for and study the flanking loss between window/wall interface during testing.
- The project should also look into developing ratings for these types of systems to help consumers select the appropriate products.

Project #12266: Validation Studies of High-R Windows

Presenter: Katie Cort, Pacific Northwest National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

In general, reviewers found the approach to the Validation Studies of High-R Windows project well-thought out in order to achieve the team's goals. One reviewer stated that the project approach would mitigate risks and help the team overcome the technical challenges and barriers. It was noted that the supply-push and demand-pull strategy was likely to solve the previous issues regarding triple pane integration. While a reviewer appreciated the field study and testing plan, they posed multiple questions for the project team on cost, safety, and design of the thin triple pane window technology.

Reviewer comments on the project impact were overwhelmingly postive with three out of the four reviewers rating the project as "Outstanding." The contribution to DOE goals, if successful, was described as tremendous with the possibility of a large impact on energy use at a low cost. Several reviewers stressed that affordability would be key for market adoption, while one reviewer noted that it was critical that the thin triple insulating glass unit (IGU) could be inserted into existing frames. In addition, the fact that the technology could be adopted without relying on himan invervention versus attachements was also highlighted.

In terms of project progress and collaboration, reviewers were generally complimentary, but provided suggestions for areas of improvement. One of the recommendations was for the team to expand the study into more extreme climate zones. Another reviewer commented that they were "concerned that large window manufacturers will not be willing to adapt lines for thin glass handling." The reviewer continued by remarking that this issue might inhibit large scale adoption and was reiterated in a later comment. On the other hand, the remaining reviewers applauded the team's stakeholder engagement and their partners' involvement with the planning and experimental design of the project. Reviewers also mentioned that the project team was planning to recruit and pursue additional partnerships including utilities.

Weighted Average: 3.30 # of Reviewers: 4
Approach: 3.30 Impact: 3.80 Progress: 3.00 Collaboration/Coordination: 3.30 Remaining Work: 3.00

Program Response

The project team shared reviewer concerns regarding manufacturer's willingness to adapt lines to accommodate thin glass. As a result, the team is leveraging strong engagement between LBNL and large manufacturers (i.e., Andersen Windows) and is focusing a significant effort to demonstrate the advantages of this product to their customers, such as builders. The PI also recognizes that affordability will be a major factor for increasing demand and is hence working closely with field testing and manufacturing partners (i.e., Alpen and Kensington) to develop lower-cost vinyl-framed thin triples for field demonstrations.

The project team also noted the lack of tempered thin triple glass has been identified as a potential market barrier by builders in the initial market analyses, and hence is prioritizing the integration of safety glazing in their research by examining various temperable glass options that could be affordably integrated into the thin-triple design.

A. Approach

This project was rated **3.30** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project is well planned and involves multiple parties.
- The project's supply push - demand pull approach seems able to overcome past failures to develop triple integration. Using thin triple to overcome the barriers encountered in past triples research is a good strategy.
- The project makes use of a lot technical expertise. The project utilizes a good approach for field study and testing.
- Does Alpen have a thin triple design?
- Is there a spacer design that allows for high volume window assembly? Is Lisec involved?
- Will the spacer and sealant maintain the krypton concentration for the life of the window?
- Will the thin glass pane distort when used for large window sizes?
- Are there possible safety issues? I don't think the thin glass can be tempered. Laminated film is expensive.
- The project approach is well planned and the project is highly likely to achieve its goals and contribute to overcoming barriers, technical challenges, and mitigating project risks.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.80** for the degree to which the project is ***expected to*** contribute to ***program goal(s).***

- The project has tremendous potential for impact, without relying on human intervention versus attachments.
- Integrating thin triple into single family homes will likely contribute to the BTO 40% reduced energy use goal. Affordability is a concern.
- The project can have a big impact on energy use at low cost if thin triple insulated glass units (IGU) can be inserted into existing frames.
- The project will help achieve the goals to introduce triple pane windows, by using a middle glass pane that is very thin (0.7mm), highly efficient, cost effective, and lighter in weight. The window can be a retrofit for the double pane window width.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals.***

- The project is in its early stages; a comprehensive plan and stakeholders have been assembled.
- I would like to see the project include more extreme climate zones in the study (2, 7).
- I am concerned that large window manufacturers will not be willing to adapt lines for thin glass handling; this would inhibit large scale adoption.
- The project has made good progress in assembling the team and creating a test protocol.

- I don't think building a thin triple that can be reliably tested is that easy. The test can't be conducted on a lab prototype.
- The project is in its early stages but the presentation demonstrated the team has made significant progress towards project goals.

D. Collaboration and Coordination

This project was rated **3.30** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The team has assembled a strong group of stakeholders including targeting of utilities and ENERGY STAR®.
- I need more information about why large window manufacturers wouldn't partner with this project. The team needs a plan to convince them to join the project.
- Many stakeholders have been involved in designing the experiment and planning the testing and evaluations.
- The project staff demonstrated excellent strategic collaboration or coordination with relevant stakeholders during the presentation.

