Building Technologies Office
FY16 National Laboratory Call for Proposals & Merit Review

Amendment 000002

Lab Call Released	February 2, 2015
Informational Webinar	February 6, 2015, 2 – 4 PM ET
Letters of Intent Due (submitted to EERE Exchange)	February 17, 2015, 5 PM ET
Proposals Due (submitted to EERE Exchange)	March 13, 2015, 5 PM ET
Reviewers' Initial Comments Due	April 1, 2015, 5 PM ET
Presentations Due (submitted to BTOLabCallFY16-18@EE.DOE.Gov)	April 8, 2015, 5 PM ET
Lab Call Merit Review Meeting (Washington, DC)	April 16 – 17, 2015
Reviewers' Final Comments Due	April 24, 2015, 5 PM ET
Notification of Decisions for FY16 – 18 Lab AOP Projects	May 8, 2015

BTO Lab Call Announcement/Merit Review Informational Webinar

Join us for a webinar on Feb 06, 2015 at 2:00 PM EST.

Register now!

https://attendee.gotowebinar.com/register/7245235514569200 65

After registering, you will receive a confirmation email containing information about joining the webinar.

Note: The webinar will be recorded and will be made available on the BTO website (http://energy.gov/eere/buildings/building-technologies-office).

Merit Review Meeting: April 16-17, 2015; Sheraton Tyson's Hotel, 8661 Leesburg Pike, Tysons, VA 22182, (703)448-1234, http://www.sheratontysonscorner.com/

Registration: To be announced

Questions: Please address all questions about this Lab Call to BTOLabCallFY16-18@EE.DOE.Gov, and include 'ET,' 'CBI,' or 'RBI' in the subject heading, as appropriate. Answers will be posted on EERE Exchange under this Lab Call's Frequently Asked Questions (FAQS) section. No questions should be addressed to BTO staff.

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1. Introduction

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

BTO's **mission** is to develop, demonstrate, and accelerate the adoption of technologies, techniques, tools and services that are affordable and enable high performing, energy efficient residential and commercial buildings. This mission requires a multi-pronged strategy to address diverse market, technology, and regulatory challenges. BTO's strategy, or ecosystem, functions through five interdependent programs:

1. **Emerging Technologies (ET) s**upports research and development of high-impact building energy efficiency technologies, taking into account both performance and cost in order to drive these technologies to successful commercialization.
2. **Residential Buildings Integration (RBI)** accelerates energy performance improvements in existing and new homes by integrating technologies and practices to verify and optimize performance in buildings; providing data, design, and decision support tools; and partnering with public and private stakeholders to increase adoption of energy-efficiency services, technologies, and practices.
3. **Commercial Buildings Integration (CBI)** accelerates the commercialization and market uptake of energy efficient technologies and practices in existing and new commercial buildings; providing interoperable data tools and design and decision support guides and resources; and partnering with market leaders to increase adoption of those technologies and products, developing, demonstrating, and deploying a suite of cost-effective technologies, tools, and solutions.
4. **Building Energy Codes (BEC) s**upports increased energy efficiency in commercial and residential buildings through the upgrade of model building energy codes and by providing technical assistance to states as they implement energy codes.
5. **Appliance and Equipment Standards** develops and implements energy conservation standards for appliances and building equipment, and enforces standards through product testing and compliance efforts.

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

BTO's overarching goal is to develop and demonstrate technologies and solutions enabling 50 percent reduction in building primary energy use. To achieve this, BTO's R&D goal is to enable the development of cost-effective technologies that will be capable of reducing a building's energy use by 25 percent relative to 2010 technologies, and 35 percent by 2030.

BTO's Buildings Integration goals are:

- Demonstrate at scale by 2020 market adoption strategies for *new* commercial buildings offering savings of 50 percent or more; and by 2025 for new homes.
- Demonstrate at scale by 2020 market adoption strategies offering savings of 20 percent or more for *existing* commercial and residential buildings; by 2025, 25 percent or more for existing homes; by 2030, 40 percent or more for homes and 50 percent for commercial buildings.

Since 2013, BTO has held an annual "Peer Review" to provide external stakeholder review of its existing projects within the ET, RBI, and CBI programs. In 2015, BTO will again conduct a "Peer Review" of many of its existing projects, and in addition will hold a "Merit Review" for future direct lab projects starting in FY2016. The purpose of this Merit Review is to gather feedback from external stakeholders on these proposed projects. Similar to how external stakeholder feedback is used to inform, improve, and (at times) terminate ongoing projects, this feedback will be used by BTO in its decision-making process to award projects to the national laboratories.

2. FY16 Lab Call & Merit Review

The Department of Energy's Building Technologies Office (BTO) is seeking multi-year (2 or 3 years) project proposals from national laboratories ('Labs') for activities to incorporate into the FY 2016, FY 2017, and FY 2018 Annual Operating Plans (AOPs). **Only proposals for which a DOE national laboratory is the prime recipient will be considered for funding; all other proposals will be returned without review.** This Lab Merit Review will fund the vast majority of the Emerging Technologies (ET) direct lab work starting in FY 2016, and portions of the Commercial Buildings Integration (CBI) and Residential Buildings Integration (RBI) direct lab work. This Lab Call & Merit Review is meant to solicit and select two- to three-year projects that will be assessed with quarterly milestones, including annual Go/No-Go decision points. BTO may subsequently issue supplemental Lab Calls should other topics or needs arise.

For the ET Program, almost all direct lab work starting in FY 2016 needs to be proposed in response to this Lab Call, including both work in progress and new work. This includes all previously designated "core" and "enabling" capabilities. The topics solicited for the RBI Program are extensions of ongoing work, while CBI is soliciting only new work under this Lab Call.

Eligibility

Only DOE/NNSA Federally Funded Research and Development Centers (FFRDCs) and DOE Government-Operated Government-Owned laboratories (GOGOs) are eligible to apply for

funding as a prime recipient. These laboratories include all the "Labs and Technology Centers" listed on http://energy.gov/offices. Prime recipients are encouraged to include other entities as subrecipients, and to form teams with other Labs, as appropriate.

Topics of Interest

Specific topics of interest are described in APPENDIX A (ET), APPENDIX B (RBI), and APPENDIX C (CBI), which include the anticipated deliverables and the planned annual budget.

Evaluation Process & Criteria

A four-step application process will be followed:

- The first step is the submission of a letter of intent that will not be reviewed, but rather serves to assist BTO in organizing reviewers and the review sessions.
- The second step is the submission of a written proposal, with page lengths for the Technical Volume specified in Table 1 that vary depending on the program (ET, RBI, or CBI).
- The third step is the submission of a PowerPoint slide deck prior to the Merit Review. Note that applicants will have the benefit of seeing the reviewers' initial comments prior to submitting this slide deck.
- The fourth step is the delivery of an oral presentation to an external review panel in a closed (private) setting, using the slide deck submitted earlier. The length of the presentation depends on the program (ET, RBI, or CBI) and is also specified in Table 1. The presentation period will include time for questions from the external review panel.

2.1.1. Submit a 1-page letter of intent

Applicants are required to submit a 1-page letter of intent (LOI) by the submission deadline specified on the first page. The LOI must be submitted via EERE Exchange at https://eere-exchange.energy.gov/. The LOI should include the following information:

- Program area (ET, RBI, or CBI)
- Sub-program area or "open" topic, if applicable
- Project title
- Lead laboratory & project director
- Partner institutions (if any), including labs, companies, universities, non-profits, etc.
- 1-paragraph description of the proposed project

2.1.2. Submit a written proposal

Only applicants who submitted a timely Letter of Intent are eligible to submit a written proposal. Written proposals in the format described in APPENDIX D are due by the date given on the first page. The proposals must be submitted via EERE Exchange at https://eere-exchange.energy.gov/. Page limits for the written Technical Volumes vary depending on the program (ET, RBI, and CBI), and are specified in Table 1. The proposals will be reviewed by

Table 1 Merit review Technical Volume length and oral presentation duration for ET, RBI, and CBI

Program	Merit Review Technical Volume Length	Oral Presentation Duration (Including Questions)
Emerging Technologies (ET)	15	60 min
Residential Buildings Integration (RBI)	7	30 min
Commercial Buildings Integration (CBI)	7	30 min

external reviewers, who will provide an initial evaluation of the proposals based on the review criteria defined in APPENDIX E, and using the review form provided in APPENDIX F. The evaluators' comments, in turn, will be made available to the applicants by the date specified on the first page so that the applicants can take those comments into account as they prepare their PowerPoint slide deck for the oral presentation.

2.1.3. Submit a PowerPoint slide deck

Only applicants who submitted a timely written proposal are eligible to submit a PowerPoint slide deck. All applicants to this Lab Call are required to make an in-person oral presentation to an external review committee, and the PowerPoint slide deck used for the presentation must be delivered to BTO by the deadline specified on the first page so that it can be made available to the review committee prior to the presentation. The slide deck must be submitted via email to BTOLabCallFY16-18@EE.DOE.Gov, and cannot be modified once it has been submitted. Applicants are free to choose the format and content of their presentation; no template will be provided by BTO. Applicants should prepare their presentation to conform to the time limits detailed in Table 1, keeping in mind that the total time allotted includes time for questions and answers. Reviewers will be able to comment on both the written proposals and on the PowerPoint slide decks.

2.1.4. Make an oral presentation to an external review panel

During the merit review each applicant will make an oral presentation, using the slide deck provided earlier, to a review committee consisting largely of non-Federal experts. Each program area (ET, RBI, and CBI) will assemble its own review committee. The oral presentations will take place one-by-one in a closed-door session (not open to the public, nor to other applicants). All members of the review committee will be encouraged to ask questions of the applicants, and to provide written comments and scores after the presentation.

Funding Decisions and Next Steps

BTO will make funding decisions, by the date shown on the first page, that are informed by the written comments and scores provided by the external review committees. BTO may choose to fund all, some, or none of the applicants. After funding decisions are announced, successful applicants will be asked to develop corresponding multi-year Statements of Work

(SOWs) based on their proposals, feedback from the external reviewers, and feedback from BTO.

APPENDIX A. Emerging Technologies (ET) Topics of Interest

Proposals are sought for direct lab work in the ET sub-programs listed in Table A 1, which includes a brief description of each sub-program and the anticipated planned annual budget available. For ET, the topics of interest are based largely on the BTO Multi-Year Program Plan

Table A 1 ET sub-programs and planned annual budgets for peer review

Sub-Program	Brief Description	Anticipated Planned Annual Budget ($M/yr)
Solid-State Lighting	R&D and commercial application activities for light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs)	$6.75
HVAC, Water Heating, & Appliances	R&D for vapor-compression, non-vapor-compression, electric-driven and natural-gas-fired HVAC systems, water heaters, and major energy-consuming appliances	$5.25
Windows & Building Envelope	R&D and software development for energy-efficient windows, highly insulating materials and systems for the opaque building envelope and roofs, air-sealing technologies, dynamic windows & window films, and visible light redirection technologies (daylighting). This work does not include the scope of work in support of the Attachments Energy Ratings Council (AERC) FOA project (http://energy.gov/eere/buildings/downloads/attachments-energy-ratings-council) awarded to the Windows Covering Manufacturers Association.	$2.00
Sensors & Controls	R&D for self-configuring, self-commissioning, self-optimizing controls, and low-cost self-powered wireless sensors	$2.00
Building Energy Modeling	R&D and software development for the EnergyPlus building energy simulation package, including testing and validation	$1.75
Manufacturing Analysis	Analysis to understand the competitive advantage along the value chain, U.S.-specific competitive advantages and potential market impacts of building energy efficiency technologies	$0.20
Open	Any R&D topic not described elsewhere in this document that can contribute substantially to realizing the ET goals given in Table A 2	$1.00

Table A 2 BTO emerging technology (ET) program goals

As a result of ET-sponsored research, cost effective technologies will be introduced into the marketplace by 2020 that will be capable of reducing a building's energy use by 25% relative to 2010 cost effective technologies, and 35% by 2030.

Target primary energy savings relative to the 2030 primary energy consumption projected by the *2010 Annual Energy Outlook*:

	Primary Energy Savings Targets	
End Use	**2020**	**2030**
Lighting	30%	65%
HVAC	10%	25%
Water Heating	20%	35%
Appliances	15%	30%
Windows/Envelope	15%	35%
Sensors & Controls	10%	20%

(MYPP), and an "open" topic is included as well. Applicants for the "open" topic should provide exceptional justification for their proposed work, and show how it helps to achieve ET's stated energy savings goals given in Table A 2. All applicants are strongly encouraged to review the existing ET portfolio.[2] Technology-specific metrics and targets, including current status, are described for each sub-program, with the exception of the sensors & controls sub-program for which appropriate metrics and targets are currently being determined through an ongoing roadmap development process.

Annual progress will be monitored through go/no-go SMART[3] milestones, with the possibility that tasks or even entire projects could be terminated due to lack of progress. Unless stated otherwise, in addition to achieving the broad goals defined in Table A 2, project success will be measured by the metrics specified in Table A 3. Note that the two most important metrics are commercialized products, and the projected primary energy savings resulting from those commercialized products. It is not expected that each project will lead to progress in all metrics (e.g., CRADA projects may not yield peer-reviewed publications), but the performance of ALL projects (except the Manufacturing Analysis) will be measured by at least these two most important metrics (commercialized products and projected primary energy savings), with the understanding that software is considered 'commercialized' if it is available to the public and broadly distributed.

Estimates of technical potential primary energy savings should clearly state the baseline technology (or technologies) being replaced, the size of the relevant market in the year 2030,

[2] http://energy.gov/eere/buildings/emerging-technologies
[3] SMART: S = Specific, M = Measurable, A = Achievable, R = Relevant, T = Timely

Table A 3 Description of metrics by which progress will be measured

Metric	Description
Commercialized Products at Market-Acceptable Costs*	Number of products that are commercialized, with corresponding primary energy savings impacts
Primary Energy Savings*	Projected Quads of primary energy (technical potential) saved through commercialized products
Industry Interactions	Number of private and public organizations which are supplying funds or in-kind support for research projects
Cost Share	Amount of funds or in-kind support supplied by private and public organizations (non-BTO)
Intellectual Property (IP)	Number of invention disclosures, patent applications, awarded patents, and licensing agreements
Communications	Number of peer-reviewed journal articles

* Most important metrics, and required for ALL projects except the Manufacturing Analysis.

and any assumptions applied in the analysis. The *Primary Energy Savings Technical Potential* is calculated from Eq. (1):

$$\left[\begin{array}{c}\text{Primary Energy Savings}\\ \text{Technical Potential}\\ \text{(TBtu)}\end{array}\right] = \left[\begin{array}{c}\text{\% Energy Savings}\\ \text{Over Typical New}\\ \text{Technology}\end{array}\right] \times \left[\begin{array}{c}\text{2030 Energy Market}\\ \text{Size}\\ \text{(TBtu)}\end{array}\right] \quad (1)$$

The *2030 Energy Market Size* (TBtu) can be determined from the market addressed by the technology (residential, commercial, new, retrofit, etc.), the end use (space air conditioning, lighting, cooking, refrigeration, etc.), the climate zone (1 – 5), and other information. Applicants are encouraged to use the "Building Technologies Office Market Definition Calculator" posted with the recent BUILD FOA (DE-FOA-0001167).[4] The "Typical New Technology" is the technology that is being replaced. For "covered" technologies, that is, technologies subject to minimum efficiency standards,[5] Applicants should assume the efficiency of the "Typical New Technology" to be greater than or equal to the applicable efficiency standard.

