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

High-Impact Technology Catalyst: Technology Deployment Strategies

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Prepared by Navigant Consulting, Inc.

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List of Acronyms

ACEEE	American Council for an Energy Efficient Economy
AERC	Attachments Energy Rating Council
AFDD	automated fault detection and diagnostics
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
BAS	building automation systems
BBA	Better Buildings Alliance
BEMOSS	Building Energy Management Open-Source Software Development
BMS	building management system
BOMA	Building Owners and Managers Association
BTO	Building Technologies Office
COP	coefficient of performance
CBEI	Consortium for Building Energy Innovation
CBERD	Center for Building Energy Research and Development
DOE	U.S. Department of Energy
DLC	Design Lights Consortium
EIS	energy information system
EMIS	energy management and information system
EMS	energy management system
ET	Emerging Technologies (Program)
FDD	Fault Detection and Diagnostics (Tool)
FEMP	Federal Energy Management Program
FY	fiscal year
GSA	U.S. General Services Administration
GPG	Green Proving Ground
GWP	global warming potential
HIT	high-impact technology
HVAC	heating, ventilation, and air conditioning
HFC	hydrofluorocarbon
IFMA	International Facility Management Association
ILC	Interior Lighting Campaign
IT	information technology
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
LEED	Leaders in Energy and Environmental Design
LEEP	Lighting Energy Efficiency in Parking
LUMEN	Lighting Utility Midwest Exchange Network
M&V	measurement and verification
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NREL	National Renewable Energy Laboratory

NYSERDA	New York State Energy Research and Development Authority
OEM	Original Equipment Manufacturers
ORNL	Oak Ridge National Laboratory
P-Tool	Prioritization Tool
PIER	Public Interest Energy Research Program
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
R&D	research and development
REEO	regional energy efficiency organizations
RFI	request for information
SCE	Southern California Edison
SMUD	Sacramento Municipal Utility District
SSL	solid-state lighting
TBtu	trillion British thermal units
TWh	terawatt-hour
USGBC	United States Green Building Council
VFD	variable frequency drive
VRF	variable-refrigerant-flow
WCMA	Window Covering Manufacturers Association
WHPA	Western HVAC Performance Alliance

Table of Contents

List of Tables and Figures

Tables:

Figures:

1 Introduction and Purpose

The High-Impact Technology (HIT) Catalyst was initiated by the U.S. Department of Energy's (DOE) Commercial Buildings Integration (CBI) program to identify cost-effective, underutilized building technologies with large energy savings and adoption potential, and to provide resources and the focus needed to accelerate their adoption. In addition, the HIT Catalyst serves to align all of CBI's technology-specific market transformation activities under a single, cohesive strategic framework.

The energy savings opportunity in commercial buildings varies according to building type, systems, climate zone, construction type, and occupant density, among other factors. To translate this complexity and opportunity into actionable, strategic approaches, DOE's Building Technologies Office (BTO) conducts a research, identification, and evaluation exercise. This exercise analyzes and lays out potential deployment strategies for those technologies that can make the most impact in achieving BTO's energy savings goals, high-impact technologies or HITs. HITs are prioritized based on key quantitative and market criteria to generate a priority list for deployment, the "HIT List." The key question for each technology on the HIT List is: "Which of the HIT core activities can most effectively improve market adoption for this technology?" Core activities are selected using criteria that rely on an assessment of the technology landscape and the most significant market barriers. Five core activities reflect proven and successful market stimulation work. The core HIT market stimulation activities function as follows:

- **Challenge**: Triggers product development where the market has not met current owner and designer demands for more efficient products.
- **Demonstration**: Overcomes owner uncertainty about how the technology will perform in real-world settings.
- **Purchase Support Resource**: Answers the need for technical and functional guidance on the selection of the highest performing technologies. Often takes the form of a procurement specification.
- **Application Resource**: Highlights best practices in design, installation, and ongoing maintenance of HITs.
- **Adoption Campaign**: Provides incentive for owners/operators to choose and implement high-impact technologies. Adoption campaigns provide assistance and recognition for participants, help drive down costs, and enable the BTO to share best practices and energy savings results from real projects that achieve maximum energy savings.

An understanding of the landscape and barriers for each HIT leads the BTO to activities that have the greatest likelihood of positively and significantly affecting the markets for the chosen technologies—The Game Plan. Tailoring activities and transformation plans to each HIT ensures that resources will be allocated in the most effective manner attainable for the greatest market impact.

The HIT Catalyst program operates cyclically. Each year, new technologies are added to the program. Existing HITs are reevaluated and new activities are initiated to build on existing work, or are given to external organizations to maintain efficiency efforts. Figure 1-1 discusses the annual efforts.

Figure 1-1. HIT Catalyst Annual Cycle

<table>
<tr><th>Stage</th><th>Action Steps</th><th>Ongoing Activities (Year-Round)</th></tr>
<tr><td>Technology Identification</td><td>• Initiate request for information (RFI) to gather suggestions on new candidate HITs
• Conduct literature and market review on possible new HITs, including new Prioritization-Tool measures and “graduates” of other technology R&D programs (Tech Sweep)
• Add new inputs to the HIT Matrix
• Use BTO Peer Review and Better Buildings Summit to review HIT Catalyst program feedback</td><td rowspan="3">• Catalog data and suggestions on possible HITs for next cycle
• Initiate new market transformation activities
• Reevaluate deployment plans for existing HITs and move to next step upon activity completion
• Hand off HITs once CBI work complete</td></tr>
<tr><td>HIT Prioritization</td><td>• Conduct workshops to answer qualitative questions, understand changing market conditions and uncover work by others
• Refresh HIT selection matrix with workshop feedback
• Revisit HIT priority list based on HIT Matrix updates
• Develop HIT Watch List based on emerging high-potential techs</td></tr>
<tr><td>Market Transformation Planning</td><td>• Develop market transformation plans for new HITs (as applicable for new technologies)
• Update Game Plans for existing HITs based on new market conditions</td></tr>
</table>

Source: Based on DOE internal strategy.

This document serves as an overview of the HIT Catalyst program activities, including a summary of the selection process BTO uses to identify, evaluate, and prioritize the current HITs, descriptions of the technologies and markets for each HIT, and plans for deployment.

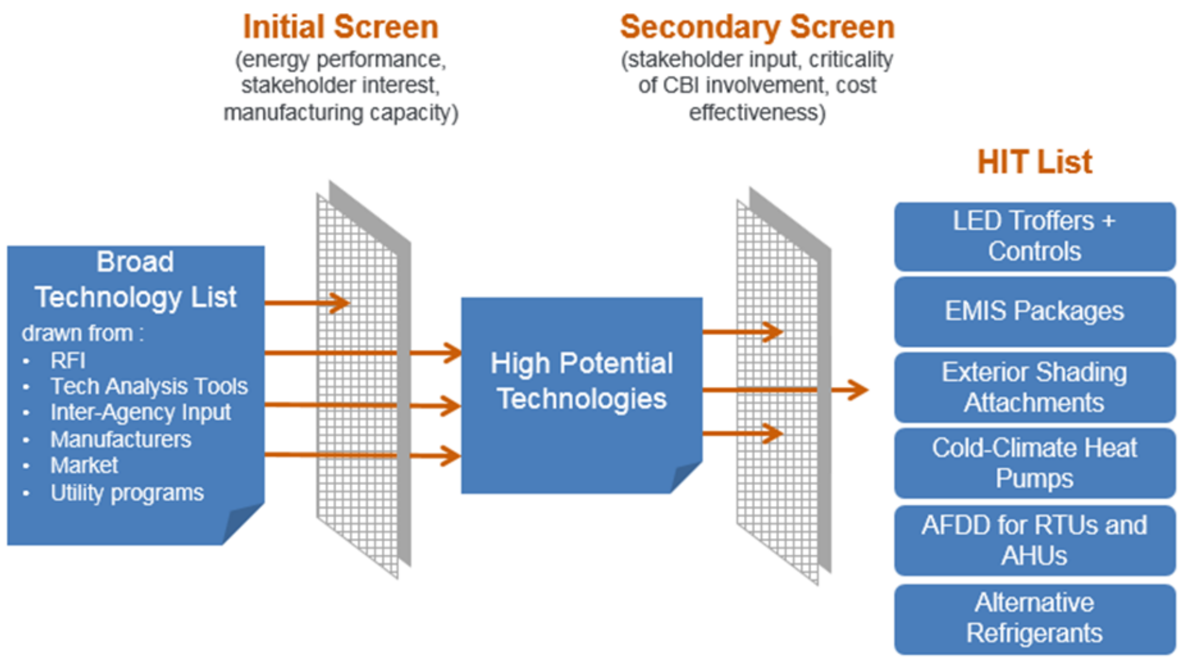
2 HIT Background and Selection Methodology

2.1 HIT Selection Methodology

DOE's initial list of candidate technologies was drawn from a thorough literature review (the Tech Sweep) and from the BTO Prioritization Tool (P-Tool, or Scout[1]), a spreadsheet model developed by BTO to track the potential energy savings impacts of all of the energy efficiency technologies within BTO's purview. Technology descriptions and energy savings potential values were migrated from the P-Tool to seed the HIT Matrix and were augmented with additional technologies from supplementary channels. In total, BTO evaluated more than 400 candidate technologies for 2016.