E. Remaining Project Work

This project was rated **3.00** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals*.**

- The timeline looks solid although additional recruiting needs to be done.
- The project is still in early stages, but the plan looks well thought out.
- The key to project success is the design of an easy to manufacture low cost thin high-R triple. I don't think that it will be that easy to convince people to buy new windows to replace existing double panes. Some kind of tax credit may be required.
- The project is in its early stages, however the project work is well planned and progress towards achieving the deliverables is being made.

F. Additional Comments and Recommendations

1. Project Strengths

- The team's technical background as it relates to triple pane, and the cross-section of stakeholders.
- The thin triple form factor will allow the product to be adopted into existing sashes. The team is also partnering with a company that has thin triple-polymer experience.
- The team has assembled an excellent group of stakeholders. The concept of a drop-in high-R replacement window is great. Making it happen will be a challenge.
- The project team has required expertise and is knowledgeable.

2. Project Weaknesses

- I have concerns about manufacturing issues, as well as product handling to the build or install site.

- Will the thermal benefit from the same form factor be large enough to stimulate adoption versus the price? The project also lacks large manufacturing partners.
- The project has not yet produced the lightweight triple safety glazing design.
- The project is in its early stages and does not have any weaknesses.

3. Recommendations

- Do we feel comfortable about the ability of the thin triple pane window to travel or be shipped?
- The team should convince larger manufacturing partners to join the project. The team should establish how it will conduct the R&D for thin glass low-e coatings.
- The team should work very hard to design and build a reliable, safe, durable, manufacturable lightweight triple glazing. Make no assumptions. Be sure to address every issue.
- The project team should look into cost to service life benefits and also the durability of the product performance.

Project #12269: Max Tech HPWH Field Test

Presenter: Jeff Munk, Oak Ridge National Laboratory; Cheryn Metzger, Pacific Northwest Nation Laboratory; Walt Hunt, Pacific Northwest National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Most reviewers concluded that the project approach was well-designed and that conducting field validation for a next generation, low global warming potential (GWP) heat pump water heater (HPWH) would prove useful towards contributing to program goals. The reviewers believed that a low GWP refrigerant coupled with a high-efficiency water heater could be valuable product with a high potential for energy savings. However, one reviewer commented that he/she would have preferred if more modeling had been performed by the team. Another reviewer conceded that it is still unclear that the project's HPWH will be any more efficient than existing water heaters but was optimistic about incorporation of the low GWP refrigerant as a phase-out of high GWP refrigerant.

Despite being in its early stages, most reviewers believed that the project was on-track and had made significant progress towards meeting its goals. In addition to the modeling activity, two reviewers highlighted the real-world field testing across a range of building sizes and applications. Furthermore, most reviewers were satisfied with the degree to which this project team is collaborating with relevant stakeholders. Two reviewers commended the team for including a leading manufacturer in HPWHs, A.O. Smith, as a part of the team.

Overall, reviewers commented that the project is well-planned but that significant work remains to be done, including building prototypes, performing field tests, and analyzing and comparing test performance data. One reviewer would also like the team to add performance evaluation of HPWHs at standard rating conditions. Another reviewer believes that the team should look at the options of further cycle enhancements (e.g., advanced cycles).

Weighted Average: 3.34 # of Reviewers: 5
Approach: 3.40 Impact: 3.40 Progress: 3.00 Collaboration/Coordination: 3.40 Remaining Work: 3.40

Program Response

The project team acknowledged that several reviewer comments were directed towards a related project (32226s – Max Tech Efficiency Electric HPWH with Low-GWP Halogenated Refrigerant), which focuses on the design and development of the Max Tech HPWH equipment that is utilized in this Max Tech HPWH Field Test project. As a result, the team will better clarify the scope of this Field Test project and its related counterpart in future project evaluations. Furthermore, the project team emphasized that the complementary BTO project scope includes laboratory testing at standard rating conditions to evaluate the uniform energy factor (UEF) of the proposed designs, directly addressing one reviewer comment on including this in the Field Test project scope.

Per reviewer feedback, the PI will also emphasize that the field evaluations of this project will allow for an efficiency assessment of the Max Tech HPWH at both controlled research homes and occupied field studies which will inform the impact analysis based on the HPWH performance established in this study. Moreover, one task in this Field Test project is to perform life-cycle cost and climate performance calculations for both the baseline and Max Tech HPWH to help evaluate the cost-effectiveness and environmental benefits of this technology, in addition to examining different ducting configurations and non-energy related impacts.

Another complementary project (14119 – Technology Integration) is exploring the load shifting capabilities of HPWHs for the electric grid using an established grid interface and demand response protocol. Although the Max Tech HPWH Field Test project is focused on the system's efficiency impact, a load shifting characterization of the baseline and Max Tech HPWH prototype (to the extent possible) will be performed in the aforementioned research homes.