Starting in FY16, all software developed under ET support must be open source. For existing software products that are not currently open source, plans for converting the software development process to open source must be presented such that the software is open source by the end of FY16. The definition of open-source software and acceptable licenses are provided in APPENDIX G.

[4] Available on EERE Exchange at https://eere-exchange.energy.gov/default.aspx#Foaldb1ef4b8e-7e75-43fc-a2ac-af86bb5d3a75

[5] http://www1.eere.energy.gov/buildings/appliance_standards/standards_test_procedures.html

A detailed description of the specific topics solicited under each ET sub-program is provided below. **Proposals for a given sub-program should be comprehensive and include ALL the solicited topics, subject to the anticipated planned budgets given in Table A 1.** In other words, we do not seek proposals for only a portion of a sub-program, but rather want proposals that address an entire sub-program comprehensively (e.g., both windows and envelope efforts should be proposed together). If an Applicant determines that the anticipated planned budgets in Table A 1 are not sufficient for all solicited activities in a sub-program, then the Applicant should prioritize those activities so as to best meet the goals of the ET Program in Table A 2. Labs are encouraged to partner with external organizations and/or with one another to incorporate all the capabilities and facilities needed to meet the needs of each sub-program.

Solid-State Lighting

DOE SSL competitive R&D awards have yielded scores of patents and have done much to support SSL technology progress. Each award focuses on a narrow aspect of the technology, or a single product development, potentially limiting the widespread impact DOE seeks to have in SSL product innovation. Therefore, the program has simultaneously pursued a technology innovation strategy that reaches much more broadly out to the industry and challenges them to continually and aggressively improve LED lighting products, fix performance problems, and develop new, innovative solutions to light buildings and outdoor areas.

This strategy, called *Applied Technology R&D*, provides critical LED product, system, and lighting application performance information to the whole SSL industry, multiplying the impact of scarce public dollars many times over. The strategy recognizes that we are still in the first 10 years of technology innovation for SSL, and that commercially available products continue to need a wide range of major technical improvements. The investigations conducted to develop this information are most commonly aimed at newly developed commercial products, but in some cases include pre-production prototypes. The investigations are used to create a tight feedback loop for technology innovation, providing technology developers with detailed

Table A 4 LED package price and performance to 2020

Metrics and Milestones: LED Package Price and Performance					
Package Type	**Project Areas**	**Metric**	**Status***	**2017**	**2020**
Cool-White	Efficacy	lm/W	166	211	231
	Price	$/klm	4	1.3	0.7
Warm-White	Efficacy	lm/W	135	197	225
	Price	$/klm	5.1	1.4	0.7

**Current status of 2013*

investigations of performance and features available in new products and systems, including detailed characterizations of product strengths and weaknesses.

Topic: SSL Applied Technology R&D

This topic area encompasses a set of integrated activities intended to cause comprehensive, accelerated technology development in the SSL industry. Results from these activities will be aimed at the entire industry, not just individual companies.

SSL Applied Technology R&D includes technical investigations of newly developed commercial products and prototypes intended to fully characterize and quantify a wide variety of performance and operational parameters. These investigations will typically include lab and field testing, comparison with benchmark products, and detailed descriptions of technical shortcomings encountered during the investigations. Examples of the technical investigations to be conducted to support this strategy are those that address chromaticity maintenance, lumen maintenance, veiling and disabling glare, lighting system component interoperability, lighting controls systems interoperability, thermal performance, lighting system reliability, beam quality, component serviceability, circadian lighting, short wavelength eye safety, color tunable systems, control system user interfaces, color quality, and lighting system level interactive and synergistic effects.

Results of the above investigations will be used to support the SSL industry in addressing system performance and application problems. For example, technology competitions will be used to challenge technology developers to develop new products meeting aggressive performance specifications and new systems designed to light traditional building spaces in entirely new ways. Entries in these competitions will be subjected to rigorous evaluations and testing, and benefit from detailed feedback to be provided by DOE and outside experts.

Expected Activities at the National Laboratories: SSL Sub-Program

Research findings and other work products from the above investigations and activities will be widely communicated to the SSL industry via workshops, journal articles, and other channels. An increasing emphasis on OLEDs is anticipated, as well as the transition of deployment-focused activities to the Commercial Buildings Integration (CBI) program and to the private sector. The SSL sub-program will coordinate carefully with the minimum efficiency standards program, and with the CBI program on deployment activities.

Table A 5 Required facilities and capabilities for the SSL sub-program

Facilities	Description
Photoelectric Testing	A set of equipment for measuring various electric power (including power quality) and photometric (including light output and flicker) characteristics of light sources when operated on both switched and phase-controlled circuits.
Accredited Integrating Sphere Testing	An integrating sphere (min. 2 meters) and related equipment. Lamp and luminaire testing must be accredited by at least one of the accreditation bodies listed on the U.S. DOE LED Lighting Facts website.

Long-term Lamp Testing	Environmental test chambers and related test equipment. Must be capable of performing long-term testing of lamps at elevated temperatures for measurement lumen and chromaticity maintenance. Test chambers must have a minimum capacity of 200 lamps. Elevated temperatures must be controlled within ± 5°C.
Lamp and Luminaire Stress Testing	Environmental test chambers and related equipment capable of performing electrical, vibration, thermal, and humidity stress testing. Equipment must be capable of achieving 170° C to - 50° C, 30 to 210 RMS voltage, humidity up to 100%, and up to 20 peak g force.
Luminaire Mock Up Space	Indoor space (at least 300 sq. ft.) with mounting hardware, wiring, and control gear capable of displaying lamps and luminaires in intended operating locations (ceiling, wall, and track mount). Mounting hardware must be highly flexible with regard to various mounting and spacing schemes for lamps and luminaires.
Capabilities	**Description**
Luminaire and Lamp Performance Testing	a. Photoelectric Testing (for dimmed and non-dimmed light sources) i. Flicker (flicker index, percent flicker) ii. Input power quality (power factor, THD-I) b. Integrated Sphere Testing i. All key photometric measurements c. Long-Term Testing (for lumen and chromaticity maintenance measurements) i. All key photometric measurements d. Stress Testing i. Multi-stress (thermal, humidity, electrical, and vibration) ii. Relative (to benchmark product) robustness iii. Time to catastrophic failure iv. Parametric degradation measurements
Lighting Field Demonstrations	a. Field lighting and electrical measurements b. Long and short-term measurements c. Quantitative and qualitative lighting quality assessment
Lighting Technology Assessments	Detailed technical and subjective evaluations of lighting products; including lab and field measurements, performance analysis, benchmark comparisons
Lighting Application Engineering	Lighting design, lighting simulations, lighting calculations, lighted space evaluations
Color Science	Technical investigations of spectral composition issues and

	interactions with human visual system
Lighting Controls Systems	Technical investigations of lighting control systems performance, operations, and communications
Lighting Product and Application Specifications	Detailed product and application specifications development for a wide range of lighting products and applications
Lighting human Factors	Ability to assess human responses to glare, photometric flicker, changing lighting spectra, beam quality, general lighting quality and others

Deliverables: SSL Sub-Program

Activities related to LEDs will support the milestones given in Table A 4, and the corresponding primary energy savings. The set of minimum facilities and capabilities required for the SSL program are described in Table A 5. In addition, the following deliverables are required:

- At least 8 complete investigations per year, including lab and field measurements as needed.
- At least one technology competition per year.
- Delivery of at least one major technology workshop per year.
- At least 30 formal presentations per year, via workshops, webcasts, and conferences.

HVAC, Water Heating, and Appliances

The heating, ventilation, and air conditioning (HVAC), water heating (WH), and appliances sub-program focuses on developing improved materials or components, improving equipment design or engineering, developing lower cost manufacturing processes, or enabling easier installation. The research and development activities in this sub-program often include crosscutting technologies and justifies its integrated/multidisciplinary R&D efforts across several end uses.

To advance energy efficiency, the sub-program pursues solutions that are systems-oriented to optimize energy use in the entire building. R&D priorities include developing integrated systems that combine end-uses, such as energy cascading where heat from one process is used as the source of energy for another as in integrated heat pump technologies. Another sub-program priority is to explore new or different next-generation components to find the best possible, cost-effective combination. These efforts will result in innovative, energy-saving components and technologies for HVAC, WH, refrigeration, and laundry systems that have the potential to fully replace or be integrated with conventional technologies, often across end uses. Improved HVAC, water heating, and appliance technologies offer significant opportunity for energy savings. Energy savings can be realized not only in individual end uses, but in optimizing and reducing building energy use through integrated systems. This requires improving the design and sizing of systems, and integrating them into the building design and for operation and control. One example of this is an integrated packaged heat pump system capable of cooling and heating indoor spaces and space and water heating simultaneously for

various applications. These system-based solutions also require researchers who are system based also, more than just component researchers.

The HVAC/WH/Appliance sub-program uses the strategies outlined below to develop and advance affordable, cost-effective technologies that improve system energy consumption. R&D includes both near-term advances as well as development of next-generation technologies that "leapfrog" existing technologies and result in drastically improved efficiency. The sub-program aims to introduce next-generation technologies in the simplest applications first for the highest probability of success. Subsequently, DOE can utilize these approaches in more complex technologies with confidence in the additional investment. For example, the sub-program would consider implementing advanced, non-vapor compression heat pump technologies into refrigeration systems before rollout to space-conditioning applications.

1. R&D Strategy–Near Term Technology Improvement–Improve performance and reduce the cost of near-term highly energy-efficient technologies.
2. R&D Strategy–Next Generation Technology Development–Develop the next generation of technologies that represent entirely new approaches and cost-effectively achieve significant performance improvement.
3. Commercialization Support Strategy–Accelerate the market availability of technologies through cooperative research and development agreements (CRADAs) with manufacturers.

This sub-program places a strong emphasis on the commercialization of technologies and pursuing innovative solutions. To accelerate the commercialization and market viability of new technologies, the HVAC/WH/Appliance sub-program supports R&D and demonstrations that engage key manufacturers. After product development, the sub-program partners with industry through CRADAs to accelerate market introduction. CRADAs allow non-federal entities to collaborate with DOE to accelerate the transfer of technologies DOE has supported to the private sector for commercialization. A common goal of a CRADA is to refine and demonstrate a system, not just the technology. CRADAs are focused on engineering development and making compromises so that the resulting product is market viable, and energy efficient. Completion of a CRADA, when the product is commercially available, typically signals the project's transition from the sub-program to the Residential and Commercial Building Integration Programs (RBI and CBI) or other deployment efforts to help promote the products, increase awareness, and ensure that the sub-program's R&D efforts have as high an impact as possible in the marketplace. The team performing work for the HVAC/WH/Appliance sub-program will need to generate interest from industry for the development and execution of CRADAs for market-ready solutions.

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

the Air-Conditioning, Heating & Refrigeration Institute (AHRI) to help accelerate market acceptance. The sub-program implements activities to increase U.S. competitiveness in manufacturing and learn of promising new technologies through international collaboration. Participation in the International Energy Agency Heat Pump Programme and the International Institute of Refrigeration (IIR)[6] activities builds awareness of and insight into the latest international R&D and technology developments in Europe and Asia on improved building energy efficiency and CO_2 emission reductions.

Expected Activities at the National Laboratories: HVAC/WH/Appliances Sub-Program

The national laboratories play an important role in meeting our overarching goal for the HVAC/Water Heating/Appliances sub-program due to BTO's past investments, technical capacities and talent. Historically, the national labs' strengths for this sub-program has been in longer-term efforts in which technologies at low technology readiness level (TRL) of 4 or 5 are fully developed with industry partners to a TRL of 9. These successful projects were only realized with strong industry participation and long-term support from BTO. This is not to say that the national labs are not encouraged to pursue technologies at the TRL of 3 or 4, but these efforts should be first seeded via Funding Opportunity Announcements (FOAs), or a small effort at the lab which would result in a CRADA project(s) with a manufacturer(s) within 12 months of the project starting (hard gate requirement). Ideally, the national lab could be leveraged to support successful BTO or ARPA-E FOA projects via CRADAs to aid their market introduction via teams or with manufacturers directly. An example of this type of FOA CRADA transition is the GE CRADA on magnetocaloric refrigeration which initially started as an American Recovery and Reinvestment Act (ARRA) FOA project and was transitioned to a national laboratory CRADA project for additional development.[7] This is more than just a laundry list of discrete one-off projects in the sub-program research portfolio but developing a continuum or track from a low TRL engineering effort into a "market-ready" product, requiring some shepherding by BTO and leveraging our past investments at the national laboratories.

Deliverables: HVAC/WH/Appliances Sub-Program

All the technologies being developed and pursued under the HVAC/WH/Appliance sub-program will support the metrics and milestones listed in Table A 6 (HVAC), Table A 7 (water heating), and Table A 8 (appliances). CRADA projects will work with CRADA partners to develop market-ready devices. Table A 9 lists the facilities requirements for the HVAC/WH/Appliances sub-program. Specific milestones will be developed with the performer and partners, balancing available funds. Existing projects will be given priority over new starts since they are near completion and close to market introduction.

[6] The IIR is the only independent intergovernmental organization which promotes the advancement of basic scientific knowledge of refrigeration and associated technologies including energy efficient HVAC equipment and the use of non-ozone-depleting and low-global warming refrigerants.
[7] http://energy.gov/eere/buildings/downloads/magnetocaloric-refrigeration

Table A 6 HVAC metrics and milestones to 2020

Metrics and Milestones: HVAC					
Project Area	**Metric**	**Building Milestone Type**	**Status**	**2017**	**2020**
Advanced vapor compression technologies	Primary seasonal COP; Installed cost premium per kBtu/hr, in 2013 $	Residential and commercial	1.84; $68.5†	2.30; $33.6	2.01; $22.9
Non-vapor compression HVAC systems		Residential and commercial	Not on market	2.28; $29.9	2.28; $20.3
Natural gas driven heat pumps		Residential and commercial	1.2; $101.8*	1.4; $35.0	1.38; $23.9
Cold climate Heat pump		Residential and commercial	0.85; $36†	1.00; $36.7	1.07; $25.0
Air source-integrated heat pump	Primary energy savings; Installed cost premium per sq. ft.	Residential	Not on market	45%; $2.0	49%; $1.5
Multifunction natural gas-driven heat pump		Residential and commercial	30%; $9.4‡	42%; $1.5	44%; $1.1

† Based on Navigant HVAC Historical and market analysis comparing best in market to typical of 2013.
** No BIM Natural gas driven HP exist on market; compared typical natural gas heat pump to typical AC.*
‡ Currently available only for commercial markets.