The BTO organized the HIT Matrix using two screens to gauge technical energy savings potential with market interest, cost, and manufacturing readiness and capacity. This technology evaluation ensures that BTO can effect structured, activity-based technology market transformation. Figure 2-1 depicts the technology screening process.

Figure 2-1. HIT Technology Screening Overview



Source: Based on DOE internal strategy; adapted from http://energy.gov/eere/buildings/identify-potential-hits.

2.1.1 Technology Evaluation Criteria

A number of criteria were used to characterize the candidate technologies and develop the initial outputs of the HIT selection process, depicted in Table 2-1. The criteria used in the first screen are largely quantitative and are used to eliminate technologies inappropriate for the program. The criteria in the second screen were used during workshops with subject matter experts to rank the technologies based on qualitative factors for further consideration. DOE selected specific

[1] Scout, the successor to the BTO Prioritization Tool, will launch publicly in summer 2016. For updates on Scout progress, see https://github.com/trynthink/scout/wiki.

criteria, building from successful technology deployment projects and discerning pre-existing conditions that helped lead these projects to success.

Table 2-1. HIT Screening Factors

Screen	Evaluation Criteria
First	• *Significance of unit savings potential* • *Significance of national savings potential* • *Specificity of measure*[2] • *Deployment readiness* • *Alignment with HIT program methodology* • *GHG emissions reduction potential* • *Water savings potential*
Second	• *Level of stakeholder interest* • *Criticality of CBI involvement* • *Existing manufacturing capacity* • *Current cost-effectiveness* • *Cost reduction potential*

Source: Based on DOE internal strategy.

2.1.2 HIT Matrix

The HIT List is developed using the HIT Matrix, an internal Excel-based tool created for use in categorizing the data for each candidate technology and ranking the HITs. The HIT Matrix includes information for each technology in the following key areas:

- Technology description and overview
- Technology area (end-use sector)
- Per-unit and national technical energy savings potential (drawn from the P-Tool/Scout and Tech Sweep)
- Estimates of technology readiness and appropriateness for the HIT program[3]
- Quantification of the status of key market factors (as described in previous section)
- Discussion of existing CBI efforts focused on the technology[4]

The HIT Matrix allows for the CBI Program to continually grow its database of known technologies and associated attributes as new technologies and supporting data arise from literature review, RFI responses, stakeholder workshops, and other channels. It is a living document that can be easily updated in real time. This tool also provides an easy mechanism for sorting HITs based on their technical energy savings potential, market factors, relevant end-use sector, and other key areas. The sorted list of HIT Matrix entries is used as the basis for final discussion and selection of HITs for targeted market transformation activities.

[2] To be considered as actionable within the HIT framework, a technology must be defined with sufficient specificity to allow a quantitative assessment of the market potential, barriers, and deployment steps to be performed. Measure groupings that are too broad to allow this are generally broken down until a workable level of granularity is achieved.
[3] Appropriateness depends on work by others. In cases where BTO can leverage this work, this informs market transformation planning. In other cases, work by others may be sufficiently broad that a BTO market transformation role is unnecessary.
[4] Deployment activities may include work with utilities, trade associations (such as ASHRAE, Illuminating Engineering Society of North America, or USGBC), regional energy organization and nonprofits as well as the activities of the Better Buildings Alliance., https://www4.eere.energy.gov/alliance/

In future evaluation cycles, the HIT Matrix will reflect new data available from Scout, which can be used to support multi-system/integrated measure analysis. BTO will conduct a supplemental HIT analysis to identify any opportunity to deploy technologies that affect multiple systems and groupings or packages of building efficiency measures.

2.1.3 Stakeholder Workshop Process

BTO collects comprehensive ongoing technology inputs and feedback through existing stakeholder networks, such as the Better Buildings Initiative, the Consortium for Building Energy Innovation (CBEI), state and local governments, and utility groups. The HIT Catalyst Program is discussed at the annual BTO Program Review, and HITs are emphasized as part of the Better Buildings Summit technology tracks. In 2016, the HIT Catalyst methodology and HIT List were presented at Greenbuild, Building Owners and Managers Association (BOMA) International, American Council for an Energy-Efficient Economy (ACEEE) Summer Study, for the U.S. Veteran's Administration, Department of Commerce, Consortium for Energy Efficiency, and as part of the Better Buildings annual webinar series.

A key component of the HIT List development process is the convening of discussions among the CBI Program and a number of specific external and federal inter-agency stakeholders. These meetings allow the program to solicit specific feedback on the HIT Catalyst methodology, candidate technologies, and other programs underway in key commercial building technology sectors. As part of the development process for the 2016 HIT List, a number of webinars were conducted with major stakeholders, as well as in-person meetings to solicit feedback from federal entities. A list of participants in the workshopping process is provided in Table 2-2.

Table 2-2. HIT Workshop Participants

Workshop Participant		
Con Edison	Lawrence Berkeley National Laboratory (LBNL)	Oak Ridge National Laboratory (ORNL)
SkyFoundry	KGS Buildings	U.S. General Services Administration (GSA)
Northeast Energy Efficiency Partnerships (NEEP)	SageGlass	E Source
Bonneville Power Administration	Lutron Electronics, Inc.	National Grid
Pacific Northwest National Laboratory (PNNL)	Xcel Energy	Penn State University Consortium for Building Energy Innovation
National Renewable Energy Laboratory (NREL)	Rocky Mountain Institute	New York State Energy Research and Development Authority (NYSERDA)
South-Central Partnership for Energy-Efficiency as a Resource	Better Buildings Steering Committee Partners	

Source: Results of outreach by DOE CBI, DOE National Laboratories, and Navigant.

These workshops provided a broad perspective on the various technologies under consideration and in shaping the final HIT list. Going forward, CBI plans to continue and expand these discussions as part of the annual HIT prioritization process.

Based on the HIT List, BTO convenes ongoing technology-specific discussions during the deployment planning phase of the program to continually improve its understanding of the market landscape for that technology, uncover specific barriers or challenges, and to identify new promising emerging products that meet deployment goals.

2.2 Selected HITs

As a result of the initial selection process described in Section 2.1, BTO prioritized deployment of three new HITs, alongside continued focus on three legacy HITs from the 2015 prioritization process. Furthermore, BTO identified technologies to watch for future deployment opportunities (the HIT Watch List). The HIT Watch List is compiled from analysis of HIT criteria, but for technologies still in development; thus current manufacturing and cost thresholds may inhibit those technologies from passing the screens. Future deployment of technologies on the Watch List will depend on the state of the technology and the market at that time. Questions BTO will ask include: Has the technology already been demonstrated? Are resources widely available? Is the energy savings opportunity large enough and is there significant stakeholder interest necessary support impactful deployment activities?

The HIT Watch List for 2016 includes:

- Envelope retrofit measures
- Water-saving measures, including advanced laundry technologies and commercial irrigation controls
- Automated auditing and commissioning systems[5]

The HIT List for 2016 includes:

- LED troffers with controls (ongoing from 2015)
- Energy management and information systems (EMISs) and building diagnostics and controls (ongoing from 2015), including:[6]
    - Automated fault detection and diagnostics (AFDD)
    - Submetering
    - Monitoring-based commissioning
- Envelope attachments (ongoing from 2015)
- Cold-climate heat pumps
- AFDD systems and controls for rooftop units (RTUs) and air handling units (AHUs)
- Alternative refrigerants for supermarket refrigeration applications

Additionally, the HIT List includes two appendices addressing the HITs selected in 2015: refrigeration controls, display case door retrofits, and commercial fans. These items will continue

[5] These systems, also known as “touchless” energy auditing measures, employ various software tools to retrospectively analyze existing building energy performance data. These packages can operate on a whole-building or system-level basis, and can, in some cases, work in conjunction with EMIS measures.
[6] Throughout this document, this broad technology area will be referred to as EMIS.

to be included in refrigeration and heating, ventilation, and air conditioning (HVAC) deployment activities, but will not be new focus areas moving forward.

Table 2-3 through Table 2-8 provide specific details about each of the HIT List measures and the outcomes of the HIT prioritization process. The tables include estimates of the national technical energy savings potential for each technology, along with market factor assessments on a 1-3 scale, with 3 being the highest level of opportunity, need, or interest.

The tables also describe the peak demand impact potential of the technology beyond the baseline reduction offered through implementation of the measure. This takes the form of a preliminary, qualitative characterization of the impact potential. In later studies, CBI plans to incorporate more quantitative information on potential through analysis using Scout or other tools. The qualitative descriptors used at this time are:

- Significant benefit: The technology has the potential to significantly decrease building energy consumption at peak-demand periods.
- Moderate benefit: The technology has the potential to decrease building energy consumption at peak-demand periods.
- Neutral: The technology will produce peak demand reduction levels commensurate with the overall average energy benefit of the technology; technology performance does not disproportionately fluctuate at peak-demand periods.
- Negative benefit: The technology may experience higher energy consumption during peak load periods, generally corresponding to most adverse ambient conditions.