A. Approach

This project was rated **3.40** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- This project is well thought.
- A low global warming potential (GWP) heat pump (HP) water heater is a potentially valuable product. This general investigation as to how it may perform compared to existing is useful.
- A field-validation of a high-efficiency, low-GWP HPWH is a practical approach to expand HPWHs for energy saving.
- The project involves looking at next generation heat pump water heater with the use of low GWP refrigerant CO2 which is an excellent refrigerant for hot water heating. The program is well defined and includes testing and field measurements. I would have liked to have seen more modeling and also inclusion of advanced cycles that are now being developed for CO2 systems.
- The project approach is to develop a HPWH with low GWP that is both efficient and market ready, with performances being field validated.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.40** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- This project is promising.
- It's not clear this will be any more efficient than the current HPWH, but the low GWP refrigerant is a plus.
- An 0.87 quad energy savings/year is good energy savings.
- With the move to carbon neutral and renewable energy, this is an important project to improve the efficiency of water heaters as well as reduce the GWP impact through the use of low GWP refrigerants.
- There is a need to promote HPWH over electric/gas water heating because of the potential for decreased energy consumptions. Also, of importance, is the phase-out of GWP refrigerants that are currently used in HPWH’s with environmentally friendly substitutes.

C. Progress

Based on current project efforts, the project was rated **3.00** for the degree to which the project has met ***project-specific goals***.

- This project is on track.
- It is early in the project, but the issues being considered are in alignment with what is required.
- Good progress is being made: Model developed, Experiment with R134a, R1234yf and R290 (1 kg).
- It is a fairly straight-forward project, and they are making good progress.
- To date, baseline data has been taken to include hot water draws and energy consumption in several real-world testing facilities, representing a range of building sizes and applications.

D. Collaboration and Coordination

This project was rated **3.40** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- No comment.
- The project team's coordination with major equipment manufacturer and energy association is good.
- The project has a HPWH manufacturer in the team, which is great.
- They are collaborating with major industry manufacturers, so I think they have the right amount of collaboration.
- The key partners working with ORNL are PNNL and A.O. Smith, a leader in manufacturing water heaters.

E. Remaining Project Work

This project was rated **3.40** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- This project is well planned.
- The tests and correcting HW load profiles will assist in tuning final selected configuration.
- This project has a good plan but it would be better to add performance evaluation of HPWHs at standard rating conditions.
- I think they could look at the options of further cycle enhancements as well as grid interface.
- The remaining effort is finalizing designs, building prototypes, and performing field tests, along with analyzing and comparing test performance data.

F. Additional Comments and Recommendations

1. Project Strengths

- This project has very important potential.
- The project strength is its analytical method to design and configure the HPWH.
- This project has a good research plan in timely manner to prepare for R134a regulation.
- One strength is the understanding of the systems and inclusion of field testing.
- The project strength is the study of a subject matter that has the potential to reduce energy consumptions significantly.

2. Project Weaknesses

- None so far.
- Heat recovery sources and methods are likely to be dead ends
- The project team needs to improve impact analysis.
- There is a lack of standard rating test.

- It would be better to analyze the effect of ambient temperature to cycle efficiency and load demand for better load shift strategy.
- Did not see a lot on cost analysis. Did not see any approach to protect system for the use of supercritical refrigerants and the high pressures that can develop.
- None.

3. Recommendations

- I look forward to new progress and outcome.
- I recommend consideration of other refrigerants to achieve the low GWP objective.
- I recommend the project team:
  - Quantifies Maxtech HPWH savings as compared to state of the art HPWH.
  - Adds testing of HPWHs at standard rated test condition first before field testing.
  - For load shifting, understands the effect of Tamb variation of the day and its effect of HPWH cycle efficiency though computer modeling for better load shifting strategy.
- I recommend more cost analysis. The team should look at options for cycle enhancement and further grid interface evaluations for management of peak.
- None.

Project #14119: Technology Integration

Presenter: Michael Baechler, Pacific Northwest National Laboratory
DOE Manager: Marc LaFrance

Brief Summary of Reviewer Comments

Most reviewers approved of the approach for this project and noted the aim to study load shifting with HP water heaters to strengthen the alignment between energy use and renewable energy production. One reviewer recognized that this approach is a big effort, while another reviewer stated that it is realistic and promising. Another reviewer argued that the major stakeholder should be the public, and since the primary goal of utilities is to sell electricity, developing this platform to be controlled by utilities is a significant oversight.

Multiple reviewers recognized this project's potential impact on increasing energy savings and renewable energy use. One reviewer praised the project's impact for its great potential. However, one reviewer cautioned that the focus of this program should be rethought as it may be driving grid interaction in a direction that will not achieve long term public objectives.

Two reviewers highlighted that the team has identified regions offering the greatest potential for connected HP water heaters. The project is well-executed so far, and they have made good progress. In addition to these comments, one reviewer expressed skepticism if overall energy or user costs will be saved, since the project is specifically aimed at reducing utilities' costs.

In general, reviewers recognized the project's collaboration and coordination with utilities, and one reviewer suggested that seeking the utilities' cooperation with other potential alternative sources of demand limiting will provide insight into where their interests really are. Three reviewers agreed that they have a good collaboration team. The project led by PNNL has significant collaboration and coordination with ORNL, BPA, PGE, NEEA, and Duke Energy.