HVAC Projects

Ending in FY15:

- Project 3.2.2.14 Multi-Function Fuel Fired Heat Pump (Existing, CRADA, ending in FY15)
- Project 3.2.2.21 Multi-Zone HVAC Air Source Integrated Heat Pump (Existing, CRADA, ending in FY15)
- Project 3.4.2.10 Develop Standard Method of Test (Existing, ending in FY15)
- Project 3.9.1.14 Ground Source Heat Pump Demonstration Projects (Existing, ending in FY15)

Table A 7 Water heating metrics and milestones to 2020

Metrics and Milestones: Water Heating				
Project Area	**Metric**	**Building Milestone Type**	**Status**	**2020**
Non-CO_2 vapor-compression HPWH	Primary energy factor; Installed cost premium per first hour rating ($/gal)	Residential and commercial	0.79; $21.4†	0.81; $8.13
CO2 vapor-compression HPWH		Residential and commercial	Not on the market	0.94; $11.94
Non-vapor compression HPWH		Residential and commercial	Not on the market	0.52; $4.00
Gas-fired absorption/ adsorption HPWH		Residential and commercial	Not on the market	1.20; $7.14

† Based on Navigant Water Heater Historical and market analysis comparing best in market to typical of 2013.

Projects for FY16-FY18

- Project 3.2.2.12 Advanced Variable Speed Air Source Integrated Heat Pump (Existing, CRADA, ending in FY17): Goal to develop and facilitate market introduction of a new product with a target of ≥ 45% HVAC energy savings and a cost premium of ~$2/ft^2 by 2017. In addition, it is also expected to achieve water heating energy savings of ≥ 65%.
- Project 3.2.2.13 Cold Climate Heat Pump (Existing, CRADA, ending in FY16): The two cold climate heat pump (CCHP) CRADA activities are working toward demonstrating the potential to achieve a site heating seasonal performance factor (SPF) of ~2.7 (~0.9 source SPF assuming a 3.0 site-to-source electric energy conversion factor) and an installed cost premium of ~$148/kBtuh nominal heating capacity.
- Project 3.2.2.15 Next Generation Rooftop Unit (Existing, CRADA, ending in FY16): The advanced RTU CRADA is working to demonstrate the potential to achieve a site cooling seasonal efficiency or integrated energy efficiency ratio (IEER) of 22 (~2.2 source IEER assuming the 3.0 site-to-source factor) and an installed cost premium of ~$148/kBtuh nominal cooling capacity.
- Project 3.4.2.11 International Energy Agency Collaboration (Existing, continuing): This is a government function task. The primary project objective is to maintain collaborative contacts with other IEA and IIR participants engaged in technology development of core interest to BTO. Particular work will focus on participation in collaborative HPP projects (aka Annexes) dealing with improved cold climate performance of air-source heat

pumps (Annex 41), advancing methods of test/rating for multi-function heat pumps (Annex 39), heat pump equipment solutions for very high efficiency housing (Annex 40), integration of heat pumps with smart grid systems (Annex 42), and natural-gas-driven sorption cycle based heat pump technologies (Annex 43). Significant effort will also be devoted to initiating plans for a short course sponsored through the USNC/IIR at the *2016 International Refrigeration and AC Conference* at Purdue University.

- New Project: Residential Absorption Heat Pump (New, CRADA, expected start in FY16): Goal to develop and facilitate market introduction of a new product, a residential absorption heat pump, first prototype.
- New Project: Commercial Integrated Heat Pump with Thermal Storage (New, CRADA, expected start in FY16): Goal to develop and facilitate market introduction of a new commercial integrated heat pump with thermal storage, evaluate concept and submit stage gate report.
- New Project: Separate Sensible and Latent Cooling Air Conditioning System (New, expected start in FY16): Project will address Table A 6 requirements; evaluate prototype system and submit stage gate report.
- New Project: Membrane Based Air Conditioning System (New, expected start in FY17): Project will address Table A 6 requirements; evaluate prototype system and submit stage gate report.
- New Project: Novel Solar Absorption Cooling System to Reduce Peak Loads (New, CRADA, expected start in FY17): Goal to develop and facilitate market introduction of a novel solar absorption cooling system to reduce peak loads, evaluate concept and submit stage gate report.

Water Heating Projects

Projects for FY16-FY18

- Project 3.1.2.14 Adsorption Water Heater (Existing, ending in FY17): Complete work on the adsorption water heater prototype.
- Project 3.1.2.16 Commercial Absorption Water Heater (Existing, CRADA, ending in FY17): A “near field test ready” beta prototype will be prepared in FY16.
- Project 3.2.2.17 Absorption Heat Pump Water Heater (Existing, CRADA, ending in FY16): Finalize a CRADA partnership and proceed to move towards market introduction with industrial partner.
- Project 3.2.2.18 CO2 Heat Pump Water Heater (Existing, CRADA, ending in FY16): Final CRADA report will be submitted, product is market ready.
- Project 3.1.2.100 Combined Water Heater, Dehumidifier, Evaporative Cooler (CWH/DH/EC) (New, FOA, CRADA expected, starting in FY17): Support FOA project, accelerate the development.

Table A 8 Appliances metrics and milestones to 2020

Metrics and Milestones: Appliances					
Project Area	**Metric**	**Building Milestone Type**	**Status**	**2017**	**2020**
Advanced compressor technologies	Primary energy savings; installed cost premium per unit	Residential	Not on market	20%; $300	25%; $225
		Commercial	10%; $63,000*	15%; $2,000	15%; $1,000
Advanced refrigerators		Residential	28%; $162†	40%; $600	47%; $420
		Commercial	37%; $8840‡	25%; $4,000	28%; $3,000
Heat pump dryer		Residential and commercial	Not on the market	45%: $750	50%; $565
Non-vapor compression refrigeration technologies		Residential	Not on the market	50%; $500	55%; $285
		Commercial	Not on the market	30%; $6,000	32%; $2,100
Low-emission refrigeration	Life cycle direct emissions in at least 5 HVAC&R applications capturing >50% of the national HVAC&R direct emissions	Residential and commercial	Not on the market	50% Reduction	75% Reduction

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

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

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

Table A 9 Facilities requirements for the HVAC/WH/Appliances sub-program for project development and testing

Facility	Description
Small Appliance Environmental Chamber	Chamber to be used to test appliances such as residential water heaters and refrigerators. Should control dry-bulb temperature from −17.8 to 48.9°C (0 to 120°F) and relative humidity from 40 to 80% at a cooling load of about 4000 Btu/h. Utilities include 480 V, 3-phase power at 40 A with step-down transformers to provide 240, 208, and 120 V.
Mid-Size Appliance Environmental Chambers	Chamber to support testing of gas and electric space-conditioning and combined heat and power components and systems (up to 10 tons). Gas and electricity are supplied, with 480 V, 3-phase power at 225 A and step-down to 240, 208, and 120 V. Dry bulb temperature is controlled at −23–54°C (−10–130°F) and relative humidity at 30–90%.
Large Appliance Environmental Chambers	Chamber to support testing of commercial HVAC, refrigeration, and combined heat and power systems (up to 20 tons). Gas and electricity are supplied, with 480 V, 3-phase power at 225 A and step-down to 240, 208, and 120 V. Dry bulb temperature is controlled at −29–54°C (−20–130°F) and relative humidity at 30–90%.
Multi-Zone Environmental Chambers	Chamber to test multi-zone electric or gas HVAC systems (up to 10 tons) for residential and small commercial use. Chambers should be able to be divided into up to four spaces controlled at different conditions to represent separate zones. Dry-bulb temperature is controlled at −23–54°C (−10–130°F) and relative humidity at 30–90%. Safety systems and alarms support tests using low GWP as well as HFC refrigerants.
Water Temperature Control Loop	Apparatus to tests heat-pump–based water heating systems (e.g., heat pump water heaters and integrated heat pumps) for space conditioning and water heating in the mid-size and small appliance chambers. Supply water is provided to test systems at 4.4–43.3°C (40–110ºF). The plant for the loop should include a 2 ton nominal capacity variable-speed refrigeration system and an 18 kW electric resistance immersion heater for precise water temperature control.
Water Heater Durability Test Facility	Facility to test up to 10 residential heat pump water heaters simultaneously, simulating 10 years of residential operation in 10 months, to support statistical service life estimates. Electricity and gas are supplied. Total rated input power is 50 kW; supply voltage is variable from 190 to 240 V to simulate grid voltage droop. Supply water is provided over a 40 to 75°F range.
Small Compressor Calorimeter Test Stand	Test stand to experimentally generate compressor performance maps for fractional-ton compressors (300 to 3600 Btu/h) used in refrigerators and other small appliances and equipment. It is equipped to safely test compressors using alternative refrigerants with some level of flammability (e.g., isobutene, propane) and nonflammable refrigerants such as HFCs and low-global warming potential (GWP) hydrofluoroolefin alternatives.
Large Compressor Calorimeter Test Stand	Apparatus to experimentally generate compressor performance maps for compressors of up to 3 tons (3,000 to 36,000 Btu/h) like those in air conditioners and heat pumps. It can safely test compressors at very high pressures using transcritical CO_2 as the refrigerant and nonflammable refrigerants such as HFCs and low-GWP hydrofluoroolefin alternatives.
High Temperature Heat Exchanger Test Loop	Loop to test air-to-water HXs at high air-side temperatures like those encountered in recovering heat from turbine exhaust in combined heat and power applications. It features variable air flow from 10 to 1500 cfm, entering air temperatures from room temperature up to 1100°F, and entering water temperatures from 50 to 200°F.
Computational Fluid Dynamics Modeling Lab	A Computational Fluid Dynamics Modeling Lab
Pumped Liquid Refrigerant Test Loop	A test loop for testing refrigerant-to-air HXs precisely controls entering refrigerant temperature and pressure. It accommodates evaporators with capacities up to 2 tons (24,000 Btu/h) and evaporating temperatures of 4.4–10°C (40–50°F), and condensers up to 3 tons (36,000 Btu/h) and condensing temperature of 48.9°C (120°F). Alternative pure refrigerants can be tested without lubricating oil. The air-side loop moves up to 7000 cfm of air against a 4 in. (w.g.) HX pressure drop. Thermal imaging to determine flow maldistribution through the HX.
Bench Top Wind Tunnel	A bench top wind tunnel to test novel HX concepts and features such as fin performance. Hot wire anemometers and other air flow sensors are calibrated for internal use. The test chamber has a cross-section area of 10×10 cm (4×4 in.) and induces a flow rate from 25 to 9,000 cfm. It is fully instrumented with high-accuracy barometric pressure, differential pressure, temperature, and relative humidity sensors. Flow rate accuracy ranges from 1 to 2%. All instruments are provided with NIST-traceable calibration.
Additive Manufacturing Plastic Heat Exchanger 3-Dimensional Printer	A 3D printer for rapid prototyping of functional heat exchangers (HXs) from plastics.
Fluid Physical Properties Laboratory	A lab to measuring density, viscosity, thermal conductivity, thermal diffusivity, and specific heat of fluids. Which can be programmed to perform a temperature scan of a sample and measure properties over a broad temperature range while unattended?
Two-Phase Flow Neutron Imaging Test Stand	Two-Phase Flow Neutron Imaging Test Stand to simultaneously measure refrigerant 2-phase flow void fraction, pressure drop, and heat transfer in single- and multi-channel HXs. Images and other information generated guide HX redesign (e.g., to eliminate refrigerant maldistribution). The test apparatus accommodates flow channels of various sizes and materials and operates over a range of operating conditions and with several low-GWP refrigerants. It consists of a refrigerant flow loop and a test section that allows microchannel HXs to be interchanged.

- New Project: Commercial CO2 Heat Pump Water Heater (New, CRADA, expected start in FY16): Goal to develop and facilitate market introduction of a commercial CO2 Heat Pump Water Heater.
- New Project: Max Technical Efficiency Electric HPWH with Low-GWP Halogenated Refrigerant (New, CRADA, expected start in FY16): Goal to develop and facilitate market introduction of a HPWH with Low-GWP Halogenated Refrigerant, low-GWP effort and addressing our water heating goals combined.

Appliances Projects

Projects for FY16-FY18

- Project 3.1.2.10 Working Fluids – Low Global Warming Refrigerants (Existing, CRADA, ending in FY16): Complete the evaluation of lower GWP refrigerants in an enhanced refrigeration system using scroll compressors and to evaluate a lower GWP refrigerant option in a third-party refrigeration system.
- Project 3.1.2.12 Advanced Compressor Technologies (Existing, CRADA, ending in FY17): Goal to develop and facilitate market introduction of a variable capacity modulation feature of linear compressors to design the next-generation household refrigerator.
- Project 3.2.2.10 Heat Pump Dryer (Existing, CRADA, ending in FY17): Complete laboratory testing of the heat pump clothes dryer prototype.
- Project 3.2.2.16 High Efficiency, Low Emission Refrigeration System (Existing, CRADA, ending in FY17): Complete laboratory performance testing of advanced 2nd generation prototype refrigeration system.
- Project 3.2.2.20 Advanced Rotating Heat Exchangers (Existing, ending in FY17): Evaluate the market potential for the 1 kW rotating HX, assess the potential for market growth if capacity may be scaled, and determine potential technology diffusion. Prepare a draft technical report summarizing the performance and market assessment of the 1 kW rotating HX.
- Project 3.2.2.22 Magnetocaloric Refrigerator (Existing, CRADA, ending in FY17): Goal to develop and facilitate market introduction of a magnetocaloric refrigerator, identify optimal magnetocaloric material based on life expectancy and performance and perform component testing.
- Project 3.1.2.97 Ultrasonic Clothes Dryer (New, FOA, CRADA, starting in FY 16): Support FOA project, accelerate the development.
- Project 3.1.2.98 Thermoelectric Clothes Dryer (New, FOA, CRADA, starting in FY 16): Support FOA project, accelerate the development.
- New Project: Alternative Refrigerant Evaluation for R32 in Heat Pumps (New, expected start in FY16): Complete testing of the refrigerant evaluation for R22 (in heat pumps), addresses energy efficiency targets and potential for high ambient operating conditions.

- New Project Electrochemical Compression Refrigerator (New, expected start in FY17): Preliminary test results of electrochemical compression for refrigerator applications.

Windows & Building Envelope

The Windows and Building Envelope sub-program focuses on advancing technologies outlined in the Windows & Building Envelope R&D roadmap.[8] This includes developing improved materials or components, improving equipment design or engineering, developing lower cost manufacturing processes, or enabling easier installation. As with the other topics in the ET program, the windows and building envelope direct lab efforts, which historically have largely been independent, must be combined into a single proposal, and their scopes of work should be coordinated and informed by one another to the extent possible.

The highest priority R&D topic areas include cost-effective highly insulating windows, high-performance thermal insulation for retrofitting existing walls, and system-level air sealing technologies. These technologies have the greatest national potential for energy savings, but require significant reductions in installed cost to achieve mass-market penetration. Other technology areas of interest for the sub-program include dynamic windows and window films, visible light redirection technologies and highly insulating roofs for commercial buildings. The sub-program is careful to consider non-energy drivers and other key variables that will impact the successful market adoption of a new technology, such as installation improvements, overall aesthetics, acoustics, and building occupant thermal comfort. Note that the support of the Window Covering Manufacturers Association's Attachments Energy Ratings Council (AERC) Program is NOT included in the merit-reviewed scope of work for the Windows & Building Envelope sub-program.

All technology areas in this sub-program have specific performance and installed cost targets that are summarized in Table A 10 and Table A 11. The Windows & Building Envelope sub-program uses the strategies outlined below to develop and advance affordable, cost-effective technologies that improve the energy performance of the building envelope. This includes both near-term advances as well as development of next-generation technologies:

1. R&D Strategy–Near Term Technology Improvement–Improve performance and reduce the cost of near-term highly energy-efficient technologies.
2. R&D Strategy–Next Generation Technology Development–Develop the next generation of technologies that represent entirely new approaches and cost-effectively achieve significant performance improvement.
3. Commercialization Support Strategy–Provide enabling technical support, such as simulation tools, testing procedures and design expertise, to manufacturers of all sizes to accelerate the commercialization of highly efficient and cost-effective technologies.