Table 2-3. LED Troffers with Controls – Overview

Description	Deploy high-efficiency (solid state) troffers with integrated controls.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
500-1,000 Trillion British Thermal Units (TBtu) Estimated annual energy savings if all existing fluorescent troffers were switched to LED troffers with controls.	**3** Stakeholders understand the high energy and cost savings potential is attainable through lighting retrofits.	**2** Although many efforts on LED lighting exist, DOE can support operators by providing performance information, technical assistance, and recognition for best practices to drive adoption.	**2** Solid-state lighting prices are currently on a downward trajectory, and further decreases are expected.
Peak demand impact potential: *moderate benefit*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

Table 2-4. Energy Management and Information Systems/Whole Building Diagnostics – Overview

Description	Demonstrate and benchmark performance of EMISs. These systems encompass a broad family of tools and services to manage commercial building energy use including energy information systems (EIS), equipment-specific fault detection and diagnostic systems, benchmarking and utility tracking tools, automated system optimization tools, and building automation systems.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
1,000+ TBtu Estimated annual energy savings if all commercial buildings adopted advanced EMSs/EMISs.	**2** CBI efforts focusing on EMISs to date have drawn significant interest from building owners.	**3** The market is crowded and competing data exists. There is a strong opportunity for DOE to play a key facilitation role.	**2.5** Systems can currently achieve desirable paybacks; however significant volume opportunities may still exist.
Peak demand impact potential: *Significant benefit*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

Table 2-5. Attachments – Overview

Description	Demonstrate energy use reduction and other benefits arising from the use of optimized static attachments and dynamic window attachments to manage solar gain and daylight.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
500-1,000 TBtu Estimated annual energy savings if all applicable commercial buildings employed shading elements.	**2** Participants in the DOE workshops and stakeholder meetings have expressed significant interest.	**2** This technology is mature globally but nascent in the United States. DOE can help bridge the gap to domestic acceptance.	**2.5** Many technology types are rare in the United States; thus significant volume opportunities exist to bring down costs.
Peak demand impact potential: *Significant benefit*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

Table 2-6. Cold-Climate Heat Pumps – Overview

Description	Demonstrate the performance potential of commercial-scale heat pumps for use in cold climates where electric resistance heating has traditionally been employed.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
500-1,000 TBtu Estimated annual energy savings attributable to complete displacement of electric resistance heating in relevant commercial applications.	**3** Stakeholders have exhibited significant interest in this technology, particularly in regions with large heating loads and use of electric resistance heat.	**3** There has been limited field-demonstrated evidence of the performance potential of these units in commercial settings in the United States.	**2** With an increase in production volume and continued evolution of the technology, paybacks for commercial heat pumps in cold climates could become attractive.
Peak demand impact potential: *Neutral*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

Table 2-7. AFDD Systems for RTUs and AHUs – Overview

Description	Assist commercial building owners in selection, installation, and optimized use of aftermarket control packages for existing rooftop HVAC units and AHUs.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
1,000+ TBtu Estimated annual energy savings possible through installation and use of retrofit AFDDs controls for existing RTUs and AHUs.	**2** Stakeholders are aware of the technology, but need assistance and information to facilitate proper choices for their applications.	**3** DOE could serve a key role in helping to differentiate and disseminate useful data regarding product selection and capabilities.	**2.5** Current cost effectiveness is fairly high, as these equipment types are significant energy consumers and packaged controls have reasonable installed costs.
Peak demand impact potential: *Significant benefit*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

Table 2-8. Alternative Supermarket Refrigeration – Overview

Description	Demonstrate performance potential of alternative refrigerants to replace regulated working fluids in supermarket-scale commercial refrigeration applications.		
National Primary Energy Savings Potential	**Stakeholder Interest**	**Criticality of DOE Involvement**	**Cost-Effectiveness and Reduction Potential**
100-500 TBtu While the main end-user benefits of alternative refrigerants stem from global warming potential (GWP) impact mitigation, energy benefits can also be derived from the replacement of inefficient legacy equipment.	**3** After numerous rounds of refrigerant changes and phase-outs over the past decades, end users are very interested in long-term, low-impact solutions.	**3** Independent data regarding equipment performance and implementation will help to drive new adopters towards these technologies.	**1.5** Costs are currently high, and some aspects of the technology are inherently expensive. However, economies of scale and lessons learned globally should help to push costs down.
Peak demand impact potential: *Neutral to negative benefit*			

Source: Aggregate results developed from DOE HIT Matrix and fall 2015 stakeholder workshop series.

3 Overview of Market Transformation Plans

Section 4 through Section 10 contain the respective market summaries and market transformation strategies for each of the six HITs. These sections lay out available information about the market landscape for the technology at the time of its selection as a HIT and to explain the CBI's process for mapping out market transformation activities for the HIT. Each of these sections include the following information focusing on the subject HIT:

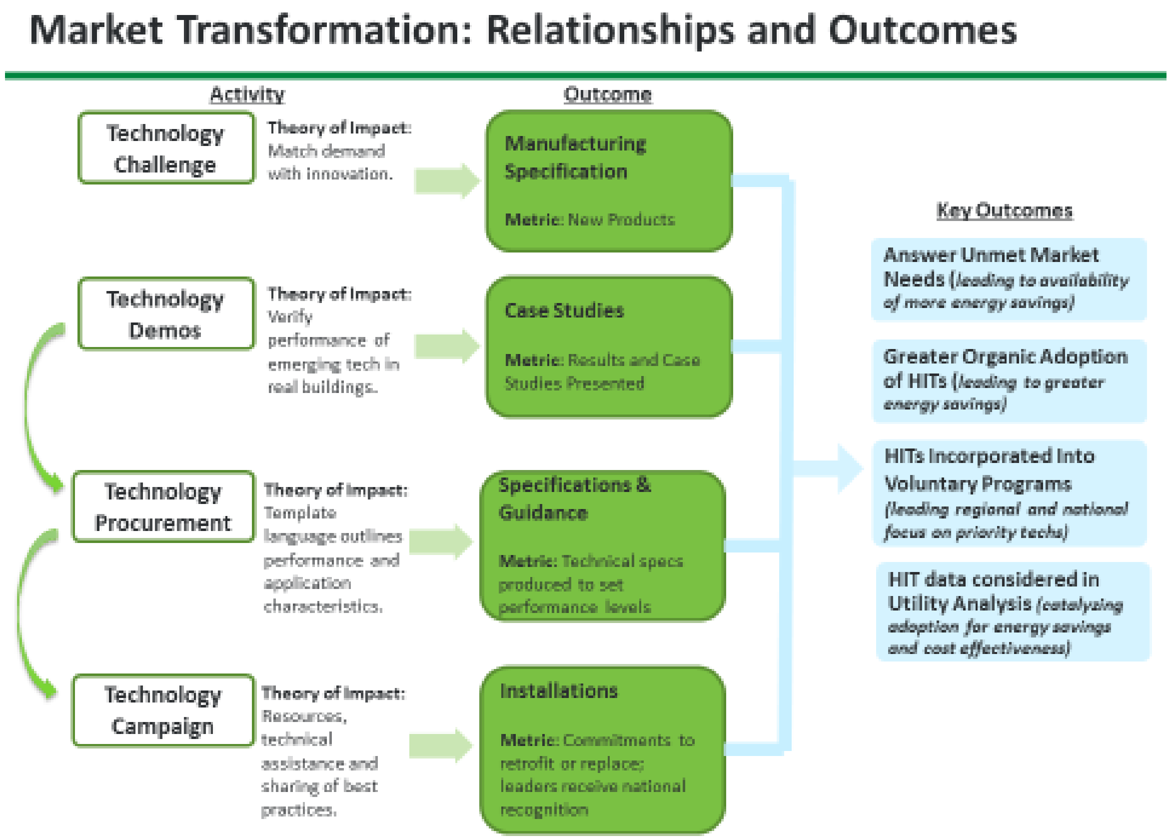
- A market summary, including:
  - Discussion of key sectors and applications for the technology
  - Major manufacturers and suppliers of the HIT
  - Relevant DOE CBI work to date
  - Technical and market barriers to enhanced market uptake
  - A summary of programs and external efforts outside of CBI focusing on the technology
- A discussion of the target outcome of the HIT Catalyst's involvement with the technology: the desired market transformation goal, the metrics of success, the time frame, and the methodology for handoff of the technology-specific outcomes and products.