Two reviewers agreed that remaining tasks and efforts are focused on completing a smart-learning algorithm to optimize load use for individual water heaters. The project is well-planned, and they are into the final phase of the project. One reviewer strongly recommended that they find partners beyond utilities and focus on partnering with utilities to develop tariffs that allow the full measure of the potential savings to be reflected in demand shifting.

Weighted Average: 3.20   # of Reviewers: 5
Approach: 3.20   Impact: 3.20   Progress: 3.20   Collaboration/Coordination: 3.20   Remaining Work: 3.20

Program Response

The project team acknowledged reviewer concerns that utility involvement in the project may lead to approaches in which connected HPWHs would benefit utilities disproportionately more than consumers. The PI noted that HPWHs can save 60% of annual energy use for water heating compared to electric-resistance water heaters, amounting to an average of $340 in annual consumer savings (according to the DOE test procedure, using the national average electricity price). Although the presentation was focused on current demand response efforts and related interactions with utility partners, PNNL and DOE engage with the full spectrum of government, academic, utility, and non-governmental organizations that research and implement HPWH programs.

Furthermore, the team added that by demonstrating that HPWHs are a viable technology to reduce peak load, utilities may justify promoting HPWHs in their demand response programs. Showing the extent to which connected HPWHs can shift loads can also help utilities better utilize HPWH technology in strategies to increase integration of renewable energy sources.

Per reviewer comments on HPWH energy saving performance in cold climates and impacts on home HVAC systems, recent research shows little interaction with HVAC systems for most water heater installations.

A. Approach

This project was rated **3.20** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- They have a comprehensive and applicable approach, and it is realistic and promising.
- The approach to demand shed only seems well planned. However, assuming the major stakeholder should be the utilities must be challenged. Rather, it should be the public, and since the primary goal of utilities is to sell electricity, developing this platform to be controlled by utilities is a significant oversight. Utilities will manipulate residential equipment to reduce their costs but, they are certainly not at all likely to reduce the user's costs. From a user's perspective, it may be advantageous to operate the water heater when their clothes dryer is operating so they can recover heat and improve the efficiency through heat recovery, or to do so when their solar panel is active. These are not in the utility's interest and would likely not have a high priority (or any priority at all) in a system operated by the utility.
- Field testing residential HP water heaters for existing homes across northwest and southeast climates is a big effort.
- The use of renewable energy storage is one of the main priorities which is the primary purpose of this project.
- The approach in this project is to study load shifting with HPWH to strengthen the alignment between energy use and renewable energy production. This study will quantify the impact on both utilities and consumers, along with performing an evaluation of customer acceptance.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.20** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- They have great potential.
- The project now being developed may be effective in reducing utility demand costs. But because this places the utility in control of its operation, and since utilities are in the business to sell energy, it is not likely this is a viable platform for other demand limiting functions, especially those intended to save energy. The focus of this program should be rethought as it may be driving grid interaction in a direction that will not achieve long term public objectives.
- Identifying real HPWH usage and energy saving data will establish good basis for energy savings.
- It could be very important to interface with smart grid and the use of renewable energy.
- The full impact of developing and evaluating load shifting of HPWH's is realized in the context of water heating being second only to heating buildings in terms of energy use and consumption.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The project is well-executed so far.
- Yes, this project may help utilities reduce their costs associated with high demand periods, but it is unlikely to save overall energy or user costs which otherwise could be attained as well. It is specifically aimed at

reducing utilities' costs. While theoretically this would result in some user costs, being skeptical as to how significant these may be would be wise.

- Some field testing is on-going, and they have identified regions offering the greatest potential for connected HPWHs.
- They are well into the project and appear to have made good progress.
- To date, shifting of energy use by HPWH's has been studied, especially in winter months, with an emphasis on reducing utility risks and the cost to consumers. Regions with the greatest potential have also been identified.

D. Collaboration and Coordination

This project was rated **3.20** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- No comment.
- While utilities are being engaged, other large and much more appropriate potential market forces appear to be ignored. For example, this would be a great product to help solar panel installers make their products more cost effective. Residential aggregators may also be a potential force of value to residential users. And the means of engaging utilities should be to offer RTP to residential customers to encourage solar panels and/or user participation in demand limiting, either automatic or manually. Seeking the utilities' cooperation with these potential alternative sources of demand limiting will provide insight into where their interests really are.
- They have a good collaboration team.
- They have manufacturers involved, as well as utilities.
- The project led by PNNL has significant collaboration and coordination with ORNL, BPA, PGE, NEEA, and Duke Energy.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The project is well planned.
- It is strongly recommended that they find partners beyond utilities and focus on partnering with utilities to develop tariffs that allow the full measure of the potential savings to be reflected in demand shifting.
- The project has good planning for a smart-learning algorithm to optimize load use for each individual water heater, pilot study, and methodology.
- They are nearing the end of the project in 2020, so they are into the final phase of the project.
- Remaining tasks and efforts are to complete algorithms to optimize load use for individual water heaters. Also, interactions with utility partners to perform pilot studies will take place.