[8] http://energy.gov/eere/buildings/downloads/research-and-development-roadmap-windows-and-building-envelope

Table A 10 Windows and window films metrics and milestones to 2025

Metrics and Milestones: Windows & Window Films							
Project Area	**Metric**	**Status**		**2020**		**2025**	
		Res	**Com**	**Res**	**Com**	**Res**	**Com**
Highly Insulating Windows	R-value with Weight & Thickness Amenable to Retrofits; V_T > 0.6 (R) and V_T > 0.4 (C);	R-5.9	R-5.9	R-10	R-7	R-10	R-7
	Installed Cost Premium ($/sq.ft.)	$63	$75	$10	$8	$6	$3
Dynamic Windows	(ΔSHGC) with V_T Bleached State > 0.6 (R) & 0.4 (C);	0.38	0.38	0.4		0.4	
	Installed Cost Premium Incl. Cost of Sensors & Controls ($/sq.ft.)	$28	$43	$15		$8	
Dynamic Window Films	(ΔSHGC) with V_T Bleached State > 0.6 (R) & 0.4 (C);	Not on market	Not on market	0.4		0.4	
	Installed Cost Premium Incl. Cost of Sensors & Controls ($/sq.ft.)	Not on market	Not on market	$8		$2	
Daylighting Technologies	Lighting Energy Use (% reduction) 50 ft. Floor Plate;	16%		35%		50%	
	Installed Cost Prem. Incl. Sensors & Controls ($/sq.ft.)	$9		$13		$5	

This sub-program places a strong emphasis on the commercialization of cost-effective, energy efficient technologies. As such, R&D projects must be done in close partnership with manufacturers. The national laboratory (or laboratories working collaboratively) performing work for the Windows & Building Envelope sub-program will need to generate interest from industry for the development and execution of cost-shared, joint R&D projects for market-ready solutions. The point at which a product becomes commercially available typically signals the project's transition from the sub-program to the Residential and Commercial Building Integration Programs (RBI and CBI) or other deployment efforts, such as EPA's ENERGY STAR

Table A 11 Building envelope metrics and milestones to 2025

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

Most Efficient Program to help promote the products, increase awareness, and ensure that the sub-program's R&D efforts have as high an impact as possible in the marketplace.

Expected Activities at the National Laboratories: Windows & building Envelope Sub-Program

The national laboratories play an important role in meeting our overarching goal for the Windows & Building Envelope sub-program. Labs can apply for BTO funds through three mechanisms: Funding Opportunity Announcement (FOAs), AOP and Lab Calls. Typically, early stage R&D projects (beginning TRL 3-5) are supported through FOAs or as a small effort through a Lab Call. If successful, these projects would mature to be supported through a joint R&D project, such as a CRADA project(s), with a manufacturer(s). Ideally, the national lab could be leveraged to support successful BTO or ARPA-E FOA projects to aid their market introduction via teams or with manufacturers directly. There are a number of different ways that labs may work to bring technologies to market either by directly doing R&D and engineering work

themselves or by doing analysis and testing work to enable manufacturers to move technologies to the market. Over time, this strategy will create a continuum or track from a low TRL engineering effort into a "market-ready" product, requiring some shepherding by BTO and leveraging our past investments at the national laboratories.

In addition to R&D collaboration, in the area of envelope modeling, DOE has funded the creation of a suite of tools for detailed characterization, certification, and design of fenestration and opaque-envelope products and assemblies. These tools are heavily leveraged by the private sector and are critical to bringing the next generation energy-efficient technologies to the mass market. As such, the labs are expected to continue to develop and advance these technologies in coordination with BTO's Building Energy Modeling sub-program.

The Windows & Envelope sub-program solicits proposals in three different topic areas described in detail below:

1) Windows R&D
2) Envelope R&D
3) Windows & Envelope Modeling Tools

All the technologies being developed and pursued under this sub-program will support the metrics and milestones listed in Table A 10 and Table A 11. Specific milestones will be developed with the performer and partners, balancing available funds. Existing projects that have proven successful in the past, specifically those supporting enabling capabilities, will be given priority over new starts. Note that simulation methods and testing procedures for rating and certifying window attachments in support of the Window Coverings Manufacturer's Association's AERC program awarded from the CRAFT FOA (DE-FOA-0001000) is not included in this solicitation. However, like all other software developed with funding from ET, the software developed in support of the AERC program must be open source and fully rationalized and integrated with the Building Energy Modeling sub program as described below.

Windows R&D

The primary goal of the windows R&D effort is to develop low-cost next-generation window technologies described in Table A 10. The highest performing fenestration systems are cost-prohibitive for mass adoption in both the commercial and residential sectors. The sub-program currently concentrates efforts on reducing materials cost, improving manufacturing processes, and making installation easier of energy-efficient fenestration technologies for retrofit applications.[9]

The highest priority R&D topic in this category is highly insulating windows, but also dynamic windows and window films, and visible light reduction technologies. All technologies have specific performance and installed cost targets that are listed in Table A 10 and are broken out by building sector, where possible, and all proposals are expected to support achieving these targets. Commercial windows must also meet much more demanding structural tests

[9] See http://energy.gov/eere/buildings/windows-and-building-envelope for a listing of current projects.

(design pressures, deflection limits, torsion, other hurricane ratings, operability), as well as very different market demands to ensure market acceptability. Please refer to the Windows & Envelope R&D roadmap[10] for further details and areas of interest for the targets described in Table A 10.

In addition, to ensure that window technologies developed through the sub-program have high impact in the marketplace, BTO is soliciting a small (not more than $75K per year DOE funds) project starting in FY16 in support of EPA's ENERGY STAR Most Efficient program. This project must include the following:

- Market assessment of NFRC-certified products for the residential buildings sector that are capable of automatically controlling SHGC, either through automated shading, electrochromic or thermochromics glazing. This must include a description of the products and a list of the companies selling them. It is also ideal to know the volume sold, but that is not a necessity.
- Performance data, including product specification ranges for NFRC-certified products
- Support in defining and specifying automated SHGC control products for inclusion in EPA's ENERGY STAR Most Efficient Program
- National energy savings estimation for automated SHGC control products in the residential buildings sector across a variety of climates/cities in the US
- Coordination with EPA's ENERGY STAR Most Efficient Program
- Significant cost-shared funding from at least two private sector partners

Building Envelope R&D

The primary goal of the building envelope program is to develop cost-effective and energy efficient materials, technologies and manufacturing processes described in Table A 11. The highest performing building envelope technologies are cost-prohibitive for mass adoption in both the commercial or residential sectors and are often not suitable for retrofit applications. The sub-program currently concentrates efforts on reducing materials cost, improving manufacturing processes, and making installation easier.[11] In many cases, performance of the highest efficiency products will be sacrificed in order to achieve an installed cost that is market acceptable.

BTO's highest priority R&D topics are high-performance thermal insulation that can be applied to the walls of existing buildings and air-sealing systems capable of preventing uncontrolled heat, moisture, and airflow at reduced installation costs. BTO is also interested in improved roofing systems for commercial buildings. All technologies have specific performance and installed cost targets that are listed in Table A 11 and are broken out by building sector,

[10] http://energy.gov/eere/buildings/downloads/research-and-development-roadmap-windows-and-building-envelope
[11] See http://energy.gov/eere/buildings/windows-and-building-envelope for a listing of current projects.

where possible. All proposals are expected to support achieving these targets. Please refer to the Windows & Envelope R&D roadmap[12] for further details and areas of interest for the targets described in Table A 11.

High-Performance Thermal Insulation. Lowering the cost of high-performance thermal insulation that can be applied to the walls of existing buildings is one of the highest priorities for the sub-program. The insulation may also be applied to other building components to reduce the impact of thermal bridging, which occurs when structural elements that connect the building exterior to the interior are not properly insulated to stop the transfer of interior heat or cool air outwards or vice versa.

Improved Roofing Systems. Develop improved roofing systems for commercial buildings that reduce the energy use, equivalent to doubling the R-value of ASHRAE 90.1 standards at an incremental cost increase of less than $1 per square foot.

Low-Cost Air-Sealing Systems. Develop new air sealing systems that are capable of preventing uncontrolled heat, moisture, and airflow at reduced installation costs. R&D activities related to air sealing focus on developing cost-effective, integrated systems that simultaneously control the flow of heat, air, and moisture. Currently, there is no technology on the market capable of this. This is one of the highest priority areas for the sub-program. In addition, techniques are needed to more easily install and verify completeness of air-sealing processes during application to ensure consistent implementation. This includes simple, non-destructive techniques to quickly and properly detect flaws and remediate them.

Windows & Building Envelope Modeling Tools

Whole-building energy modeling—software calculation of building energy use given a description of its physical assets, operations, and weather conditions—is an enabling technology for building energy efficiency. Whole-building energy modeling has multiple use cases in building design and operation, energy-efficiency codes and standards, certification, and incentive programs.

Whole-building energy modeling uses system-level simulation techniques like quasi-static heat and mass balance to calculate the interactions of the many components of a building in the context of their operation. However, within a whole-building energy simulation, individual components are typically characterized in a “compact” way that uses reduced-order models rather than detailed physics. Heat transfer through construction assemblies is modeled along the normal dimension only, ignoring two- and three-dimensional effects that are important at edges and joints—along with the fact it uses “thin-wall” representation, this is the reason that energy simulation engines cannot automatically detect and account for thermal bridging—and even one-dimensional behavior is represented via bulk properties like U-factor and Solar Heat Gain Coefficients. Equipment performance is represented as parametric curves over independent variables such as input mass-flow rate and temperature. This level of abstraction is necessary to achieve computational and cognitive tractability.

[12] http://energy.gov/eere/buildings/downloads/research-and-development-roadmap-windows-and-building-envelope

Detailed component models are also useful and necessary. For one thing, they can be used to generate the reduced models that whole-building energy simulation needs. But more importantly, just as whole-building energy simulation supports design, standard-making and compliance, and certification of whole buildings, detailed component modeling supports design, standard-making and compliance, and rating, certification and labeling of individual components and building systems.

Windows & envelope modeling tools. As with whole-building energy modeling, trusted, open, transparent, state-of-the-art tools backed by an impartial entity are essential in supporting a fair and constructive product industry. And as with whole-building energy modeling, DOE has historically assumed this responsibility and footed the bill. Specifically, in the area of envelope modeling, DOE has funded the creation of a suite of tools for detailed characterization, certification, and design of fenestration products and assemblies. This suite of tools, created at LBNL (Lawrence Berkeley National Lab), comprises:

- IGDB (International Glazing Database) for characterizing specular glazing materials.
- CGDB (Complex Glazing Database) for characterizing complex glazing materials.
- Optics for calculating the total effects of multi-layer glazing systems. Optics imports data from IGDB.
- THERM for calculating the two-dimensional thermal behavior of glazing and opaque constructions including thermal bridging and reducing them to one-dimensional form.
- WINDOW for calculating the one-dimensional thermal and lighting behavior of façade systems. WINDOW uses data from Optics, THERM, and CGDB.
- Radiance for calculating and displaying the detailed effects of lighting on arbitrarily complex spaces through arbitrarily complex façades and for calculating space lighting metrics such as illuminance, spatial daylight autonomy, and glare index. Radiance uses data from WINDOW.
- COMFEN (Commercial Fenestration) and RESFEN (Residential Fenestration) for detailed commercial and residential façade design. COMFEN and RESFEN use WINDOW, Radiance, and EnergyPlus.

An opaque-envelope tool has been developed at ORNL (Oak Ridge National Lab):

- AtticSim calculates the thermal behavior of certain attic configurations and specifically includes phenomena that manifest in attics, e.g., heat gain and loss through ducts.

Unlike the whole-building energy modeling tools, which over the last few years have undergone licensing and development process rationalization and updates, these tools are still developed using an ad hoc mixture of licenses, contracts, partnerships, and development processes. For instance, Radiance is open-source software, the other tools are not. Updates are released at arbitrary times with no roadmap.

FY15 Windows & envelope modeling projects

In FY15, projects include the integration of WINDOW with EnergyPlus; developing a new pathway between THERM and EnergyPlus which is the start of a multi-year collaboration between LBNL and Fraunhofer-CSE; and developing the Fraunhofer Attic Thermal Model (FATM) which will be integrated with EnergyPlus upon completion.

FY16-18: Rationalization and alignment

The plan for FY16-18 is to rationalize the detailed windows and building envelope modeling tools from a license, process, and scope standpoint and to align and integrate them with the whole-building energy modeling tools. Some of this work has already begun as WINDOW and FATM—both one-dimensional thermal models—and are in the early stages of being integrated into EnergyPlus proper.

THERM, WINDOW, and Optics will be re-licensed as open-source software and their development will re-focus on core functionality and linkage to existing tools including EnergyPlus. The work on developing a two-dimensional to one-dimensional path between THERM and EnergyPlus will continue as will the investigation of whether THERM can be extended to model moisture transfer, giving DOE an open-source moisture-transfer model. As with EnergyPlus and the OpenStudio SDK, DOE and the selected lab performer will try to identify commercial partners for developing interfaces and/or embedding the engines into other design and tools. DOE may fund interface development for these tools insofar as is needed to support NFRC (National Fenestration Rating Council) and AERC (Attachments Energy Ratings Council) Programs.

IGDB and CGDB will be funded by a public-private funding model. DOE will provide limited funds to support submissions for pre-commercialized technologies. LBNL will work with NFRC and ultimately AERC to collect fees for submissions for commercialized technologies. DOE may provide limited additional funds to subsidize submissions from small companies and recently commercialized technologies.

Radiance will continue as open-source software with emphasis on speedups, and features that support whole-building analysis and complex fenestration/shading.

COMFEN and RESFEN will be terminated or spun-off as these are pure graphical user interfaces that sit outside DOE's strongly-preferred development sphere of engines, software development kits, and program-specific tools like the Commercial Energy Asset Score.

The tools will be updated annually, in synchrony with one another and with DOE's whole-building modeling tools where appropriate. Development roadmaps will be created, publicized, and vetted by the corresponding user communities.

Deliverables: Windows & Building Envelope Sub-Program

All the technologies and approaches being developed and pursued under the Windows & Envelope Sub-Program will support the metrics and milestones listed in Table A 10 (windows) and Table A 11 (envelope), and/or will support the development of windows & building envelope modeling tools. CRADA projects will work with CRADA partners to develop market-

ready devices. Table A 12 lists the facilities requirements for the windows & building envelope sub-program. Specific milestones will be developed with the performer and partners, balancing available funds.

Sensors & Controls

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

BTO envisions a future in which buildings will be self-configuring, self-commissioning, and self-learning, so that the integrated result is optimized operations, maximized energy savings, and participation in grid services. According to this vision, energy is capable of being transacted within the building (through the offering of end-user services), between buildings (through the offering of energy market services), and with the electric grid (by offering grid services).[13]

The Sensors and Controls sub-program includes two topics:

- ***Create an open-source sensor platform that is able to sense multiple parameters, including temperature, humidity, occupancy, and indoor air quality.***
- ***Develop open-source controls and applications that support self-configuration, self-commissioning, self-learning, self-calibrating, and self-discovering leading to a self-aware buildings and which can communicate with each other on a transactional network.***

These topics are described in more detail below.