- The market transformation activity that is matched to the particular HIT as identified from these core market stimulation activities:
  - **HIT Challenge:** Implemented to help overcome a communication and solution delivery failure in the market—when building owners desire a specific product that is not being provided by manufacturers. DOE convenes building owners, lays out performance requirements, and helps challenge manufacturers to meet this demand.
  - **HIT Demonstration:** Addresses the lack of objective performance and cost data that inhibit some technologies from finding their customer base. DOE collaborates with GSA's Green Proving Ground (GPG) and other programs to match HITs with host sites, to install and monitor the performance of a HIT in a real-world installation, and to communicate the results to the public via a case study.
  - **HIT Purchase Support Resources:** Provides guidance on product selection reflecting technical and energy performance topics. DOE works with purchasers, technology providers, and other stakeholders to incorporate technology attributes that will streamline product selection for energy performance. Technical specifications should be supported with demonstration or case study examples. DOE also works with potential buyers and interested utilities to define the HIT's energy savings potential and to produce information and data to support incentive levels.
  - **HIT Application Resources:** Improves the understanding of how to select, size, install, and properly operate a HIT for optimal performance and thus maximize the value of the HIT. DOE works with designers, engineers, installers, and technicians to identify barriers and solutions to help improve these processes. In addition, in select instances, DOE will conduct training sessions to support this effort.

- **HIT Adoption Campaign:** The terminal HIT activity that brings together other resources developed via the program, such as specifications and case studies. DOE works through strategic industry partnerships to facilitate scaled adoption, providing technical support to encourage adopters to commit to installing a HIT, and offering recognition to promote participation.

All market transformation activities are based upon specific theories of impact, serve specific purposes within the structure of the HIT program, and possess unique target outcomes. Figure 3-1 shows the activities, their functions, and the relationship between them.

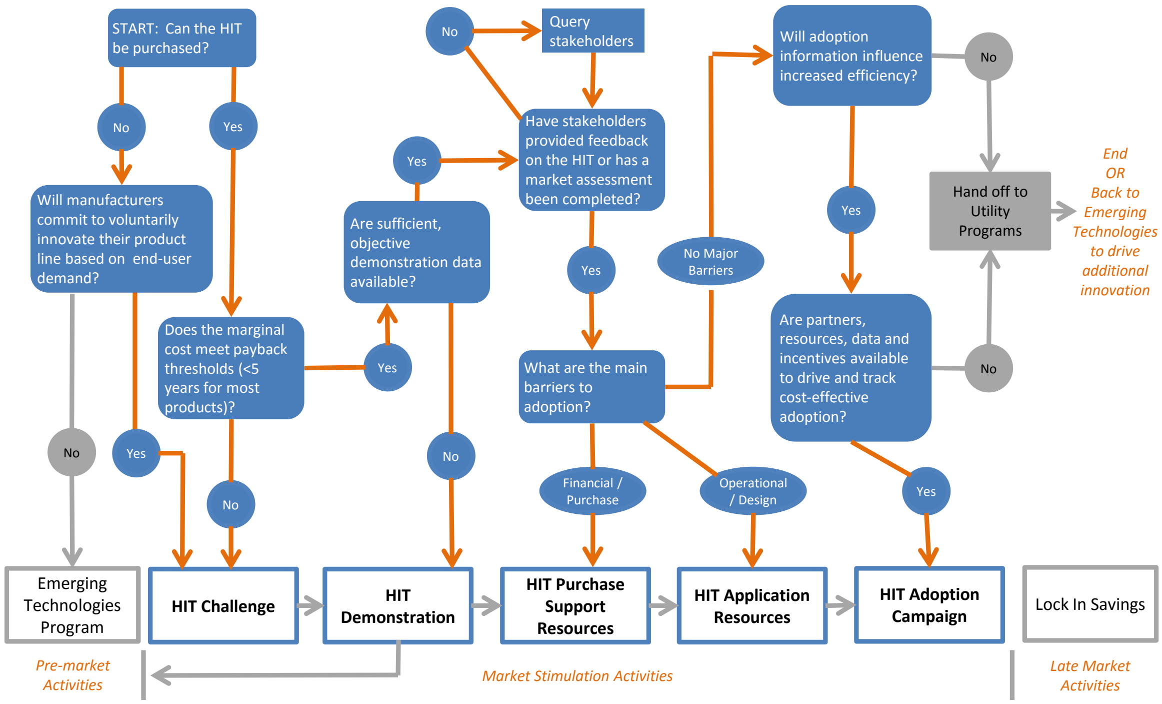
Figure 3-1. Market Transformation Activities



Source: Based on DOE internal strategy.

The HIT Activity Decision Map, depicted in Figure 3-2, was developed to help visualize the process used to identify the most effective deployment activities—how DOE CBI defines the Game Plan. For each HIT, the pathway of CBI's involvement is determined using the Decision Map.

Figure 3-2. HIT Activity Decision Map



Source: Based on DOE internal strategy; figure developed by Navigant.

For each HIT, the starting point for market stimulation work is determined based on the status of activities undertaken to date, an assessment of the market, and a quantification of barriers to implementation and stakeholder needs. Then, based on those factors, CBI selects the appropriate core market stimulation activity for that technology. At the conclusion of that activity, the market is reassessed, the map updated, and the next applicable activity initiated. This process is repeated until CBI's goal for the technology is achieved. The starting position of the technology and optimal activity flow to achieve CBI's goal for that technology results in a unique, custom pathway for each HIT. Core activities remain constant for consistency and standardization, which helps set expectations over time.

In 2015 and 2016 to date, CBI has pursued and initiated a closer partnership with GSA's GPG program. This program works with national labs, industry, and stakeholders to identify and select technologies that hold promise to reduce energy consumption in federal-sector buildings within the GSA portfolio. GPG conducts field demonstrations of the technologies and develops publicly available studies of the performance of the measures. High-performing measures are showcased and prioritized for wider deployment within the portfolio, driving federal leadership by example. CBI, in partnership with GPG, is examining methods to potentially advance and accelerate the inclusion of performance information from complete and widely deployable demonstrations into the Facilities Standards for the Public Buildings Service (P-100, the federal building code) as well as GSA Advantage (a procurement channel for federal agencies).

4 Market Transformation Plan – LED Troffers and Controls

4.1 Evaluation of Current Market Landscape

4.1.1 Key Sectors and Applications

LED troffers and controls have applications in all sectors of commercial buildings and provide opportunities for significant energy savings. Lighting accounts for approximately 20% of commercial building energy consumption. The majority of commercial buildings use linear fluorescent lighting fixtures; in 2010, fluorescent lighting systems accounted for more than 75% of commercial building lighting.[7] The most common commercial lighting fixtures are: 2' x 4', 2' x 2', and 1' x 4' recessed lighting troffers. These are the fixtures DOE's Interior Lighting Campaign[8] (ILC) is focused on. DOE estimates that 50% of commercial lighting fixtures were 1' x 4', 2' x 4', or 2' x 2' recessed lighting troffers that operate for more than 10 hours per day (on average) and consume more than 96.7 TWh of electricity annually.[9] LED troffer technologies have the potential to provide up to 60% energy savings in typical commercial office building applications. Energy savings can reach up to 75% if lighting control systems (e.g., motion sensors, daylighting sensors) are incorporated. Savings associated with lighting controls can be particularly high in intermittently occupied spaces.[10,11]

A broad range of LED troffer and control technologies are available for both new construction and retrofit applications. There are varying degrees of retrofit options for installing LED technologies in existing buildings, including replacing the lamp with an LED lamp, replacing the lamp and other luminaire components with an LED retrofit kit, or replacing the entire luminaire with a luminaire designed for LED lamps, including integrated control sensors. Although adoption of LED troffers has been increasing steadily, Figure 4-1 shows that LED technology still represents less than 2% of current installed base of linear fixtures in commercial buildings.[12]

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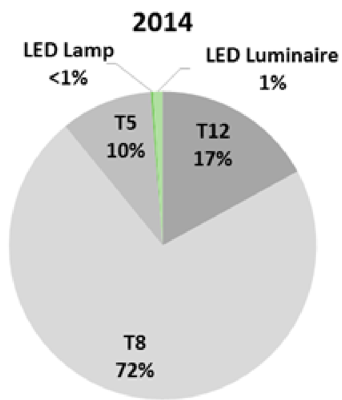
[7] Solid-State Lighting Technology Fact Sheet, DOE Building Technologies Office, available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_troffer-upgrades_fs.pdf
[8] http://www.interiorlightingcampaign.org/
[9] DOE Commercial Building Energy Alliance, 2012 Annual Report, Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/cbea_annual_report_2012.pdf
[10] A 2015 compilation of data from 16 lighting control demonstration sites showed an average use reduction across all sites of 46%. Available http://www.gsa.gov/portal/content/240287
[11] LED Lighting - The New Low-hanging Fruit in a Lighting (R)evolution, Kyle Hemmi, CLEAResult.
[12] BBA High-Efficiency Troffer Lighting Specification Brochure, DOE Better Buildings Alliance, Available at: https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/troffer_factsheet.pdf

Figure 4-1. Composition of Linear Fixture Installed Base



Source: Adoption of Light-Emitting Diodes in Common Lighting Applications. July 2015. Prepared by Navigant for the U.S. Department of Energy Solid-State Lighting Program. Available http://energy.gov/sites/prod/files/2015/07/f24/led-adoption-report_2015.pdf.

4.1.2 Major Manufacturers

The LED troffer and controls market consists of a range of different industry players, from large multinational corporations to small startup companies. Many of the larger players provide holistic lighting solutions including troffers, lamps, and controls for all of the major lighting types; alternatively, many of the smaller companies focus only on specific technologies or products. Table 4-1 lists the major industry players in the LED lighting space and identifies each player's target market and sector.