F. Additional Comments and Recommendations

1. Project Strengths

- The project has great ideas with serious efforts. It is well thought out and executed.
- Engaging with heat pump HWH manufacturers to incorporate controls to allow reasonably straightforward offsets for operation and temperature adjustment is extremely important to get this to become standard practice in this equipment, and perhaps translate to other residential equipment.
- However, the concept that the utilities should be predominate, as has been noted, will not yield desired overall energy and cost reductions.
- The project has done extensive efforts for field testing and advancing for demand response.
- This is a straightforward project. They have manufacturers and utilities involved to make sure there is a demand and customer.
- The project strength is to promote the use of sustainable energy by promoting load shifting of HPWH to coincide with periods of peak energy production.

2. Project Weaknesses

- There are none so far.
- This approach is "Utility-Centric" since the utility controls the load shifting. This will help utilities but not necessarily the home-owners. Utilities will engage the load shaving when it suits them, not necessarily the home owners. For example, as a switch to real time pricing moves to residential metering, utilities will not be incentivized to shed residential loads at times of high pricing if they are making a reasonable gain from that pricing. They will not be encouraged to shift demand when excess solar power is available from the homeowner panels.
- This program should take a step back from their association with the utility industry and look at a more effective means to incentivize energy reduction at the retail level. Incentivizing utilities to reduce their costs will not necessarily result in reducing energy consumption since utilities revenue is based on selling energy. A better approach would be to encourage RTP and require (through PUC) pricing signals to be transmitted to consumers (and/or their agents) so the controls can be locally managed to reduce costs AND reduce energy use at the consumer level.
- There is a lack in standard testing for rated performance.
- It might have been good to also combine with an advanced heat pump water heater, which is another project. Also, it would be good to have seen economic payback analysis.
- There are none.

3. Recommendations

- Look forward to the trend.
- As noted, it is recommended that the engagement of stakeholders be expanded, and a greater emphasis be placed on reducing the end user's costs of connection to the grid both by demand shift savings and energy reductions.

- They need to establish performance data according to standards too (for example: ISO 19967-1:2019, Heat pump water heaters—Testing and rating for performance—Part 1: Heat pump water heater for hot water supply and AHRI-1301 (2013)).
- Release a final report and the full economic analysis.
- There are none.

Project #15148: Home Energy Score

Presenter: Glenn Dickey, Allegheny Science & Technology
DOE Manager: Madeline Salzman

Brief Summary of Reviewer Comments

Reviewers were impressed by this project's approach to overcoming barriers, technical challenges, and mitigating project risks. There was near unanimous consent that the thoughtful, methodical, and well-balanced approach employed by this project team has contributed to its "long and successful track record." With regards to mitigating risks, one reviewer was particularly supportive of the harmonization of the Home Energy Score (HES) tool with EnergyPlus and Open Studio SDK. In a similar vein, another reviewer cited the harmonization of HES and the HERS Index Score as an important step in overcoming technical barriers. The only critical comment regarding this project's approach concerned the adoption of data validation functions that mirrored actions already employed by the market and the failure to effectively communicate this effort with stakeholders. Regarding the degree to which this project is expected to contribute to program goals, reviewers believed that Home Energy Score will prove critical to standardizing the measurement of efficiency in existing homes and expanding the number of energy efficient single-family homes. However, one reviewer expressed concern that the project metrics are focused more on communicating information than on reaching the program goal of 40% energy use reduction in residential buildings.

Most reviewers commented that this project is successfully meeting its project-specific goals by increasing traction (e.g., by increasing the number of partners, scores, and APIs) and expanding its audience. Two reviewers specifically remarked upon the work being done to attract state and local governments and the tremendous potential these stakeholders represent in making the Home Energy Score a national, federally managed standard. However, some reviewers noted that there are even more opportunities to expand adoption of the tool, including with appraisers and the mortgage industry.

Nearly all reviewers were impressed by the project team's collaboration and coordination with relevant stakeholders, with one reviewer going so far as to state, "the collaboration is perhaps the strongest of any project seen at the Peer Review." Specifically, reviewers were excited by the sheer breadth of the number of stakeholders involved in this project, including the Department, three national laboratories, two private sector companies, local governments, NGOs, utilities, and software providers. However, one reviewer emphasized that more collaboration and coordination was needed, and that this coordination should focus on standardization.

Overall, most reviewers were satisfied with the remaining project work, though at least two reviewers were concerned with issues regarding utility data accuracy and integration within in the HES tool. Many reviewers also offered insight on where they envision strategic opportunities with the remaining project work, including integration with SEED; integration of electrification, demand flexibility, grid-interactivity, and/or EVs; and the development of a systemized process for addressing technical questions (e.g., a "help desk"). Additionally, reviewers noted the importance of market transition plans and increased stakeholder coordination as the team moves toward maintenance mode.

Weighted Average: 3.40   # of Reviewers: 5
Approach: 3.60   Impact: 3.40   Progress: 3.20   Collaboration/Coordination: 3.40   Remaining Work: 3.20

Program Response

The project team recognized reviewer feedback on communicating updates to software providers, adding that they will ensure that partner implementers are included on related communications earlier for their input and awareness while also maintaining the integrity of data validation efforts on behalf of DOE. The team also agreed with reviewers that noted additional opportunities for expanded adoption of the tool (i.e., with appraisers, the mortgage industry, etc.) and supported one reviewer's recommendation to update NREL's assessment of HES vs. actual utility data to improve accuracy and reliability of the tool and its outputs, and will address these items accordingly.