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

Table A 12 Facilities requirements for the windows and building envelope sub-program

Facility	Description
Advanced Windows Testbed	Three full-scale, side-by-side instrumented test chambers, where each chamber is thermally isolated so that window heat flow measurements can be made on a comparative basis
Solar Optical Properties Laboratory	A facility that applies and develops methods to characterize the solar-optical properties of specular and optically complex glazing and fenestration materials that are used as components in window and shading systems, and includes the following measurement capabilities: * Solar spectral transmittance and reflectance on 2 x 2 centimeter (cm) samples at variable angles of incidence using spectroradiometers covering the 300–2,500 nanometer spectral range. * Full bidirectional transmittance and reflectance properties of 8 x 8 cm sample materials or systems. * Chromogenic sample measurements * Emittance of specular and diffuse materials
Infrared Thermography Laboratory	Characterizes heat transfer through window and framing systems using measurements combined with high-resolution infrared thermography imaging of samples placed within a controlled environmental chamber
Dynamic Windows Accelerated Aging Testing Laboratory	Dynamic windows and films can be cycled up to 50,000 times, under light that can be greater than 1-sun of global terrestrial air-mass 1.5 spectrum, and at ambient temperatures of -5° to 60°C and humidity of 2% to 5%.
Differential Thermal Cycling Unit	Vacuum-insulated glass and other IGUs can be tested under severe thermal conductions, ranging from - 50°C to 110°C, relative humidity from 5 to 95%, at a maximum thermal ramp rate of 2°C/min. The maximum sample size is 40” x 40” x 8”.
Large-Scale Climate Simulator	Provides controlled conditions of temperature and humidity above and below test sections as big as 12.5 ft by 12.5 ft. Steady-state temperatures can be maintained from 150°F to -40°F, and dewpoint temperature is controllable from 37°F to 122°F. Infrared lamps can heat surface temperatures to 200°F.
Rotatable Guarded Hot Box	Used to test full-size wall, fenestration, roof, and floor systems in accordance with ASTM C236. This facility can accept test specimens that are up to 13 ft by 10 ft in cross-section, and up to 24 inches thick, with a metering chamber that is approximately 8 ft by 8 ft.

Create an open-source sensor platform that is able to sense multiple parameters, including temperature, humidity, occupancy, and indoor air quality

BTO is developing open-architecture sensors and sensor systems that are able to easily share data to enable building operators and owners to capture energy and cost savings through the use of new and existing control system applications. The objective is to make new sensors and configurations available in the marketplace that make it easy to adapt building operations, collect data from an open-access platform, and apply that data to building management systems. The sub-program is particularly interested in innovative approaches that reduce the cost and energy needs of data collection for common building operation variables such as temperature, pressure, and relative humidity. Specifically, the sub-program is interested in open-source sensor packages that allow for data acquisition and transmission that requires fewer manual calibrations and "virtual sensors" enabled by innovative combinations of hardware and software that are easily installed. Additionally, the sub-program is interested in "plug-and-play" sensor packages that are automatically recognized by building energy management systems, similar to how printers are easily recognized by an existing computer network. They should have secure, nonproprietary communication protocols that have self-calibrating and auto-mapping features, as well as fault-tolerant characteristics. They should be installed, configured, and calibrated to meet lower life-cycle costs than traditional sensors. Finally, they should not require complicated calibration and should provide continuous measurements over time.

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

Current projects include the development of open source, wireless peel-and-stick sensors at ORNL for the building environment at costs of $1 to $3 per node, compared with the costs of existing sensors at $150 to $300 per node.[14] Two awards from the FY14 BENEFIT FOA are on low-cost, self-powering wireless sensors (led by Case Western Reserve University)[15] and on a non-intrusive load monitoring system (led by ORNL).[16]

[14] http://energy.gov/eere/buildings/downloads/low-cost-wireless-sensors-building-monitoring-applications
[15] http://energy.gov/eere/buildings/downloads/transforming-ordinary-buildings-smart-buildings-low-cost-self-powering
[16] http://energy.gov/eere/buildings/downloads/university-industry-national-laboratory-partnership-improve-building

Develop controls and applications that support self-configuration, self-commissioning, self-learning, self-calibrating, and self-discovering leading to self-aware buildings and which can communicate with each other on a transactional network

Sensors and, more importantly, controls, are the most basic requirements for traditional building operations because, when they work as intended, they lead to "smarter" buildings and transactive energy vision. Over 90% of the buildings have no and very little controls infrastructure to manage building operations. Even the buildings that have building automation systems (BASs) do not make use of the full capabilities of the BAS. This state of current operations results in significant energy waste (>30%).

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

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

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

Enabling efficient energy utilization through open markets and across-the-meter transactions will encourage the innovation and new investments necessary to enable the grid of the future and fully realize the benefits of clean energy technology. Current projects include the development of an open-source controls platform for small- and medium-sized buildings at

Virginia Tech University.[17] ORNL is integrating local solar PV generation with a package roof top unit and weather forecasting to provide an efficient, cost-effective demand response strategy.[18] Pacific Northwest National Laboratory (PNNL), in collaboration with several other national labs, is developing applications for VOLTTRON,[19,20] an open-source software platform that enables networked building equipment and entire buildings, distributed generation sources, and the grid to transact in a secure and efficient environment.

Expected Activities at the National Laboratories: Sensors & Controls Sub-Program

The lab performer(s) is expected to coordinate work closely with industry, FOA awardees, and SBIR awardees to advance open-source sensors and controls solutions to the marketplace. Research collaborations may take the form of CRADAs or other beneficial relationships, as appropriate. The performer(s) must have the capabilities and expertise to conduct the following R&D:

- Develop and test low-cost "plug-and-play" sensor solutions for the building environment
- Develop and test open-source control applications and platforms for the building environment that lead to the self-aware buildings' vision for both small and large buildings

Given that sensors & controls intersect with a large part of the ET, CBI, and RBI programs, it is essential that the lab performer(s) establish and maintain excellent communications with their counterparts funded by other parts of BTO. This is to ensure that the sensors & controls solutions will find widespread application in lighting, HVAC, dynamic windows, etc., in both commercial and residential buildings.

Deliverables: Sensors & Controls Sub-Program

Specific deliverables will be established as part of the ongoing sensors & controls roadmap effort, which will be completed in FY15. Likely project areas for sensors include

- Low-cost, low-power sensors
- Self-calibrating, reliable sensors
- Data and communications standard

Similarly, likely project areas for controls include

- Open-source control systems
- Fault detection and diagnostics
- Advanced and self-correcting control applications for both small and large commercial buildings

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

- Plug-and-play control systems

Building Energy Modeling

Whole-building energy modeling—software calculation of building energy use given a description of its physical assets, operations, and weather conditions—is an enabling technology for building energy efficiency.

Energy modeling supports system-level "integrative design" that simultaneously optimizes the building's envelope and systems to match its anticipated use profile and local conditions. A recent study of 1,112 design projects submitted to the *AIA 2030 Commitment* program shows that buildings designed using energy modeling have a design energy consumption that is 44% lower than CBECS 2003 stock. Buildings designed using prescriptive one-system-at-a-time rules outperform stock by only 29%.[21] Increasingly, energy modeling is used to maintain, diagnose, and improve building energy performance during occupancy. Comparing modeled operations to actual operations can detect and diagnose equipment and control faults and more generally divergences from design intent. Model-predictive control uses energy modeling, real time weather forecasts and (price) signals from the grid to tailor short-term control strategies for energy reduction, peak power reduction or other objectives. Integrative design and "integrative operation" use energy modeling as virtual prototyping—an important capability as buildings are prohibitively expensive to prototype physically.

Other uses of energy modeling exploit its ability to evaluate a building's physical assets independently of occupancy and operation. Energy modeling supports the creation of energy-efficiency codes and standards like ASHRAE 90.1 and California's Title 24 whose prescriptive requirements are developed by modeling many alternate configurations for different building use types and in different climate zones and then analyzing and distilling the results. Similar analysis underpins above code prescriptive guides and "deemed savings" calculations. Energy modeling is also the basis of performance-path code compliance—model-based comparison of the actual building to a code-minimum version of the same building—and "beyond-code" programs including green certification.

Work solicited under the Building Energy Modeling sub-program is divided into two tasks:

- EnergyPlus + Modelica Buildings Library = Spawn-of-EnergyPlus
- Testing and Validation of Energy Modeling Engines

Related work on windows and building envelope detailed modeling is described under the Windows and Building Envelope sub-program, but is expected to be closely coordinated with the Building Energy Modeling sub-program.

EnergyPlus + Modelica Buildings Library = Spawn-of-EnergyPlus

*EnergyPlus***.** An open, transparent energy-modeling engine created and maintained by a neutral entity is necessary because energy modeling is used in the development of energy-

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

efficiency codes and in evaluating physical technologies against one another. With some help from the Department of Defense and the California Energy Commission, DOE has assumed this responsibility since its inception in 1977. It initially developed the engines DOE-1 and DOE-2 and began developing EnergyPlus in 1996 after LBNL (Lawrence Berkeley National Lab) lost the rights to distribute DOE-2 to a former employee and contractor.

EnergyPlus is a state-of-the-art, industry-leading product that serves as the basis for U.S. and some international energy-efficiency codes and commercial products. Since 2012, it has been available under an open-source license. Since 2014, it has been developed "in the open" on the open-source site GitHub. EnergyPlus is fully documented and has a support help-desk. The AIA dataset shows that projects using EnergyPlus achieve an average of 49% reduction relative to baseline, supporting the assertion that EnergyPlus has advanced capabilities for modeling low-energy designs, systems, and controls.

DOE releases two major updates to EnergyPlus every year. Each update includes numerous bug fixes and usually between 15 and 20 new features. Features are drawn from requests made by users, software vendors, organizations that use EnergyPlus as the basis for standards, and DOE itself. Features are prioritized by need and requestor and selected and assigned by availability of resources and development expertise. FY15 features include an upgraded ground heat-exchange model, new models for integrated air-source heat-pumps, new models for servers and data-center cooling equipment, more flexible handling of outdoor air, models for residential equipment, new routines for equipment sizing, a new JSON (Java Script Object Notation) input-output module, and performance improvements.

Originally written in FORTRAN, EnergyPlus was translated to the more modern C++ programming language in 2014. Since June 2014, all development is being done in C++. Version 8.2, released in September 2014 is the first release of the C++ codebase.

The EnergyPlus development team currently consists of mechanical engineers and simulation researchers from LBNL, ORNL (Oak Ridge National Lab), and the NREL (National Renewable Energy Lab) and a large set of competitively-solicited development contractors from companies, universities, and energy consultancies. NREL manages both the development process and sub-contracting. The team meets virtually every other week—smaller working groups that work on specific sub-areas meet virtually on the off-weeks—and in-person once a year before the ASHRAE summer meeting.

Modelica Buildings Library. Although it has the most detailed physics of any energy-modeling engine and received a language makeover, EnergyPlus remains a traditional simulation program in which the equations of the system are implicit and programmers develop solvers for those equations. Although well understood, this structure makes simulation engines difficult to update and maintain as the solvers for new component models must be carefully integrated with the existing solver. It also makes sub-optimal use of development resources as the mechanical engineers who have expertise in the building physics and systems domain rarely couple that knowledge with similar depth in the numerical analysis and algorithms domain.

The Modelica language was developed to address these problems. In Modelica, developers write down the equations of the system. These are then simulated by a domain-independent solver. Modelica allows domain experts to focus on their domain while leveraging outside expertise to develop high-performance simulation platforms. Modelica makes it easy to prototype new models, to share models between simulation environments, and even to re-purpose models for other applications—in the specific case of buildings, Modelica control models can be directly translated into working controller code. The idea for equation-based simulation is not new, even in the building space. In the 1980's and 1990's, researchers experimented with systems like SPARK (Simulation Problem Analysis and Research Kernel) and NMF (Neutral Model Format). If these early efforts laid the foundations, Modelica built and occupied the house. Leveraging over thirty million Euro in EU investment and intense interest from the automotive and aerospace simulation industries, Modelica has grown into a robust international standard with a growing ecosystem of tools capable of solving large real-world problems.

Although a relative newcomer, the building simulation industry is quickly discovering the virtues of Modelica, especially in the areas of HVAC and controls modeling. A number of component model libraries have been created at various institutions, both in the U.S. and abroad. IEA Annex 66 was created to harmonize and advance these. LBNL's open-source Modelica Buildings Library includes over 200 models for zones, envelope assemblies, air-side and plant components and controls. It has been used in plant control and monitoring projects at the Washington Navy Yard, in experiments at LBNL's FLEXLAB, and in the educational software LearnHVAC.

FY16-18: Spawn-of-EnergyPlus

EnergyPlus is a long-running, continuous project that is almost certain to outlive this planning period. Within this timeframe, DOE plans to continue to make regular update releases to the product, incorporating high-leverage modeling features that track new technologies. Although the precise feature set is difficult to anticipate, a large general thrust is clear.

We want to and plan to merge the EnergyPlus and Modelica Buildings Library into a single project, both organizationally and technically. EnergyPlus can already talk to Modelica components on a limited basis via its external interface. These conversations are limited to master/slave setups in which both EnergyPlus and the coupled model are solved independently. The goal is to allow EnergyPlus to use Modelica component and system models in a more balanced setup in which both are slaves to an external simulation master. This "model-exchange" setup is more flexible, more general, and supports much larger simulations with much faster runtime as the simulation master can evaluate each module with a frequency proportional to its gradient—modules with fast moving dynamics are evaluated frequently to accurately capture behavior, ones with slow-moving dynamics are evaluated less frequently saving execution time. We internally refer to this deeply "model-exchange"-enabled EnergyPlus as Spawn-of-EnergyPlus. The plan is to create Spawn capabilities with EnergyPlus, and then gradually, opportunistically, and transparently transition its stock of HVAC and component models to Modelica.

Spawn-of-EnergyPlus requires modifications to EnergyPlus including new internal interfaces and new algorithms with specific numerical properties in some modules like wall heat transfer. It also requires the creation of a suitable simulation master tool—LBNL is currently experimenting with Berkeley's Ptolemy II software, but a custom master may be needed for production code. Finally, it may merit an investment in free Modelica tool-chains.

Testing and Validation of Energy Modeling Engines

For energy modeling to be both useful and trustworthy, energy modeling software must demonstrably represent actual building behavior with a measurable and acceptable degree of fidelity. This is a challenging task because: i) although building physics is steady, building components, configurations, and contexts are numerous and ii) existing, occupied buildings make for poor experimental testbeds due to high levels of uncertainty in key parameters and low levels of instrumentation.

To address these challenges, NREL and ASHRAE have developed a tiered, multi-prong testing and validation methodology and have codified it in ASHRAE Standard 140 "Method of Test for Building Energy Simulation Computer Programs". The Standard 140 framework combines three kinds of tests: i) analytical tests with "closed-form" results, ii) empirical tests with results measured in well-characterized well-instrumented facilities, and iii) comparative tests with results generated using simulation with programs that successfully pass the analytical and empirical tests. The analytical and empirical tests anchor the framework while the comparative tests provide most—currently more than 90%—of the structure. Analytical tests are few and simple by definition. The ratio of empirical tests to comparative tests has thus far been driven by the difficulty and cost of conducting validation-grade physical experiments.