Table 4-1. Major Industry Players - LED Troffers and Controls[7]

Company	Products	Target Markets
GE Lighting	All major lamp and luminaire technologies	Global, large U.S. focus
Philips	All major lamp and luminaire technologies	Global
Acuity Brands Inc.	All major lamp and luminaire technologies	North America, some international
Cooper Lighting	All major lamp and luminaire technologies	Global, large U.S. focus
Cree, Inc.	LED lamps and luminaires	Global
Finelite	LED lamps and luminaires	United States
Hubbell Lighting, Inc.	All major lamp and luminaire technologies	North America, some international
Lutron	Control technologies	Global
WattStopper	Control technologies	Global

4.1.3 Relevant CBI Work and Resources

CBI works hand-in-hand with the Solid-State Lighting (SSL) Program within BTO's Emerging Technologies Group to support market adoption of LED lighting and control technologies. This joint strategy for R&D and deployment supports a range of efforts, including demonstration projects, testing, and field studies. Although BTO has supported many demonstrations of LED lighting technologies through its GATEWAY Demonstration Program, most of the demonstration projects have focused on LED spot, exterior lighting, and other non-troffer LED types. DOE has, however, conducted research and testing on LED troffer systems. Table 4-2 summarizes some of the most relevant activities supported by CBI and the SSL team for LED troffers and controls.

Table 4-2. DOE Efforts Supporting Market Adoption of LED Troffers and Controls

Project Title	Lead Performer	Report Link
Market research on the adoption of solid-state lighting and future savings potential	Navigant Consulting	Link
CALiPER Report 21.4: Summary of Linear (T8) LED Lamp Testing	Pacific Northwest National Laboratory	Link
Exploratory Study: Recessed Troffer Lighting	Pacific Northwest National Laboratory	Link
LED T8 Replacement Products: Seattle, Washington	Pacific Northwest National Laboratory	Link
Electronics, Lighting, and Networks Group (focusing on lighting controls, communications networks, and electronics)	LBNL	Link
Measured Energy Savings from Lighting Controls at 16 Demonstration Sites	LBNL	Link
LED Office Lighting and Advanced Lighting Control System	Pacific Gas & Electric	Link
Study on Luminaire Level Lighting Controls	Northwest Energy Efficiency Alliance (NEEA)	Link
A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings	LBNL	Link

Source: Developed by Navigant research and DOE national laboratory subject matter experts.

DOE also supports adoption of LED technologies through the Better Buildings Alliance (BBA), DOE's partnership with building owners and key industry players focused on improving the energy efficiency of commercial buildings. The BBA High-Efficiency Troffer Performance Specification provides a framework for commercial building owners on best practices for selecting and installing LED lighting systems. Since 2012, the BBA has maintained a High-Efficiency Troffer Lighting Specification, which offers suggested optimal performance requirements for high-efficiency LED and fluorescent troffer products in the 2' x 4', 2' x 2', and 1' x 4' configurations.[13] An updated version of the specification was released in May 2015 (version 5.0).[14]

4.1.4 Technical and Market Barriers

LED troffer and control technologies have developed into highly advanced lighting solutions; however, they still face significant barriers to adoption. The technical and market barriers known to DOE are detailed in Table 4-3.

Table 4-3. Barriers – LED Troffers and Controls

ID	Barrier	Description
1	Concerns over product inconsistency	Perceptions of quality and performance inconsistency among LED products has led to skepticism and uncertainty by commercial building owners, making them less likely to install LED technologies. Even with recent product improvements, anecdotal concerns may remain. Because of these inconsistencies, buyers need to spend more time evaluating products, especially when making large purchases. This adds cost and increases risk.
2	Performance inconsistency	The performance of some LED products changes based on operating time and environmental conditions, such as ambient temperature. This can lead to potential problems with color consistency, flicker, and glare. These issues present barriers to adoption by commercial building owners, particularly in applications that require high-quality, consistent lighting.
3	Controllability	The primary technical barriers in LED lighting controls include improving the quality of LED dimming controls and developing more standardized design and control strategies to increase integration of LED lighting and control technologies with other building and energy management technologies. Additionally, compatibility between hardware and software systems is a limiting factor. Most building owners have stated that the lack of interoperability between systems has hindered building performance evaluation, thus leaving owners without a full picture of building operations. Data should be exchangeable between systems (e.g., fixture status, occupancy, energy consumption).

[13] BBA High-Efficiency Troffer Lighting Specification Brochure, DOE Better Buildings Alliance, Available at: https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/troffer_factsheet.pdf
[14] https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/high-efficiency-troffers-specification.pdf

ID	Barrier	Description
4	Lack of data on daylighting control performance	There is insufficient data on how reliably fixtures with individual or autonomous controls perform. Recent LED demonstrations have evaluated total energy performance, but few, if any, have evaluated if historical issues related to daylighting (such as hysteresis and inappropriate dimming on a per fixture or zone basis) have been solved with these new products.
5	Upfront cost	Although the costs of LED technologies have dropped significantly and continue to decline, one of the single largest barriers to the adoption of LED troffers is their high upfront cost relative to legacy lighting technologies. Despite the proven short-term payback period of LEDs in some applications, the return on investment may still not be immediate enough for some commercial building owners. Fluorescent systems are efficient, and the actual energy cost of operating a troffer equates to \$18–\$53 annually, with a typical operating cost of around \$28 of energy per year. The cost of a new luminaire along with labor to install is hard to offset when the annual unit costs of the troffers is so low. A 50% energy cost translates to around \$15 – which means that to achieve even a 5-year simple payback that the equipment and labor must only cost \$75.
7	Lack of compatibility and interoperability	LED lighting retrofit technologies are available for most applications. However, current lighting infrastructure and a lack of interchangeability in some applications still limit opportunities for LED adoption. Greater interoperability of lighting control components and more universal specifications for lighting control systems are required to maximize the energy savings potential from LED troffers and controls.
9	Security concerns	LED troffers with controls can be tied directly into building data networks to enable communication between the troffers themselves, as well as with other lighting and building systems controls. The addition of these extra devices to the network brings with it concerns over potential network security issues or the creation of unintended access points.

Sources: Table developed by Navigant and DOE national laboratories, and fall 2015 workshops stakeholder participants.

4.1.5 Other Complementary Programs and Cross-Cutting Opportunities

In addition to CBI's efforts to support market adoption of LED troffers and controls, many energy efficiency organizations also play important roles in LED technologies transformation. Table 4-4 summarizes some particular programs and activities that other government and non-government organizations have conducted.

Table 4-4. Other Efforts Supporting Adoption of LED Troffers and Controls

Provider	Program Highlights	Source
Pacific Gas and Electric (PG&E)	• Develops emerging technology projects including retrofits for LED troffers with control systems in office space • Offers many rebates for LED lighting measures • Looks into potential rebates for troffers in the future	Link
GSA GPG	Has conducted preliminary or real world technology assessments in: • LED replacement lamps for compact fluorescent lamps • LED retrofits for fluorescent luminaires • Networked lighting • LED lighting with integrated controls • LED retrofit luminaires • Wireless lighting control system	Link
Federal Energy Management Program (FEMP)	• Provides guidance for commercial and industrial luminaires, including troffers, which are a covered category within the FEMP efficiency requirements. • Deploys technology efforts including wireless lighting occupancy sensors, which have been designated as a "promising technology" for potential future focus.	Link Link
NYSERDA	• Conducts SSL R&D and demonstration projects	Link
NEEP	• Works with market players throughout the SSL industry across North America and around the world to maximize the potential of LED technologies, including commercial lighting and controls	Link
NEEA	• Develops luminaire level lighting controls initiative	Link
Design Lights Consortium (DLC)	• Since 2010, administers the Qualified Products List, a leading resource that distinguishes quality, high-efficiency LED products for the commercial sector. Also released a Network Lighting Control Systems Specification on April 21, 2016.	Link
Midwest Energy Efficiency Alliance	• Produces the Midwest Advanced Lighting Solutions Guide • Facilitates the Lighting Utility Midwest Exchange Network (Midwest LUMEN)	Link

Source: Developed by Navigant, DOE national laboratory reviewers, and stakeholder participants in fall 2015 workshops.