A. Approach

This project was rated **3.60** for the degree to which the project's approach contributes to overcoming barriers, technical challenges, and mitigating project risks.

- The project has had clear goals, employed a well-balanced mix of subject matter experts (business, technical, and management), and sought broad stakeholder engagement – which are all critical to addressing barriers, challenges, and risks. The team seems to have been open and transparent in sharing issues with stakeholders and seeking input.
- The project has had a long and successful track record of meeting a variety of stakeholder needs. It is constantly updating its features, interface, APIs, range of stakeholders, etc. It seems to be mitigating project risks by harmonizing the tool with EnergyPlus updates and OpenStudio SDK. This was an enjoyable presentation and a clear example of success.
- HES will no doubt contribute to overcoming barriers, technical challenges, and mitigating project risk in places where its use is either required by policy or where supporting infrastructure (e.g., trained HES assessors) is sufficiently developed. Relative to the project's desired outcome/goal, the approach has been very successful in getting HES to where it is today. I think looking forward to start to truly influence the market, the strategic approach could be more focused on building up the trained assessor base and driving more adoption (whether bottom up from consumer demand or top down from regulation).
- Project is effectively addressing technical challenges encountered by program participants. For example, the project's inclusion of an on-demand gas water heating input and use of different thermostat setting for zonal heating and cooling has improved both the perception and actual performance of the project's tool and outputs. The program's development of data validation to improve the consistency and reliability of data inputs was very useful, however this development mirrored actions already taken by market stakeholders. The project's replication of data validation functionality already in use by the market occurred without any prior communication and/or collaboration with stakeholders. This kind of uncoordinated step can somewhat undermine innovations and investments already taken by the market stakeholders.
- The project's efforts at overcoming the technical barriers to harmonizing HES and HERS has been admirable and forward-thinking. Also, the project's development of a remote quality assurance protocol is an important innovation, which will help state governments and utility programs with implementation in less populated portions of their territory. This is an important equity consideration and helps remove a cost barrier to comprehensive HES deployment. Lastly, the project is addressing a barrier to greater program uptake by updating and improving the assessor simulation training.
- Thoughtful and methodical approach.

B. Impact

Assuming that the ***project-specific goals*** are met, this project was rated **3.40** for the degree to which the project is ***expected to*** contribute to ***program goal(s)***.

- Interpreting the metrics, current averages show there is still a gap between what updates can achieve (22%) versus program goal of 40%. The project goals, however, do not seem to specifically tie to the 40% metric, but rather focus on measuring and communicating information. So, if they need to be more closely aligned with the program goals, those could be more clearly specified.
- Added capabilities such as new equipment, harmonization, run times, system load, and ease of use should all strongly contribute to the overall goals at the program level. Scaling up the use of the tool as a de facto standard and identifying energy savings opportunities for a wide range of users, use cases and industry stakeholders will surely be a success if all the goals are met.

- If the goal is to build market value for energy efficient single-family homes and townhomes that improve quality of life, HES is a critical tool to get there and there should be a national standard for measuring this in existing homes. HES will need to gain more traction in terms of broader market adoption and clearer links will likely need to be established with the appraisal industry (whether through the mortgage process or otherwise) to create a framework for, and mechanisms to, ascribe value to energy efficiency. It is possible that this happens on its own in the marketplace once HES achieves a certain scale, but since that may take more time than we have from a climate perspective, more effort could go into creating those valuation mechanisms sooner.
- The project is providing an easy to understand home rating for consumers and the real estate industry. The project is also providing lenders with a more effective and less costly way to integrate energy costs into lending decisions. The project could assist partners by creating visual mapping using the home data contained in the HES database. As a next step, the project could engage credible professionals (academics would be best and most objective parties to develop this analysis) to analyze property sales prices associated with HES scores to determine how HES is signaling the market. This project-driven/funded analysis should be consistently done across several markets if possible. Any analysis should be done in concert with HES partners.
- No comment.

C. Progress

Based on current project efforts, the project was rated **3.20** for the degree to which the project has met ***project-specific goals***.

- The project's contributions towards its goals are demonstrated in the increasing traction and growing partnerships developed. The project seems to have achieved its goal towards easy to understand home rating and comparable home energy use—the rating and materials are clear and simple. Although the project is considered late-stage there still seems to be a need for key involvement to ensure the industry will continue progression towards adoption. For example, the path towards appraiser adoption is not as clear as other areas.
- It wasn't exactly clear what the target metric goals were, but there were qualitative goals. There were also specific impacts shared, which showed number of partners, scores, number of APIs, and savings goals. These all were outstanding in showing how much of an impact the tool has had on the market.
- HES has demonstrated significant contributions to its project-specific goals. There has been good uptake by local and state governments to facilitate ordinances/programs and this should continue. Mortgage industry integration could be transformative and perhaps warrants more focus/ time/effort. The technical development of the tool and ongoing efforts to harmonize and further improve show great progress.
- The project is rapidly gaining momentum as an important means to ensure energy information is consistently provided to home buyers and becomes integral in the real estate transaction. The project will likely make increasing progress as a tool for local governments to reinforce climate action strategies, emphasize consumer protection, and identify energy cost burdens across cities/states. There is clearly a demand at the local and state level for a consistent, off-the-shelf tool for calculating a home asset rating that the federal government is best positioned to manage and maintain.
- No comment.