Standard 140 represents a baseline certification procedure for energy modeling software. The standard itself does not set acceptable divergence thresholds for its various tests—those are left up to individual certification programs—but most of these reference the thresholds set by the IRS for 179D qualifying software.[22] Standard 140 allows proprietary engines like DOE-2.2, TRACE, HAP, and Apache to validate and certify themselves relative to transparent, open-source documented engines like EnergyPlus and ESP-r. Standard 140 is the seventh most-cited ASHRAE standard.

In parallel with developing energy simulation engines, DOE has been supporting NREL and ASHRAE in the development and updating of Standard 140. Test suites typically require two to three years to develop and publish as each test suite requires three six-month "convergence" rounds in which ambiguities in the specification are rooted out and differences between simulation programs are analyzed. Numerous bugs and hidden assumptions in different engines have been discovered this way. In FY15, NREL is completing and publishing a suite on air-side HVAC equipment and conducting the first two "convergence" rounds for an updated suite of thermal fabric envelope tests.

[22] http://energy.gov/eere/buildings/qualified-software-calculating-commercial-building-tax-deductions

Test Facilities. The empirical test suites in Standard 140 were adapted from the work of IEA (International Energy Agency) Annexes 34 and 43 which used calorimetric test-chambers belonging to a French utility to characterize thermal envelope performance and the performance of simple single-zone forced-air heating and cooling systems. In general, well-characterized, highly-instrumented test facilities capable of supporting a range of "validation-grade" experiments are not widely and openly available. However, that is slowly starting to change as the importance of model-validation and the general utility of these facilities as development and demonstration testbeds becomes more widely appreciated.

One such facility is LBNL's FLEXLAB (Facility for Low-Energy eXperiments), whose construction was funded by an ARRA (America Recovery and Reinvestment Act) grant and which DOE partially supported in FY13 and FY14. FLEXLAB consists of four 30' by 40' cells, each configurable as two side-by-side compartments. One of the cells is two stories tall while another sits on a rotating platform. Each cell has one configurable façade and the facility as a whole is constructed to enable easy reconfiguration and large experimental throughput. FLEXLAB is being used as a model for several other facilities around the world, notably one in Singapore. Part of DOE funding supported participation in IEA Annex 58 on "Building Energy Performance Characterization Using Full-Scale Dynamic Measurement" which attempted to harmonize testing and data standards for test facilities.

A second facility also constructed with ARRA funding is ORNL's FRP (Flexible Research Platform). The FRP consists of two larger structures—one single-story, the other two-story—both with completely reconfigurable envelopes. Whereas FLEXLAB was conceived and designed with the empirical model validation use case in mind, FRP was not and it is questionable whether the facilities are too large and will have a high noise-to-signal ratio and whether they can support a sufficiently large number of experiments to provide significant value.

The fact that Standard 140 consists primarily of comparative tests is a public-relations challenge and provides an easy target for detractors of simulation. It gives simulation the appearance of being unfounded in reality. While this is not completely true, it is somewhat true, and it is also somewhat beside the point as Standard 140 is largely about trust, which itself is largely about perception and public opinion. With an eye towards using test facilities to increase the ratio of empirical tests in Standard 140, in FY15 DOE is supporting the creation of a roadmap for using test facilities to create empirical validation test suites. The roadmap will set specification and data collection standards as well as establish a list of high-priority experiments.

FY16-18: Empirical Test Suites

With the empirical validation roadmap set to be completed at the end of FY15, a plan for FY16-18 is to perform and then codify some of the experiments detailed therein. Experiments can be funded directly, cost-shared, or perhaps performed by others once the roadmap is published and publicized. DOE may subsequently fund the associated standards process.

The MYPP goal is to have 20 empirical test suites in Standard 140 by 2020. This is four test suites per year and the corresponding goal for FY18 is four codified test suites and another

Table A 13 Simulation software metrics and milestones to 2020

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

eight in the standards pipeline. At that rate of progress, by 2020 there will be 12 codified test suites and another eight in the standards pipeline for a total of 20. Note, a throughput of four test suites per year is six times the current throughput of one every 18 months.

Expected Activities at the National Laboratories: Building Energy Modeling Sub-Program

The metrics and milestones for the entire Building Energy Modeling sub-program are provided in Table A 13. The selected lab performer(s) is expected to contribute to the achievement of these milestones, in part through continuing development of EnergyPlus.

Deliverables: Building Energy Modeling Sub-Program

The Building Energy Modeling sub-program anticipates two major updates to EnergyPlus, and the introduction of 4 empirical test suites in Standard 140, each year.

Manufacturing Analysis

In support of the EERE's Clean Energy Manufacturing Initiative's (CEMI) efforts to strengthen U.S. clean energy competitiveness and BTO's efforts to understand the competitiveness of a wide range of technologies and to determine the most significant cost drivers for building energy efficiency technologies, the ET Program is soliciting applications for a global manufacturing competitiveness analysis of selected building energy efficiency technologies from the BTO MYPP. Solid state lighting is excluded.

Goal

The goal of this project is to understand the competitive advantage along the value chain, U.S.-specific competitive advantages and potential market impacts of the technologies. The results are to inform BTO's future R&D and manufacturing funding decisions.

In FY15, the Technology Systems and Sustainability Analysis and the Buildings Research groups at NREL are conducting an analysis of the supply chain and market competitiveness for a subset of heat pump and highly insulating window technologies. In FY16-18, a similar analysis

will be performed for additional building energy efficiency technologies from the BTO MYPP. The proposed analysis project should include:

1. Market demand forecasts influencing manufacturing
2. Supply chain data collected in five broad categories: supply and demand, price and value, supply-chain flow, manufacturing, and regional competitiveness
3. Policy data focused on manufacturing-policy drivers on the countries determined to be the dominant manufacturers
4. Bottom-up cost models will be completed for all major markets that consider a range of regional competitiveness scenarios for raw materials, intermediate and final manufactured products
5. Industry survey focusing on economic and non-economic factors that influence the choice of manufacturing location

Deliverables: Manufacturing Analysis

BTO expects analysis to be completed for 1-2 projects per year, depending on the detail provided in the project. Throughout the 3-year project, publicly relevant results should be regularly published in peer-reviewed journals and presented at appropriate conferences so that feedback from the academic community can be leveraged to improve analysis methodology.

Proposals should be technology agnostic and should instead focus on analytical methodologies that can be applied across a wide range of building energy-efficiency technologies. Proposals should include team members or a strategy to reach out to subject-matter experts from industry, specifically manufacturers.

Open ET Topic

The Emerging Technologies (ET) program is strongly interested in pursuing innovative approaches to cost-effectively reduce primary energy consumption in USA buildings, consistent with the energy-savings goals given in Table A 2. In recognition that the solicited activities do not capture all possible approaches, **we are allowing the submission of no more than one (1) proposal per laboratory to this open topic**. As with the solicited topics, applicants must first submit a timely letter of intent. These proposals should provide exceptionally strong justification. Proposed projects can be two or three years in duration, and may not exceed the anticipated total annual funding for the open topic given in Table A 1.

APPENDIX B. Residential Buildings Integration (RBI) Topics of Interest

The RBI program has a goal of demonstrating at scale market-relevant strategies (technology to market) offering a reduction in U.S. building-related energy use in existing homes by 20 percent by 2020, 25 percent by 2025 and 40 percent by 2030. For new homes, the RBI subprogram's goal is demonstrating at scale market-relevant strategies offering 50 percent energy savings above the 2009 International Energy Conservation Code (IECC) in homes by 2025 and zero energy ready homes by 2030. A Zero Energy Ready home is a high-performance home that is so energy efficient that a renewable energy system can offset most or all of its annual energy consumption. RBI will conduct focused applied research through the Building America program, resolving the major technology-to-market challenges to achieving these goals in real world homes. Coordinated with this applied research, RBI also develops or improves industry and market infrastructure (e.g., training, education, market valuation, and voluntary standards) to support the construction or improvement of homes to meet higher performance levels. With the development of advanced solutions and improved infrastructure, RBI can then demonstrate and promote higher energy efficiency home retrofits and model homes for new construction, building the business case for energy efficiency that may be implemented at the state and local level.

The overarching strategy for RBI is to identify, demonstrate, and promote adoption of technology areas and technical solutions that offer the potential for large energy savings in new and existing homes. Through its Building America, Zero Energy Ready Homes, and Better Buildings programs, RBI demonstrates the viability of these technologies, and offers solutions to the challenges inherent in integrating these technologies into residential buildings. Once these technologies are first demonstrated, then accepted in the market by leading builders and retrofit contractors, they can be addressed in industry standards and building codes based on their cost effectiveness and energy savings potential.

RBI will focus on integration of new technology into the marketplace and key issues that currently impede the adoption of more energy efficient technologies, largely due to perceived first cost and technical risks, which in turn impact the adoption of more stringent model energy codes and energy efficiency improvements. There is significant crossover between new home and existing homes research, with new technologies and processes that apply to both.

On November 12, 2014, RBI issued a Funding Opportunity Announcement (FOA) under its Building America program. The FOA focused on the three most challenging topics that offer high potential for energy savings if solved: 1) technical solutions for moisture-managed high performance building envelopes; 2) cost effective solutions to maintain indoor air quality, including smart ventilation; and 3) comfort system (i.e., HVAC) solutions for energy efficient homes with much lower cooling and heating requirements, including effective distribution and humidity control. The proposals in response to this FOA are currently under review by DOE.

DOE is also planning to engage Building America industry stakeholders later in 2015 to support development of a Building America multi-year program strategy that addresses the 3 core technical challenges and related tech-to-market barriers. Following the 2015 stakeholder engagement and public comment process, DOE will publish the Building America multi-year program strategy, and use it to develop future Building America Team FOAs beginning in FY16 and Lab Calls in FY17.

The purpose of this FY16 Lab Call & Merit Review is to help achieve the goal of zero energy ready homes in the near future by supporting those teams selected through the Building America FOA process, and to provide cutting-edge analysis in support of the RBI mission to improve the energy efficiency of new and existing homes. There are three topics under this RBI lab call, described in further detail below:

1. Analysis & Tools for Building America, Zero Energy Ready Homes, & RBI
2. Technical Quality Management Support of Building America Teams
3. Advanced Technical Solutions of Zero Energy Ready Homes

RBI is NOT interested in proposals for this FY16 Lab Call that:

1. Are focused on R&D activities that directly advance technology in the three Building America core technical challenges described above – RBI is addressing these elsewhere in FY16;
2. Are in areas not covered in the RBI mission and strategic plan.

Topic 1: Analysis and Tools to Support Building America Teams, Zero Energy Ready Homes, and RBI's Existing Homes Program

In recent years, the U.S. Department of Energy Building America program has adopted a comprehensive research-to-market strategy to achieve long-term goals and outcomes. This multi-year project continues BTO's investment in foundational tools, analysis methods, technical procedures, and data collection standards used extensively by Building America as well as ENERGY STAR and Zero Energy Ready Homes to ensure consistent, robust, and defensible results, and to optimize Building America Team research funding towards a goal of zero-energy-ready new construction and existing homes.

Programmatic analyses and simulation tools are integral to the BTO ecosystem (e.g., Staged Upgrade Initiative, EnergyPlus and OpenStudio development) in order to strategically spur innovation and sophistication in residential market tools. Designing cost-optimal zero-energy homes requires the building industry to go significantly beyond conventional design. As is evidenced by the widespread use of simulation-based models in programs such as RESNET's HERS (including the 2015 IECC's HERS-based compliance path), Energy Star, and the Zero Energy Ready Home program, practitioners increasingly rely on simulation models to predict energy

consumption of whole buildings and energy savings of efficiency measures and these tools need to accurately model zero-energy design features. Activities over the next three years will continue the trajectory of emphasizing comprehensive national-scale analyses and tools based on large sets of data that characterize the existing housing stock, rather than a small number of representative homes. These activities employ high-performance computing capabilities to address important questions (national efficiency potential for emerging technologies, segmented target market analysis, etc.) that cannot otherwise be answered with a sufficient degree of statistical reliability. Building on substantial prior-year work, this project provides enhanced analyses and tools that address high priority Building America needs.

Key analysis activities for this multi-year project include assessment of the efficiency impacts achieved by the Building America program and the future efficiency potential of the American housing stock. These require continued maintenance and improvement of the BAFDR database and Building America house simulation protocols as well as modeling support to Building America teams and program partners/stakeholders.

In addition to analysis support, RBI requires the maintenance and development of modeling software and tools needed by Building America participants and industry to achieve zero energy ready new and existing homes. This includes completing and implementing incorporation of HERS index algorithms into Building America modelling tools (e.g., BeOpt), the maintenance of the Field Test Best Practices Web-site, completing multifamily and multi-zone modeling capabilities, and additional modeling capabilities that may be necessary to support Building America program objectives and cost-effective zero energy ready homes.

Lastly, these efforts shall work in tandem with Emerging Technologies (ET) efforts to integrate residential models into EnergyPlus, as well as Commercial Buildings Integration (CBI) funding the incorporation of building geometry capabilities in OpenStudio that will be used as the basis for BEopt's geometry component. In addition, there are several co-sponsored tasks within this effort. The California Public Utilities Commission (CPUC) is funding the integration of multifamily capabilities and technologies into BEopt while the Bonneville Power Administration (BPA) has provided an official notice to award a regional-scale efficiency assessment for the Pacific Northwest, leveraging the national/regional-scale analysis tool.

Topic 2: Technical Quality Management and Program Planning Support for Building America

Technical planning and management supports the goal of the Building America team research focus on whole-house system integration challenges that limit the wide-scale adoption of advanced designs and technologies that improve efficiency (up to 50% savings) and performance. Applying total quality management approaches to the research achieves long-term success through continuous process improvement and technical oversight and services integration. It also ensures research results are consistently robust and defensible.

This multi-year project includes the following direct lab support activities: FOA support, technical support to DOE during Building America project planning, test plan review and support, advanced field test support, project tracking, project/team technical support,

deliverable review and multi-year plan coordination for the Building America Program such as stakeholder engagement and meeting support. Tasks will also include peer review administrative management and technical editing of Building America reports, as well as coordination of technical communications.

RBI also requires technical and facilitation support in the development of BASC content, outreach supporting innovation deployment, and deployment initiative support such as the Race to Zero Student Design Competition. Through active, responsive management and customized support tools (e.g., the Building America peer review system, the Building America Field Test Best Practice website), Lab project managers will help align Building America team project work with DOE strategic needs and technical focus areas. By tracking project progress RBI is able to respond to changes in project conditions and re-scope work if necessary. By actively planning in partnership between the teams, DOE and national labs, research is targeted to ensure the highest likelihood of success and market impact. The primary focus of this project is to ensure the credibility of research results, improve the market transformation impact of the work done by the Building America teams and to enhance overall program efficiency and effectiveness.