4.2 Market Transformation Goals and Timeframe

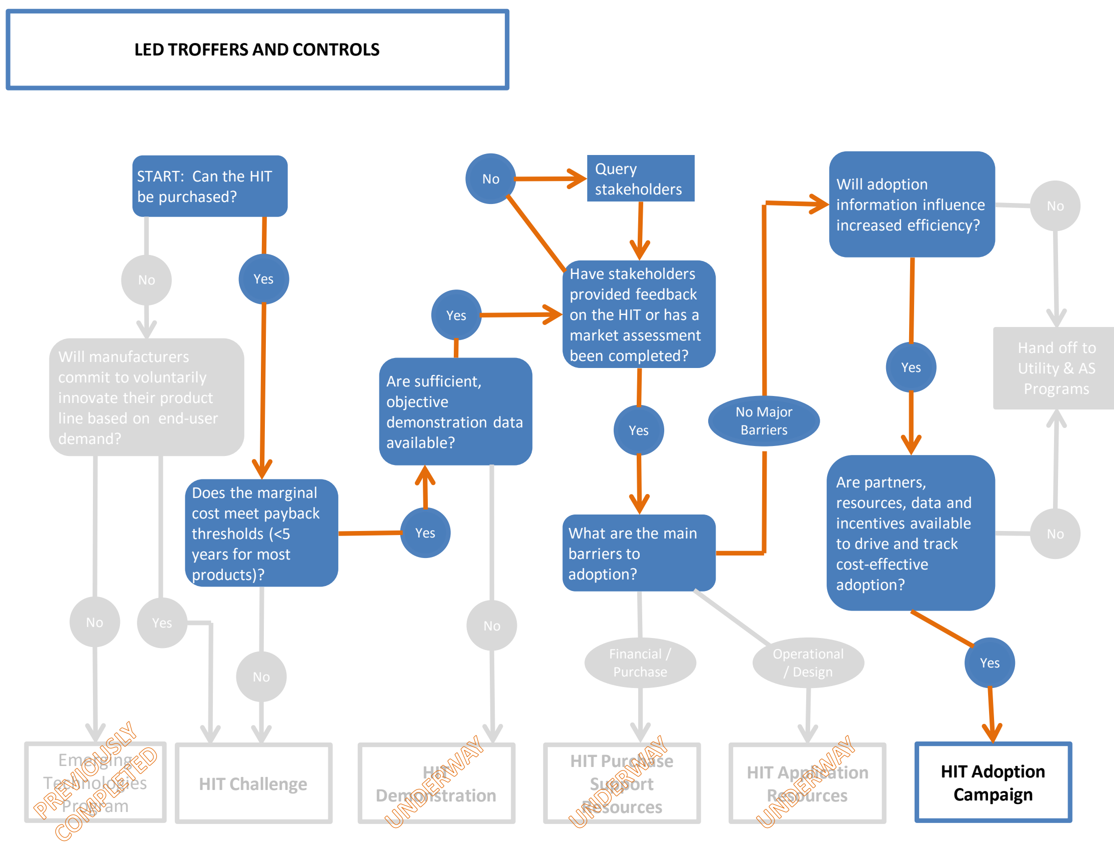
CBI will continue to collect adoption, cost, and energy savings data through the Interior Lighting Campaign. PNNL will maintain its role of providing limited technical assistance necessary to facilitate the widespread adoption of advanced interior lighting applications and programs through the ILC, including energy efficiency programs and voluntary standards. Based on national widespread adoption data, CBI will work with the BTO Building Energy Codes Program to lock in savings by improving energy conservation standards. Technology demonstrations, real project examples, and participation in programs will support technical and economic analysis.

CBI is targeting FY 2018 —after 3 years of data collection—to achieve market stimulation and hand off goals. This target year will be reevaluated annually based on changing market conditions and advances in technology.

4.3 Market Transformation Activities

Figure 4-2 shows the planned and ongoing market transformation pathway for LED troffers and controls.

Figure 4-2. Pathway for LED Troffers and Controls



Source: Based on DOE internal strategy; figure developed by Navigant.

In FY 2014, DOE launched multiple LED troffers and controls demonstrations with NEEP. In FY 2015, DOE outlined out a joint R&D/deployment strategy for lighting controls to ensure that R&D aligns with and reflects outcomes of concurrent deployment work. DOE has developed and published an updated troffer procurement specification with partners in the BBA. Using that specification, CBI has since focused on leveraging the adoption trajectory of LED troffers to drive the incorporation of controls for an added 20%–40% energy savings. These efforts are comprised of two main vehicles:

- **Adoption Campaign:** The BBA's ILC is an adoption campaign that was launched in the spring 2015 with DOE, BOMA, the International Facility Management Association (IFMA), the Illuminating Engineering Society of North America, and GSA as organizing partners. In its first year, the ILC worked to provide resources, assistance, and recognition for best practices in the application of high-efficiency troffer systems. The campaign has been designed using the proven structure of pre-existing, successful technology adoption campaigns (Lighting Energy Efficiency in Parking [LEEP] and the Advanced Rooftop Campaign). Of note, the ILC promotes the adoption of troffer controls as a best practice for participating in the campaign. Control resources that apply to LED troffer lighting will be included in the ILC suite of resources as they become available through GSA, NEEP, utility programs, and other internal and external activities.
- **Demonstration of Controls Energy Savings:** Much foundational work, including demonstrations, has examined the energy savings of LED troffers. However, significantly less research touches on which controls strategies can cost-effectively multiply energy savings. In 2015, GSA's GPG program released the results of several lighting controls demonstrations that verify 20%–40% more energy savings than with a troffer retrofit alone. NEEP examined these issues in FY 2016 as part of the Advanced Lighting Controls demonstration program. As case studies are developed, their findings will be disseminated through the BBA's ILC. Finally, NEEA is conducting assessments of luminaire level controls to identify the granularity necessary to balance energy savings with cost of lighting control systems.

5 Market Transformation Plan – Energy Management and Information Systems

5.1 Evaluation of Current Market Landscape

5.1.1 Key Sectors and Applications

The market for building controls, information, and management systems is large and growing rapidly. The scope of technologies in this market can be confusing because of the varied terminology used throughout the industry and literature. Terms such as energy management system (EMS), energy information system (EIS), building management system (BMS), building automation system (BAS), and energy management and information system (EMIS) are often used interchangeably, although there are distinct technology types within the EMIS family.

Due to this complex and overlapping assortment of terminology and technologies, the DOE BBA Energy Management Information Systems Technology Solutions Team (EMIS Team) has collaborated with a number of stakeholders to develop a technology classification framework.[15] The consensus-driven working definition of an EMIS covers a broad family of tools and services used to manage and control commercial building energy use. These technologies include, for example, EISs that analyze interval meter data, equipment-specific fault detection and diagnostic tools; benchmarking and utility bill analysis tools; automated HVAC system optimization tools; and building automation systems. This framing is used to understand principal design intent and core functionality, although certain commercial offerings may cross categories – for example, some EISs may offer FDD modules or benchmarking capabilities. In this document, the term EMIS refers collectively to these technologies.

CBI's HIT efforts focus primarily on EIS, BAS, and FDD technologies to identify low-cost/no-cost operational improvements to existing building systems and to conduct continuous monitoring, tracking, and commissioning. Other programs in the CBI portfolio focus more heavily on benchmarking and monthly data analysis tools.

An EMIS can be installed either during construction of a new building or as a retrofit measure in an existing building. In both applications, the goal is to save energy through continuous monitoring of whole-building and system-level energy consumption and system operations (e.g., HVAC; lighting; plug loads), coupled with optimized control. EMISs are often used to:

- Identify operational efficiency opportunities (e.g., scheduling, faults, suboptimal control, excessive usage)
- Trend and compare building performance to historical data
- Benchmark energy use and operations against other similar buildings
- Monitor and manage peak loads and demand charges
- Inform external data analytics services

The energy savings that are enabled using EMISs depend on four key factors: (1) the specific type of EMIS used, (2) the energy consumption baseline of the building prior to the installation

[15] http://eis.lbl.gov/pubs/emis-tech-class-framework.pdf

of an EMIS, (3) the proper installation and commissioning of the EMIS, and (4) the extent to which the EMIS is well-integrated into organizational business processes. Case studies suggest that EMISs can enable site energy savings of up to 20%. A synthesized analysis of use of analytics across two dozen organizations that was performed by the EMIS Team found median energy savings of 17% and 8% for individual buildings and portfolios, respectively.[16] Additionally, a meta-analysis by the LBNL[17] suggests that savings attributable to an EMIS could average 16% with a 1.1 year payback, which is in line with more recent study results.

Applications for EMIS-enabled energy savings include the entire commercial building sector. Although EMIS technologies are rapidly evolving, the market offers many mature EMISs that can be applied to most building systems. Table 5-1 shows current revenue estimates for energy management products in North America by customer type. Note that the figures included in this table correspond to a more general definition of energy management systems adopted by the study publisher; as noted previously, EMISs include but are not limited to the technologies included in this market study.

Table 5-1. Estimated Energy Management System Revenue by Customer Type, North America: 2015

Customer Type	Revenue ($ Millions)	Percent of Total Revenue
Enterprise/Office	$287.80	37
Government/Defense	87.3	11
Retail	147	19
Hospitality	54.9	7
Healthcare	41.3	5
Education	82.1	11
Other*	67.2	9
Total	**$767.50**	**100**

*Other: food service, warehouses, or customers that have more specialized needs
Source: Navigant Research. "Building Energy Management Systems." 2015.