D. Collaboration and Coordination

This project was rated **3.40** for the degree to which the project staff demonstrates strategic collaboration or coordination with relevant stakeholders.

- The staff is passionate and articulate and demonstrates a strategic approach towards stakeholder engagement. The housing industry, however, is extensive with many players and the project has had a relatively light staff to manage all opportunities and goals across the various stakeholder segments. Additional collaboration that might be taken for consumers would be to increase engagement with more consumer-focused organizations like utilities, housing counselors, social media players, etc.

- The collaboration is perhaps the strongest of any project seen at the Peer Review. The slide with all the partners listed is impressive. Plus, the updates to the UI to allow reduced inputs for each type of stakeholder is a great feature that casts a wider net in terms of the intended audience and use cases. This combined with the fact that there are many APIs and that it serves as an underlying tool for other products shows that the tool has been well marketed and connected to other industry stakeholders.

- There is an impressive number of different stakeholders that project staff have been collaborating and coordinating with to advance this project. In addition to the number of groups involved in the project staff alone (DOE, PNNL, LBNL, NREL, Allegheny, Interplay), the team has engaged with a number of other stakeholder groups - local governments, NGOs, utilities, software providers, etc. – and this has ultimately benefited the product offering.

- The project's collaboration and coordination with stakeholders has been good and quite effective. Sometimes there appears to be an emphasis on tactical collaboration rather than strategic collaboration, making some efforts episodic and unstructured. While there is excellent strategic thinking happening on topics like this integration of HES into financing, the project could develop more structure around the deployment of those efforts with more formal market partnerships to ensure appropriate focus is given. An example could be: Real estate industry (non-lender) engagement and supporting the development of tools for real estate industry stakeholders. Currently each HES partner is largely responsible for developing real estate outreach tools (beyond basic intro documents/PowerPoints).

- More collaboration and coordination is needed. The coordination should focus on standardization as well.

E. Remaining Project Work

This project was rated **3.20** for the degree to which the project has logically planned remaining work to meet the ***project-specific goals***.

- The summary of remaining work appears comprehensive, but the amount seems significant for a late-stage project. The technically oriented work is clearer than some of the stakeholder engagement tasks, which are broad. The team would benefit from a clear tactical plan to accomplish its remaining work and achieve a successful transition to the market.

- Harmonization of HERS/HES modeling environment (OS/E+) seems to be the most promising of all updates. This will be a great resource and will also help with the expansion of the NREL residential measures. Integration with SEED will be a huge help with state and local ordinances and further give the market confidence and the ease of use to specify the tool more. Expand features to support. It seems like these two are the most promising from my perspective and the other remaining work is likely to add great value to other stakeholders.

- On the technical side of the tool, the remaining project work presented makes sense. Two topics that were not covered but could be additive to remaining project work plans to ensure that the tool remains robust and future-proof and to maximize the accuracy of its outputs are: (1) considering ways to integrate electrification, demand flexibility, grid-interactivity, and/or EVs - if they qualify as asset vs. operational - such that these features would improve a home's score (incentivizing their adoption when HES is ultimately linked to appraisals), as these areas become more heavily prioritized by the market and policymakers; and (2) building local utility rate structures - versus relying on statewide average utility rates - into the modeling tool so that energy cost estimates (potentially the most critical output for the majority of stakeholders using HES) are more accurate and useful. There was a comment by the presenter that utility rates can't be updated more frequently because that would update the score, which was confusing because I thought the score is based on energy use, not energy cost.

- In terms of accuracy, NREL conducted an accuracy assessment of HES outputs relative to actual utility data in 2014, and many improvements have been made to HES since then. It seems like this is one topic that may keep coming up in the form of skepticism from certain stakeholders about the predictive capability of an asset rating like HES for actual energy bills, and it may be valuable to update this accuracy assessment to see if that delta has been reduced and to share that message with the market.

- On the strategic side of the program, the presentation was a little light on tactical plans to achieve the ultimate desired impacts on the lender, appraiser, and realtor communities, and to scale up the trained assessor base nationally – potentially with targeted marketing in areas of the country that have the right fundamentals in place but no certified assessors.

- As the project enters the next phase and develops more partners, it seems like developing something similar to the Asset Score Help Desk would be a useful evolution. There seems to be a need for a more systemized process for logging/ticketing technical questions from assessors, program teams, etc. with a user-friendly interface. There could also be a role developed for a “master QA provider” who reviews/supports each partner's QA protocols/outcomes. This will become more and more important as new local government partners enter the program and where public scrutiny of the score is increased due to the local policies. Assessor consistency will also be something that the project will face greater scrutiny about as more local government partners are added. In some markets, there can be a wide range of knowledge and skillsets amongst assessors, resulting in a divergence of scores. In markets where real estate agents are following scoring activity closely, they will sometimes request 2 or more assessors to score the same home. When the assessors score the home differently (sometimes considerably differently), the local real estate industry shares these results as a way to undermine the legitimacy of the scoring program. While the current assessor qualifications to become authorized are a reasonable standard, the project could develop, support, or require ongoing assessor training for assessors to develop greater understanding of the nuances of HES data inputs.