Topic 3: Advanced Technical Solutions to Achieve Zero Energy Ready Homes

As the costs of PV systems have rapidly dropped, the balance of efficiency and renewables necessary to achieve net-zero energy performance in home construction is shifting dramatically. No builder can ignore the opportunity that PV presents, yet emerging risks have prevented widespread adoption of PV as a standard home feature. For example, the availability of net metering has recently been challenged by major utilities in at least 12 states and the future of this financial foundation to a PV system investment is in doubt. Still, with homebuyers increasingly recognizing the long-term value of PV, homebuilders feel compelled to assign increased roof space to PV. This leads to additional structural, electrical, fire code, sales, marketing, and utility interconnection issues which must be addressed. Builders need fully-vetted solutions to make PV integration possible, as well as viable options if net metering is to go away in some locations. Finally, before renewable energy systems integration can occur on a large market scale, it is necessary to reduce the cost of installing both PV and solar water heating (SWH) in U.S. homes. Without compromising durability or performance, lower cost PV and lower cost SWH installation approaches are needed for Zero Energy Ready Homes and existing housing – especially in locations where there may be other cost-effective methods for heating water or where conventional utility-provided electricity is not that expensive

The goal of this project is to develop and demonstrate optimized zero energy home solutions to builders and homeowners. This project would result in viable, effective renewable integration methods for Zero Energy Ready Homes that would further advance the Building America Market Transformation Strategy. It will also result in reduced risk and cost to production builders pursuing zero energy home objectives.

This multi-year project focuses on identifying, developing and demonstrating technology packages that overcome market barriers and provide a path forward to substantially higher

penetrations of zero energy homes. The project will focus on developing technology packages for Zero Energy Ready Homes that provide cost-effective, optimized thermal comfort and, eventually will rely on renewable energy systems, such as photovoltaics (PV). In the out-years, the renewable integration activity will continue both laboratory testing and field testing of prototype integration approaches as well as data collection and analysis. After a renewable integration method is proven to be an effective solution, then installation guidance and best practices will be prepared.

Addressing the barriers to renewable energy system integration will include a mix of stakeholder meetings, problem scoping, analysis, prototype system development, field testing, and documentation of outcomes. This multi-year project will lead to best practice guidance for integrating renewables with high performance homes to create zero energy home solutions. For the next three years, renewable integration project activities will include:

- Meeting and working with stakeholders (including homebuilders, PV and SWH manufacturers, roofing contractors, plumbing contractors, electricians, and Building America teams) to develop a renewable integration workplan to achieve project objectives.
- Working with stakeholders to assess the technical potential and cost savings of various renewable integration approaches that lower the cost by 50 percent or more and simplify the installation of the following systems: Rooftop Photovoltaic so Building-Integrated Photovoltaics (BIPV); Solar Water Heating (SWH); Combined PV/Thermal (PV/T) Systems
- Working with PV and SWH manufacturers and homebuilders to develop prototype system integration approaches that can either be tested directly in the field or first in a laboratory facility before they are fully deployed in the field.
- Collection of detailed performance and operational data from the laboratory or field tests for evaluating integration effectiveness and net zero energy performance.
- Working with stakeholders to develop installation guidance and best practices for Zero Energy Ready Home builders and Building America teams on effective renewable systems integration for varying climates.

APPENDIX C. Commercial Buildings Integration (CBI) Topics of Interest

The Commercial Buildings Integration Program (CBI) is seeking project proposals from national laboratories for activities to incorporate into the FY 2016 Annual Operating Plan. CBI is seeking new ideas for projects that will have significant impact aligned with CBI's mission and multiyear plan.

CBI seeks proposals that maximize the use of national laboratory expertise and resources while partnering with industry for appropriate demonstration and deployment work. CBI expects lab proposals to identify industry partners that will execute deployment strategies with technical and analytical support from the laboratory.

CBI expects to fund one or more proposals that:

1. Align with CBI's mission and multiyear plan, suggesting work that fits into defined CBI activity areas to address specific market barriers, with a clear exit strategy, on a timeline that complements other projects.
2. Is for an integrated set of activities addressing one or more of the barriers outlined in CBI's plan that will have significant impact toward the program goals.
3. Include a defined target market, problem statement and impacts that can be measured during and after the project completion.
4. Describe a clear deployment path targeting specific use cases for specific end users with the help of industry / market partners if necessary. Proposals should also include example go/no-go milestones beginning within the first quarter that could ensure that the project is addressing pressing market needs and will result in measurable impact.
5. Include little to no deployment activity by laboratory staff. CBI expects to see laboratories working directly with market partners on deployment activities, with the laboratory playing a technical role and the market partner playing a market-facing role.

CBI is not interested in proposals that:

- Are small or one-off.
- Are focused on large-scale, real-building demonstration or deploying commercialized technologies– CBI is addressing this elsewhere;
- Are in areas not covered in the CBI mission and strategic plan
- Develop one-off software tools outside of CBI's core platforms (Open Studio, Asset Score, SEED, BPD)

Budget

Total funding up to $1 million per year (depending on annual budget) for up to three years is available for significant, impactful projects that help achieve CBI goals. DOE plans to select 1-2 projects to fund with this $1M. Projects may last 1-3 years. There will be clear go/no go milestones built in throughout each project to determine if the project will proceed.

Labs are invited to submit a maximum of one proposal to the CBI Open topic. Selected projects will proceed to develop SOWs in collaboration with CBI project managers, contingent on available budget.

CBI Strategic Plan Summary

Below is a summary of CBI's multiyear program plan, developed in FY14.

The Commercial Buildings Integration (CBI) program focuses on voluntary uptake of high-impact building technologies, systems and practices by commercial building decision makers, serving as a bridge between the research and development mission of BTO's Emerging Technologies program and the regulatory activities of the Codes and Standards programs. Program activities are developed with understanding of the constraints and opportunities in the commercial buildings market - such as building type, use and ownership structure - in order to maximize impact throughout the commercial building lifecycle, from design through construction, occupancy and renovation.

Vision

Commercial buildings are constructed, operated, renovated and transacted with energy performance in mind. Net zero energy ready commercial buildings are common and cost-effective.

Goals

In order to support the EERE Strategic Plan (Appendix A), the overarching goals of the Building Technologies Office and legislative goals defined for the Program, CBI has established the following goals:

Existing Buildings	**Mid-term (2020)**	Demonstrate that it is cost-effective to reduce energy use of typical commercial buildings by 20%.
	Long-term (2030)	Demonstrate that it is cost-effective to reduce energy use of typical commercial buildings by 50%.
New Buildings	**Mid-Term (2020)**	Demonstrate that it is cost effective to construct commercial buildings that use 50% less primary energy than ASHRAE 90.1, 2004.

	Long-Term (2030)	Demonstrate that it is cost effective to construct commercial buildings that are net zero energy ready.

Mission

Accelerate voluntary uptake of significant energy performance improvements in existing and new commercial buildings.

Challenges

Realizing significant energy efficiency improvements in the nation's commercial buildings will require addressing many entrenched information, system and market barriers, specifically:

- The commercial market does not integrate the value of energy efficiency in the transaction process (sales, appraisals, lending, leasing and insuring), as well as in the overall market.
- A limited infrastructure supports energy efficiency, and is unable to address the complexity of building new high performance buildings and upgrading existing buildings.
- Private sector research is limited and not focused on systems optimization and whole-building energy efficiency.

Additional information on these market barriers is presented in Appendix B

Strategies/Approaches

Solutions that accelerate greater energy efficiency in commercial buildings must accommodate the diversity of the commercial real estate market, working across new construction and retrofit, climate zones, building use, size and age and owner business model, but must work in an inherently local ecosystem of workers, policymakers and suppliers." DOE's role is to create standardized, low-cost, widely available solutions that can be applied at broad national scale.

CBI addresses the complex problem of accelerating commercial building energy performance by focusing on **five specific approaches**, which are:

Approach 1:

Provide objective information about building technologies and systems through real world demonstrations and deployment programs.

Approach 2:

Develop and deploy low-cost, standardized, interoperable easy-to-use tools and solutions to measure, analyze and assess whole building energy performance to support performance-based design, policies and transactions.

Approach 3:

Research, develop and deploy design and decision support resources that help stakeholders effectively understand and incorporate the value of energy efficiency into commercial real estate transactions.

Approach 4:

Prepare the workforce to design, build and operate buildings more efficiently.

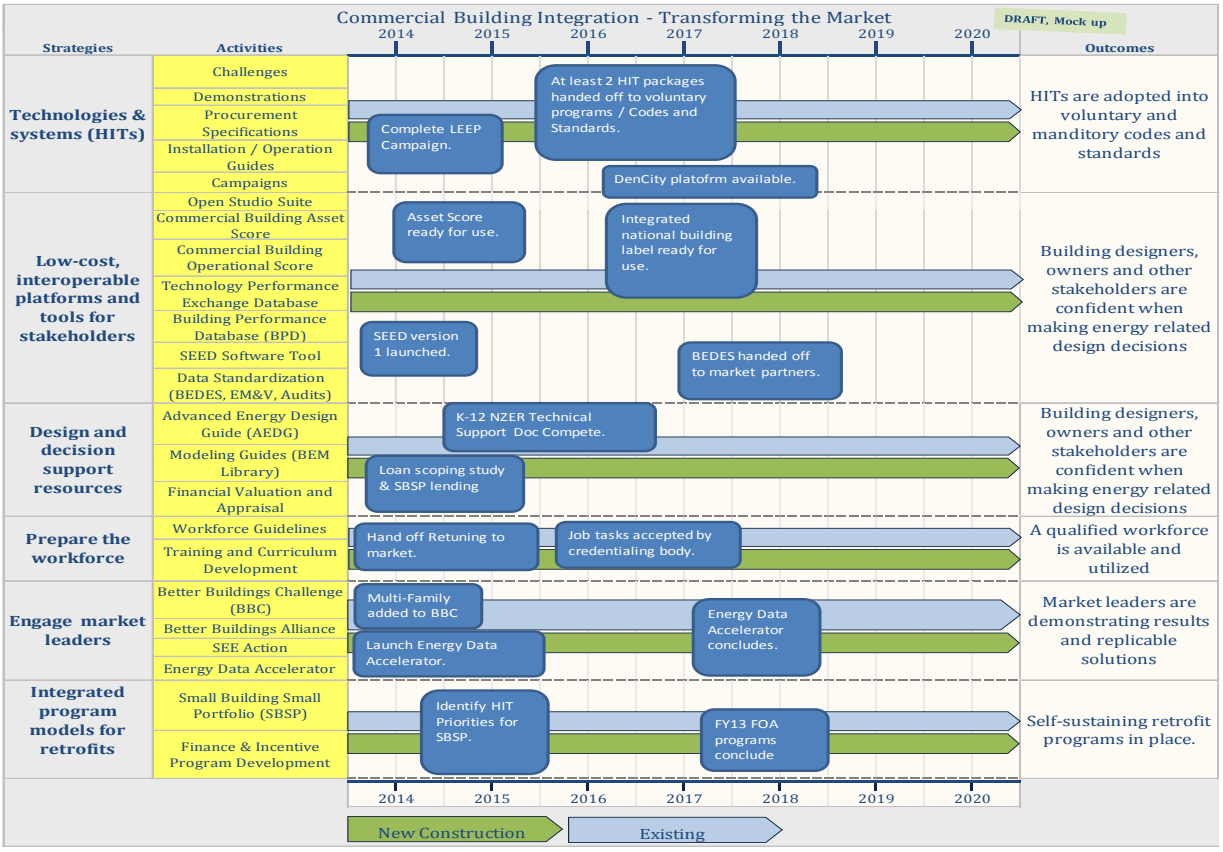
Approach 5:

Engage with market leaders to deploy business and organizational models that work.

Strategy 6:

Support the development of integrated program models for new construction and retrofit.

CBI Multi-Year Program Plan: Selected Milestones



From 2014 through 2020, CBI program work is focused on several significant barriers to the greater investment in energy efficiency and where CBI can have significant impact in this timeframe.

Key Barriers to Greater Commercial Building Energy Efficiency

1. **Information**: Lack of information leads to insufficient understanding to make rational consumption/investment decisions
   - Insufficient technical information - Lack of credible information about new technologies, products and processes and the realizable energy savings from pursuing these measures.
   - Insufficient performance data - Lack of access to consistent and transparent energy performance data
   - Insufficient EM&V – Insufficient means or ability to measure project or program results.
   - Insufficient interoperability – data is siloed, proprietary, and in different formats - cannot "move" through the building lifecycle easily and at low cost

2. **Economic**: Investors don't understand energy efficiency projects. They are (perceived as) too expensive, complicated / risky, not adding value or hard to pay for / invest in because of high transaction costs. This leads to an inability to access internal or external capital for efficiency projects.
   - First costs vs. investment horizon - The "payback" is not understood, or does not meet internal ROI requirement. Split incentives further hamper payback.
   - Valuation – the impact of improved performance is not understood and incorporated into the valuation of buildings at key transaction points. Benefits beyond pure cost savings (utility expenses and O&M costs) are not understood or incorporated into decision making.

3. **Market:** State of current real estate, design, construction and building services market hampers energy efficiency.
   - Inconsistent quality of workforce - Internal and external workers lack knowledge, skills, capacity to identify, develop, implement, and maintain energy efficiency investments.
   - Insufficiently developed energy management market. Little consistency or best practices for organization-wide energy management.
   - Design / Operation Asymmetry – There is disconnect between the design, construction and operations teams which causes buildings to fail to achieve their original predicted performance.
   - Imperfect alignment of incentives – real estate actors and transactions are not incentivized in a way that promotes better energy performance
   - Energy is not a priority – energy performance is outside core mission, insignificant in savings potential vs. barriers

4. **Institutional:** Inherent aspects of the policy, regulatory or incentive environment hamper greater energy efficiency
   - Poor implementation and compliance with building codes and standards
   - Imperfect and inconsistent local policy/regulation - Jurisdictions have insufficient capacity to develop, implement, and maintain EE programs and policies; policies/programs/ incentives are inconsistent and conflict across local/state/utility/federal agencies; some policies/laws actually block energy efficiency
   - Lack of effective public private partnerships - Government and the private sector rarely work through partnerships that tackle energy efficiency in a collaborative manner

Building Technologies & Systems

CBI supports the acceleration of energy efficient technologies and systems appropriate for the wide range of climates and building types in the U.S. by demonstrating and deploying information about:

- Improvements in the efficiency of key building equipment and systems;
- Whole-building performance in both new buildings and existing building retrofits that use significantly less energy than current standard practice;

CBI emphasis is on products that are currently market-viable but underutilized and that can cost-effectively save energy. Through this work, CBI coordinates with the BTO Emerging Technologies R&D program to pull recently commercialized, but underutilized technologies into demonstration. CBI also coordinates with the Codes and Standards programs to build market experience with high-efficiency technologies and systems that can allow regulations to recognize these advances more quickly and accelerate the national impact of energy savings. Over the next five years, CBI is focused on developing and demonstrating a process to identify and evaluate new, market-ready technologies and drive them through the deployment cycle, causing measurable acceleration and voluntary uptake.