5.1.2 Major Manufacturers

The EMIS market consists of an evolving list of vendors and service providers, many of which have emerged in recent years. While several large corporations offer EMIS products, the market also includes many smaller players. Enabled by significant innovation in new technologies and software development, the market is changing rapidly. Table 5-2 illustrates example suppliers, highlighting the diversity and breadth of offerings in energy management technology in the commercial buildings sector of the EMIS market. Because this industry is rapidly evolving—with players undergoing mergers, acquisitions, rebranding, and other activities with regular frequency—the table is a snapshot of providers as of the date of publication of this report.

[16] Granderson, J, Lin, G. 2016. Building energy information systems: synthesis of costs, savings, and best-practice uses. Energy Efficiency, published online 19 Feb, 2016, pp.1-16.
[17] http://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf

Table 5-2. System Providers – Building Energy Management and Information Systems

Company	Example Product Offering
Schneider Electric	StruxureWare
Siemens	Advantage Navigator
Elster EnergyICT	EIServer
SkyFoundry	SkySpark
Verisae	Verisae
J2 Innovations	FIN
General Electric	Predix
IBM	TRIRIGA
C3 Energy	Smart Grid Analytics
Iconics	Energy AnalytiX
GridPoint	GridPoint Energy Management System
KGS Buildings	Clockworks
Ecova	Ecova Energy & Sustainability Management Platform
Honeywell	Attune
EnerNOC	EfficiencySMART
eSight Energy	eSight Energy Management Software
Enerliance	LOBOS
Cascade Energy	SENSEI
Automated Logic	WebCTRL
EnergyCAP	EnergyCAP
Noesis Energy	Noesis Pro

Source: Navigant Research. "Building Energy Management Systems." 1Q 2015.

EMIS vendors offer an array of hardware, software, and services to their customers. Hardware can include sensors, controllers, wired (or wireless) devices, as well as public-facing user interfaces. Software may be installed locally, cloud-based, or app-based, which allows users to log in online from any Internet-enabled device. Additionally, many vendors, particularly those providing analytics or optimization solutions, offer their products through a software as a service model, which requires the customer to pay for an ongoing subscription to the vendor's software.

5.1.3 Relevant CBI Work and Resources

The EMIS Team provides technical assistance, facilitates the identification and sharing of best practices, and addresses the challenges and barriers to widespread adoption of commercial building EMIS. The EMIS Team has published procurement support materials and application guidance to provide current and prospective EMIS users the requisite knowledge to improve operational efficiency through the effective use of EMIS. These documents also aim to equip prospective EMIS adopters with information needed to understand the energy saving potential of and potential business case for EMISs. See Table 5-3 for a summary of EMIS information available through the BBA.

Table 5-3. Better Buildings Alliance EMIS Information

Name	Lead Performer	Report Link
General EIS		
Energy Information Handbook	LBNL/BBA EMIS Team	Link
Food Service EMS		
Energy Management Systems for Food Service Applications	BBA Food Service Team	Link
Making a Business Case for EIS		
EIS Business Case	LBNL/BBA EMIS Team	Link
Costs and Energy Saving Benefits of EIS Webinar Presentation	LBNL/BBA EMIS Team	Link
Costs and Energy Saving Benefits of EIS report	LBNL/BBA EMIS Team	Link
Implementing EMIS		
EMIS Technology Classification Framework	LBNL/BBA EMIS Team	Link
EMIS Crash Course	LBNL/BBA EMIS Team	Link
Synthesis of EMIS Resources	LBNL/BBA EMIS Team	Link
Regional Guide to EMIS Incentives	LBNL/BBA EMIS Team	Link
EMIS Specification and Procurement Support Materials	LBNL/BBA EMIS Team	Link
EMIS Primer	LBNL/BBA EMIS Team	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

Table 5-4 summarizes CBI's EMIS-related projects, while Table 5-5 summarizes BTO emerging technology sensors and controls projects, which will ultimately support EMIS.

Table 5-4. DOE Efforts Supporting Market Adoption of Energy Management and Information Systems

Title	Lead Performers	Overview	Report Link
Retro-commissioning sensor suitcase commercialization pilot project	PNNL, LBNL, ORNL	Turnkey hardware and software solution that enables non-experts to automatically generate low- or no-cost efficiency and operational improvements.	Link
BuildingIQ Tech Demo	BuildingIQ Inc., Foster City, CA	Next generation of advanced building system optimization technology.	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

Table 5-5. DOE Efforts Supporting Sensors, Controls, and Transactional Networks

Title	Lead Performers	Report Link
VOLTTRON	PNNL	Link
Building Energy Management Open-Source Software Development (BEMOSS)	Virginia Tech Advanced Research Institute	Link
Integrated Sensors and Controls	LBNL, U.S.-India Joint Center for Building Energy Research and Development (CBERD)	Link
Monitoring and Benchmarking for Energy Information Systems	U.S.-India Joint CBERD	Link
Sensors, Controls, and Transactive Energy Research	PNNL	Link
University-Industry-National Laboratory Partnership to Improve Building Efficiency by Equipment Health Monitoring with Virtual Intelligent Sensing	ORNL	Link
Low-cost Wireless Sensors for Building Monitoring Applications	ORNL	Link
Building Re-tuning	PNNL	Link
Smart Buildings Equipment Initiative	PNNL, NREL	Link
Transforming Ordinary Buildings into Smart Buildings via Low-Cost, Self-Powering Wireless Sensors and Sensor Networks	Case Western Reserve University, Cleveland, OH	Link
Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.		

5.1.4 Technical and Market Barriers

While EMIS technologies have evolved rapidly into robust and versatile energy management solutions, they still face significant barriers to adoption. Descriptions of the technical and market barriers are detailed in Table 5-6.

Table 5-6. Barriers – Energy Management and Information Systems

ID	Barrier	Description
1	Lack of compatibility and interoperability	Fragmentation of communication protocols, a lack of common naming conventions or standard methods for associating data points between EMIS, existing BAS, optimization algorithms,

ID	Barrier	Description
		and existing building systems (e.g., non-BAS-controlled HVAC, lighting) makes it difficult to integrate multiple systems into centralized EMIS. The proliferation of closed (proprietary) communication protocols and systems prevents quick and inexpensive adoption of EMIS. This is exacerbated by the time and cost associated with these issues.
2	Challenge of retrofit installation	Retrofitting buildings with requisite instrumentation for an EMIS is more difficult than outfitting them during new construction. While wireless systems provide flexibility for building retrofits, wireless sensor technologies may pose security issues. Some building managers mistrust wireless systems in environments that require extremely high levels of system reliability. Additionally, while perceived as more reliable, wired sensor installation is often cost-prohibitive in retrofit applications.
3	Transaction costs and value proposition	A lack of clarity within the industry regarding standard definitions and functionalities of EMIS makes procurement of EMIS platforms complex and time consuming. Limited information on and wide variability of applications makes it difficult for buyers to estimate the costs and benefits (e.g., energy, cost savings) of EMIS.
4	Difficulty of integration	Many commercial buildings already have some building automation features in place, and owners may wish to build on those rather than start anew with a completely different system. Often no one offering satisfies all requirements, and piecemeal integration of automation, control, information, and management systems can make linkages technically challenging, and thus very costly.
5	Scalability for smaller buildings	Costs are coming down and many solutions are cost-effective for large owners and enterprises, but building owners may need to shoulder the costs of IT support and repair in the event of EMIS faults or failures (e.g., lack of wireless connectivity, failed sensors, software support) depending on the terms of their particular agreement. A key barrier to adoption is that the systems are perceived as too expensive in smaller buildings and are not used at all. In small buildings, the dollar value of the energy savings that are enabled may not be high enough to offset the costs of ownership.
6	Organizational integration	EMIS-related energy savings can depend heavily on the ability to incorporate use of the EMIS into organizational practices. Since EMIS are a ”human-in-the-loop” process tool, as opposed to high-efficiency equipment, it is necessary to train users, establish standard procedures to respond to insights gained

ID	Barrier	Description
		through use of the tool, and allocate staff time and responsibilities for maximum technology benefit. Because each organization is unique, and because data-driven energy management is relatively new, this can be a challenge.
7	Market and technical diversity	While technology options are generally a benefit, today's EMIS market abounds with different platforms and options for data analyses. Users are often left wondering what to do first, which data to analyze, and which points to meter.

Sources: Table developed by Navigant and DOE national laboratories, and fall 2015 workshops stakeholder participants.

5.1.5 Other Focus Programs and Cross-Cutting Opportunities

In addition to CBI's efforts to support market adoption of EMISs, other organizations also support EMIS technologies. For a comprehensive and interactive guide on EMIS incentives, refer to LBNL's *Regional Guide to EMIS Incentives*, which provides a state-by-state summary of utility and government incentive programs for various types of EMSs. In addition, Table 5-7 summarizes some of the programs and activities that other government and non-government organizations have conducted in support of EMIS.