- No comment.

F. Additional Comments and Recommendations

1. Project Strengths

- The score is clear and easy to understand. Comparison to MPG and other consumer-oriented metrics helps to increase understanding and adoption. Project staff is experienced and seems to be successful in engaging most relevant stakeholders. The project has a focus on data and on increasing its aggregation and availability, which is critical for demonstrating trends and making decisions.

- The strengths are many with this project. The longevity in the marketplace along with the traction it has received in the market is a big factor in its success. With such a diverse set of stakeholders, it seems that so much feedback has gone into the tool that it has been well received.

- The project has a number of strengths, including its user-friendly output and simplified scoring mechanism, price point for consumers, ultimate use case and potential to transform the single-family market, technical rigor behind the scenes, coordination among a long list of stakeholders, focus on QA, streamlining of the training process, and progress to date in achieving its goals. It's clear the HES project has been a massive undertaking so far and resources seem to have been well utilized.

- Good technical team, especially Glenn Dickey. The technical team is very responsive to partner questions, requests, and updates.
- Good general direction and methodology.

2. Project Weaknesses

- Although I am not specifically familiar with the standard for a late-state project, it seems there is still a lot to be accomplished and the path to achieving the goals could be more clearly articulated. For example, adoption by appraisers is not as evident as other areas.
- The project does not appear to have any weaknesses, but in the next section will be recommendations.
- I think the project's weaknesses right now include the lack of a clear strategy to get more assessors trained and deployed nationally, the accuracy of energy cost estimates in parts of the country where local utility rates are significantly different from their statewide average, future-proofing of the features HES integrates into its scores (electrification, demand flexibility, grid interaction, EVs, etc.), and so far integration with the mortgage and appraisal industries, which will hopefully continue to progress.
- The project could more actively and proactively support efforts to engage local governments (e.g., through cohort workshops, etc.) with establishing a home energy score program. Communication of strategic project goals and inclusion of key stakeholders and partners in addressing the projects stated goals could be improved. For example: current project focus on linking the HES to lending is happening and progress is being made, but it could be strengthened through project team sharing strategic plan with stakeholders and through the development of a coalition of stakeholders who coordinate regularly, have clear roles in support of HES/lending integration. The project could act more regularly as a convener of market channel partners.
- It does not address factors that are likely to affect the success of the project, such as lack of information and limited consumer demand.

3. Recommendations

- Develop and manage a tactical market transition plan. Consider ways to engage organizations that touch and influence consumers in order to increase awareness and adoption, including technology apps and social media influencers. As part of a holistic view, articulate how increasing requirements for solar (e.g., California law) will or will not impact score.
- Although HES is an asset-based score, there is a need in the market for home energy modeling software that has the robust capabilities to perform auto calibration and parametric analysis, as well as linkages to a building/measure component library for those analytic purposes. It is recommended that as harmonization happens with OS/E+ that these two use cases are kept in mind. Often times, when characteristics of the home cannot be gathered for some use cases, the BEM techniques to identify input uncertainty analysis is conducted. It would be interesting to see how HES can be extended or leveraged for a BEM tool. Rate analysis for tariffs, MPCs, GEBs, etc. could all then fit into the residential analytic framework under this umbrella.
- Given that the project team is looking to move towards "maintenance mode" for HES, I think technical efforts should prioritize accuracy and reliability of the tool and its outputs so that it can stand on its own in the marketplace. Updating NREL's accuracy assessment of HES vs. actual utility data could prove valuable to that end (preempting concerns or pushback from different stakeholders), as could building more localized utility

rates into HES energy cost estimates. With the tool in maintenance mode, I think more strategic effort could be spent on driving more adoption locally (whether through marketing directly to consumers via certain tactical higher-impact channels or working with more local governments to develop home energy programs/policies) and better integrating the tool with appraisals to achieve the project's end goal. There is also potential to use targeted marketing efforts or other strategies to scale up the trained HES assessor base in 'ripe' parts of the country. For example, as of late last year I could find no trained HES assessors in the Philadelphia area (6th largest US city that has relatively aggressive climate action plans and is considering residential energy disclosure policies). Identifying and prioritizing these higher impact locations could make for a good near-term scaling strategy.

- See prior answers. The project is gaining greater maturity and momentum. The next phase: It makes sense that the project evolves to a place where DOEs role is to maintain the core technical elements and standards of the scoring program while at the same time identifying market partners who can effectively develop and deploy new tools and training to Program Partners. This structure will likely increase the overall impact and effectiveness of the program. However, there must be a clear strategic plan outlining what DOE will retain/manage and what the market could/should provide.
- Expand coordination and focus on more standardization of efforts, methodologies and ratings.

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