Market Infrastructure

CBI develops and deploys low cost, standardized platforms, solutions and tools that enable functioning markets for greater investment in energy efficiency. In the next five years, CBI is focused on several key areas:

- Energy Performance Data Access and Utilization
  - Building assessment tools: an integrated set of foundational, low-cost, easy-to-use platforms for the assessment of energy performance that support performance-based decision making, policy and transactions
  - EM&V: standardized, low-cost, high-quality approaches for assessing the savings from energy efficiency measures and programs
  - Data access and analytics: standardized, low-cost formats that allow customer access to energy usage information and support energy performance-aware transactions
  - Data utilization: mechanisms that allow energy performance to be incorporated into valuation at key real estate transaction points such as appraisal, insurance, leasing and sale

- Process Improvements – Decision support tools that incorporate energy performance into organizational culture and real estate transaction points.
  - Design and construction: easy to use, low-cost platforms to accelerate the use of energy modeling, energy performance-based design, high-performance operations, and deeper energy retrofits

- Leasing and tenant fit-out: tools that encourage alignment between owner and tenant with regards to reducing energy consumption
- Operations and energy management: a robust culture of organization-wide energy management
- Successful financing and business models: easier, cheaper and more transparent best practices that show results

- Clean Energy Workforce - Preparing the workforce to design, build and operate buildings more efficiently.
  - Workforce guidelines: high-quality, consistent expectations for skills and capacity of key roles in the commercial buildings market that can support an industry of training and certification
  - Training: workforce training that provides needed skills to install, execute, maintain and operate new technologies or processes

Market Partnership Programs

CBI works with industry leaders through a series of market partnership programs, including the Better Buildings Alliance, Better Buildings Challenge and SEE Action. CBI executes its strategies via these partnership programs, utilizing them to understand market needs, test and refine resources, conduct real-world demonstrations, and deploy solutions to the market through peer sharing and exchange, as well as to recognize leaders in the market for their progress and success. These programs are not separate strategies in themselves, but are a framework for market engagement that allows CBI to execute its core strategies through diverse building efficiency audiences.

Program Structure

Develop, Demonstrate, Deploy

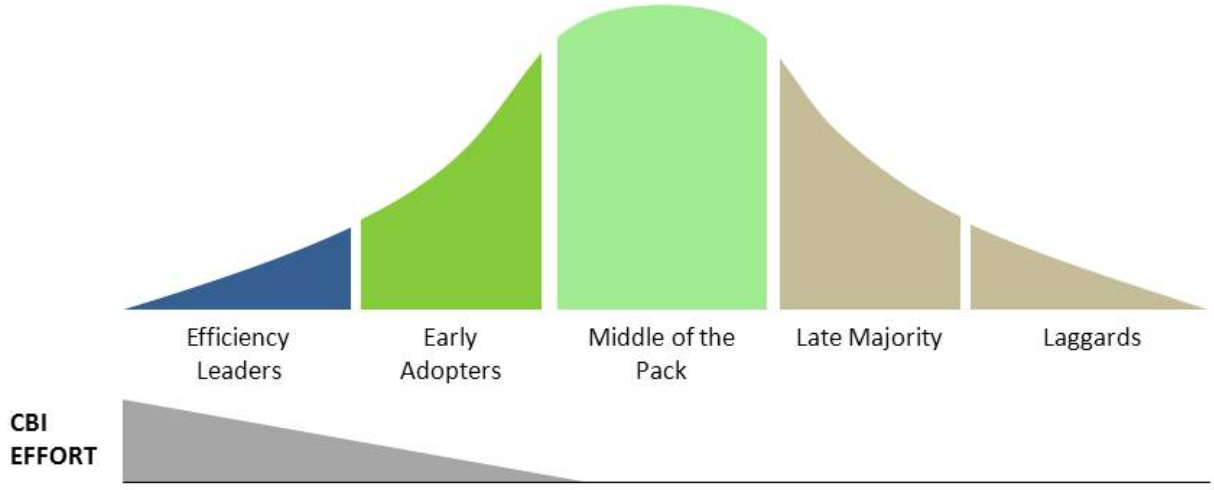
CBI executes its work in three phases:

- Where there is a clear federal role, **develop** design and decision support tools to enable adoption of energy efficient technologies and practices at scale.
- **Demonstrate** the performance and cost and energy savings impact of technologies and solutions, with market-leading partners, to identify and overcome barriers and show the business case for broader deployment.
- **Deploy** technologies and solutions to the market via partnerships with commercial building industry representatives to spur widespread adoption.

FIGURE 1: CBI PROGRAM METHOD

The CBI program goal is to demonstrate new technologies and solutions at convincing scale, defined as at least 15% of the square footage of new and existing commercial building in building types that account for 80% of sector consumption. In order to achieve this goal, CBI works with efficiency leaders and early adopters, those in the commercial building market that are first to adopt new products or processes. Market deployment research shows that if this segment of the market accepts a new technology, slow organic uptake by the rest of the market is more likely to continue. In order to accelerate broader voluntary uptake of products beyond the pace of organic diffusion, CBI works with key market partners, such as industry organizations, non-profits, energy efficiency program administrators and others who have a mission and business model to perpetuate new solutions that produce better energy performance in commercial buildings.

FIGURE 2: CBI TARGET AUDIENCE



Market Sectors

CBI's goals are to demonstrate *at convincing scale*, defined as building types covering at least 80% of commercial energy consumption in all climate zones and major business/ownership models. CBI has chosen strategies that can have the greatest impact

across this broad target audience and chooses projects on total impact across all of these variables.

However, in FY13, CBI initiated a specific "small buildings, small portfolios" activity to investigate if this market – responsible for greater than 90% of the number of buildings and half of the commercial square feet across the U.S. – needs different strategies, approaches and solutions, or if the same strategies, deployed with different partners. CBI plans to have this question answered by the end of FY15.

CBI also recognizes the need to revisit its approach to new buildings in light of the changes in the new construction market since the slowdown of 2008. CBI program goals – demonstration of net-zero energy ready new buildings by 2030 – require aggressive and coordinated work and CBI expects to have a revised multi-year approach to new construction by the end of FY14.

APPENDIX D. Content and Form of Full Proposals

Full proposals must include the following:

- Technical volume
- Budget information
- 2-page CVs
- Letters of support/commitment (as needed)

A description of each item is given below.

Technical Volume

Page lengths for the Technical Volume differ depending on the program area (ET, CBI, or RBI), as specified in Table 1, but the proposal format is consistent and is given below.

1) Project Title
2) Project High-Level Goal/Objective (2-3 sentences) that is relevant to national objectives on climate, oil dependency and economic competitiveness

Project Description – Technical Merit, Innovation, and Impact (approx. 50%)

a. For ET proposals:
   1) Overall objective and "big" outcome of the project
   2) Relevant technology barriers and targets/goals and how the proposed project addresses them
   3) Degree to which project is novel or has potential to advance state-of-the-art
b. For RBI proposals:
   1) Overall objective and "big" outcome of the project
   2) Degree to which project has potential to advance the state-of-the-art
   3) Degree to which the project supports RBI strategy and program objectives
   4) Degree to which the project improves the efficiency and effectiveness of RBI programs
c. For CBI proposals:
   1) Overall objective and "big" outcome of the project
   2) Defined target market, specific target use case, problem statement, and impacts that can be measured during and after the project completion.
   3) Describe current barriers to deployment at scale. What technical and business challenges and barriers are preventing the solution from being deployed widely? How will this project overcome those barriers?
   4) Describe a clear deployment path targeting specific use cases for specific end users with the help of industry / market partners if necessary
   5) Define the metrics of project success. Describe the energy savings opportunity in the target market segment? Please justify / source all numbers used.
d. EERE Core questions (for ALL proposals):
   1) Impact: Is this a high-impact problem?

2) Additionality: Will EERE funding make a large difference relative to existing funding from other sources, including the private sector?
3) Openness: Are we focusing on the broad problem we are trying to solve and open to new ideas, approaches, and performers?
4) Enduring Economic Impact: How will EERE funding result in enduring economic impact for the United States?
5) Proper Role of Government: Why is this investment a necessary, proper, and unique role of government rather than something best left to the private sector to address?

3) Project Approach (approx. 30%)
   a. Work Plan
      1)Key tasks with brief description, including roles and responsibilities of any partners
      2)SMART milestones, deliverables, go/no-go decisions
      3)CBI projects should include go/no-go decisions in the first quarter that ensure that the project is addressing pressing market needs and will result in measureable impact
   b. Market Transformation
      4) If the project is R&D technology focused, how does it identify and address the current and/or potential opportunities to move that technology towards eventual transition to the private sector?
      5)If a project is not R&D focused, how does it contribute to overcoming one or more key market barriers?
4) Team and Resources (approx. 20%)
   a. Total Budget: Please include any cost share and potential in-kind contribution (e.g., equipment)
   b. Qualifications
   c. Project performers / key personnel (names, brief description of pertinent qualifications)
   d. Describe Inter-lab Collaboration, as appropriate
   e. Facilities (specify where work will be done, and why it might be necessary to use unique capabilities of the facility)
   f. Teaming and industrial/market partners (as applicable) – describe the nature of the teaming arrangement

Budget Information

A completed EERE 159 Detailed Budget Justification is required as a part of the full proposal package. Applicants must use the EERE 159 form available on EERE Exchange. There are no page limits for this form.

CV's for the Lead PI and Key Personnel

CV's are required for the Lead PI and all key personnel. CV's may not exceed 2 pages per person, and should include at least the following:

- Academic/professional qualifications
- Bibliography of relevant publications and intellectual property

There are no page limits for this section, except the 2-page limit for each CV.

Letters of Support or Commitment

Applicants may attach letters of support and/or commitment (i.e., cost share) from collaborators, as needed. There are no page limits for this section.

APPENDIX E. Proposal Review Criteria

Criterion 1: Technical Merit, Innovation, and Impact (Weight: 50%)

1(a) Degree to which the project addresses program barriers, contributes to achieving Office targets/goals, and has potential to advance state-of-the-art or achieve substantial market impact

1(b) Extent to which the proposed project addresses EERE core questions – addresses a high impact problem, provides additionality, has the potential for enduring economic impact/provides high value to the government, and is appropriate for Federal funding

1(c) Sufficiency of technical detail to assess whether the proposed work is scientifically meritorious and make sense for the market

1(d) For deployment activities, the extent to which the proposal describes a clear target market, market barriers, target use case, problem statement, and deployment path

Criterion 2: Project Approach (Weight: 30%)

2(a) Relevance and appropriateness of the approach and critical path and description of key tasks, metrics (including baseline), and SMART milestones

2(b) Degree of likelihood that the work plan will succeed in meeting project goals

2(c) Identification of key technical risks and the quality of management and mitigation strategies to address them

2(d) Level and appropriateness of partnerships (e.g., “openness”), and the clarity in the description of roles and responsibilities

2(e) Degree to which the project identifies and addresses the current and/or potential opportunities to move EERE technologies towards eventual transition to the market (i.e., Market Transformation), including but not limited to product development and/or service plan, commercialization timeline, financing, product marketing, legal/regulatory considerations including intellectual property, infrastructure requirements, data dissemination, U.S. manufacturing plan, and product distribution.

Criterion 3: Team and Resources (Weight: 20%)

3(a) Degree to which the project leverages a core or enabling capability

3(b) Capability of the Principal Investigator(s) and team to address all aspects of the work – qualifications, expertise, and time commitment of the team

3(c) Sufficiency of the facilities to support the work (if applicable)

3(d) Degree to which the team demonstrates the ability to facilitate and expedite further development and commercial deployment of the proposed technologies (or wider implementation of the proposed deployment activity)

3(e) Degree to which inter-lab collaboration is occurring, as appropriate.

3(f) Reasonableness of budget and spend plan for proposed project and objectives. Sufficiency of the budget for the innovation proposed.

APPENDIX F. Project Reviewer Form

Project Title:	
National Laboratory:	**Lead PI Name:**
EERE Office/Program Area:	**EERE Project Lead Name:**
Activity:	**Sub-Activity:**
Reviewer Name:	**Reviewer Organization:**

Criterion 1: Technical Merit, Innovation, and Impact (Weight: 50%)
1(a) Degree to which the project addresses program barriers, contributes to achieving Office targets/goals, and has potential to advance state-of-the-art or achieve substantial market impact 1(b) Extent to which the proposed project addresses EERE core questions – addresses a high impact problem, provides additionality, has the potential for enduring economic impact/provides high value to the government, and is appropriate for Federal funding 1(c) Sufficiency of technical detail to assess whether the proposed work is scientifically meritorious and makes sense for the market 1(d) For deployment activities, the extent to which the proposal describes a clear target market, market barriers, target use case, problem statement, and deployment path
Strengths
Weaknesses
Recommendations for Improvement
Criterion 1 Score Assigned (0 to 5, with 5 being best)

Criterion 2: Project Approach (Weight: 30%)
2(a) Relevance and appropriateness of the approach and critical path and description of key tasks, metrics (including baseline), and SMART milestones 2(b) Degree of likelihood that the work plan will succeed in meeting project goals 2(c) Identification of key technical risks and the quality of management and mitigation strategies to address them 2(d) Level and appropriateness of partnerships (e.g., "openness"), and the clarity in the description of roles and responsibilities 2(e) Degree to which the project identifies and addresses the current and/or potential opportunities to move EERE technologies towards eventual transition to the market (i.e., Market Transformation), including but not limited to product development and/or service plan, commercialization timeline, financing, product marketing, legal/regulatory considerations including intellectual property, infrastructure requirements, data dissemination, U.S. manufacturing plan, and product distribution.
Strengths
Weaknesses
Recommendations for Improvement
Criterion 2 Score Assigned (0 to 5, with 5 being best)

Criterion 3: Team and Resources (Weight: 20%)
3(a) Degree to which the project leverages a core or enabling capability 3(b) Capability of the Principal Investigator(s) and team to address all aspects of the work – qualifications, expertise, and time commitment of the team 3(c) Sufficiency of the facilities to support the work (if applicable) 3(d) Degree to which the team demonstrates the ability to facilitate and expedite further development and commercial deployment of the proposed technologies (or wider implementation of the proposed deployment activity) 3(e) Degree to which inter-lab collaboration is occurring, as appropriate. 3(f) Reasonableness of budget and spend plan for proposed project and objectives. Sufficiency of the budget for the innovation proposed.
Strengths
Weaknesses
Recommendations for Improvement
Criterion 3 Score Assigned (0 to 5, with 5 being best)
Weighted Average Score

APPENDIX G. Open Source Software

Applicants that are applying to one or more Topic Areas for which open source software distribution is required must submit a plan describing how software produced under this Lab Call will be distributed. For a DOE National Laboratory or a FFRDC, the data rights clause, including rights and requirements pertaining to computer software, in its Management and Operating (M&O) Contract shall apply and shall take precedence over any requirement set forth in this Appendix. The plan must include the following elements:

1. A complete description of any existing software that will be modified or incorporated into software produced under this Lab Call, including a description of the license rights. The license rights must allow the modified or incorporated software to be distributed as open source.
2. A discussion of the open source license that the Applicant plans to use for the software it plans to produce under the Lab Call, and how that choice furthers the goals of this Lab Call. The discussion must also address how the license conforms to the conditions listed below.
3. A method for depositing the software in a source code repository.
4. A method for sharing and disseminating the software and other information to team members or others when multiple parties will contribute to the development of the software or the Lab Call requires that the software or other information be shared or disseminated to others.

Open Source Definition

Open source licenses must conform to all of the following conditions:

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The program must include source code, and must allow distribution in source code as well as compiled form. Where some form of a product is not distributed with source code, there must be a well-publicized means of obtaining the source code for no more than a reasonable reproduction cost preferably, e.g., downloading via the Internet without charge. The source code must be the preferred form in which a programmer would modify the program. Deliberately obfuscated source code and intermediate forms such as the output of a preprocessor or translator are not allowed.

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