Table 5-7. Other Programs Supporting Adoption of Energy Management and Information Systems

Provider	Program Highlights	Source
Consortium for Energy Efficiency Utility Members	• Commercial Whole Building Performance Programs – focusing on continuous energy improvement and EMISs	Link

Public Interest Energy Research Program (PIER, California Energy Commission)	• Automated HVAC FDD Commercialization Program
	  ○ Project team works with major manufacturers to develop systems and controls
	  ○ Includes field demonstrations to document energy performance and cost advantages of the systems
	  ○ HVAC FDD Tool marketed by Architectural Energy Corporation was demonstrated at University of California and California State University sites
		Link

NEEA	• Inventory of Commercial and Industrial EMIS for M&V Applications	Link
NREL	• Simulation of Energy Management Systems in EnergyPlus	Link
Argonne National Laboratory	• Proactive Energy Management for Next-Generation Building Systems	Link

ACEEE	• Coordinating Fault Detection, Alarm Management, and Energy Efficiency in a Large Corporate Campus	Link
Project Haystack	• Industry consortium addressing issues of data integration and EMIS interoperability by defining a common standard for the exchange of buildings data, including reference implementations that are freely available.	Link
NYSERDA[18]	• Control and Building Automation Systems ○ Provides guidance to help commercial building owners make energy efficiency improvements that measurably reduce energy costs and improve return on investments	Link

5.2 Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.Market Transformation Goals and Timeframe

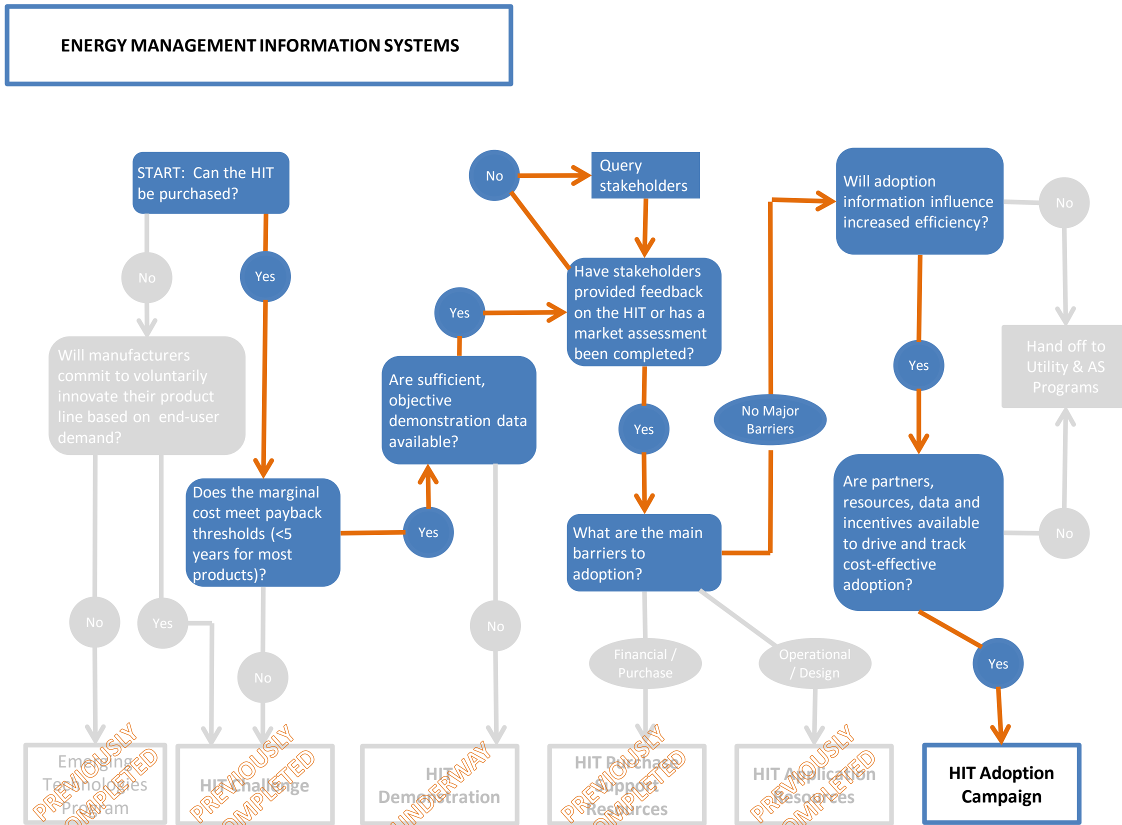
In spring 2016, CBI started recruiting partners for an EMIS adoption campaign, the Smart Energy Analytics (SEA) Campaign. The campaign focuses on the use of FDD and meter analytics, combined with continuous energy management and monitoring-based commissioning processes. This campaign will build on lessons learned through the successful LEEP Campaign, the Advanced RTU Campaign, and the ILC. As part of this EMIS-focused effort, CBI will track participants' EMIS procurements and usage specifics, including actions taken and associated energy savings benefits. A smaller set of participants is anticipated to provide more detailed information on technology costs, and labor resources committed to technology use. Information collected over the course of the 3-year campaign will be used to conduct technical and economic analyses to further to facilitate widespread EMIS applications, likely though efficiency programs, regional market transformation programs, and voluntary standards.

5.3 Market Transformation Activities

Figure 5-1 shows the planned market transformation pathway for EMIS.

[18] Also see NYSERDA's proposed Real Time Energy Management strategy, included in the Clean Energy Fund Supplemental Filing on June 25, 2015.

Figure 5-1. Pathway for Energy Management Information Systems



Source: Based on DOE internal strategy, figure developed by Navigant.

Over the past years, CBI has supported a number of efforts to date focusing on EMIS and related technologies. These foundational activities have served as groundwork for the forthcoming Smart Energy Analytics Campaign. A few of these have included:

- Wireless sub-metering challenge
- Monitoring-based commissioning sensor suitcase
- BBA EMIS procurement support materials
- FDD demonstrations
- Building re-tuning (both for BAS-controlled buildings and those without a BAS)

In addition, CBI is conducting (FY 2015-18) a series of complementary technology demonstrations to evaluate the effectiveness of an automated system optimization offering, a controls and FDD offering for small building portfolios, and a financed EMIS offering. An EIS offering for commercial offices is also being considered for demonstration. Finally, in 2017 CBI and the BTO Emerging Technologies Program will support a joint assessment of AFDD offerings in the LBNL FlexLab. This work may progress into a collaborative assessment with Natural Resources Canada.

Leveraging this ongoing technology support, CBI will conduct the following activities FY 2017 - 19.

- Assess the national EMIS landscape, scope pathways to drive and track adoption, and define trackable metrics and goals, laying the groundwork for the specific deployment steps.
- Partner with utilities and other deployment partners to identify the resource and informational requirements needed to test measures and strategies for operational efficiency, FDD, and monitoring-based commissioning; utilize laboratory facilities and real building examples, as applicable, to verify EMIS applications that meet requirements as identified by partners.
- Utilize results from laboratory tests and real building projects to develop additional application and operations guidance and training resources, streamlining adoption by simplifying EMIS selection and implementation.
- Publish case studies to disseminate public, independently reviewed data on demonstration project savings and costs to inform best practices and increase adopter confidence.
- Work with partners (national laboratories, regional energy efficiency organizations (REEOs), utilities, and technology and service providers) to begin defining key strategies, specific tasks and implementers of activities targeted at market transformation.
- Track cost, performance and adoption data collected via the SEA Campaign in order to inform regional and national voluntary programs and to support the use of more consistent data across utility offerings. This will include working with NYSERDA, Xcel, and other campaign partners to track this data from 2016 through the conclusion of the campaign.

6 Market Transformation Plan – Attachments

6.1 Evaluation of Current Market Landscape

6.1.1 Key Sectors and Applications

Attachments consist of a wide range of interior and exterior products that provide shading, insulating, and/or daylight management functions to existing glazing and fenestration systems. They also improve occupant comfort and workplace conditions. Attachments can be specified in new construction, and often are added as a retrofit to address comfort, energy, and peak demand challenges in existing buildings, particularly with the increase in glass areas in many newer commercial buildings over the last two decades. Attachments provide cost-effective and versatile methods to modulate solar heat gains, and thus space conditioning load, while maintaining visible transmittance, minimizing glare, and controlling or modulating daylight, thereby enabling the reduction of electric lighting loads. Some attachments, such as insulating shades, shutters, and storm windows, also can reduce overall window U-factor, and some can mitigate infiltration loads. Attachments may be applied inside the building, between glazing layers, or outside of the building, and as well as to skylights and sloped glazing. They are applicable in all climates and orientations, and for virtually all commercial building types.

The attachment industry is well developed in Europe, with sales that approximate new window sales. While interior devices are commonly specified in the United States, they are rarely optimized. The field of external devices, which have tremendous potential, is largely unknown in this country. Manually operated interior attachments and fixed external devices dominate their respective markets and generally fail to capture the full savings potentials across weather conditions, and across daily and seasonal sun angles. Motorized and automated systems are now offered by virtually all manufacturers for both new and retrofit applications and are widely used in Europe. The penetration rates in the United States are small for a variety of reasons described below. The increased probability of achieving aggressive energy performance goals with properly designed, installed, and operated active, “smart” systems is a key market driver for the trend toward automation.

The increase in new attachments products and controls has outpaced the designer and owner’s ability to reliably optimize, specify, install, and control these new products. As a first step to providing accurate, objective performance data, the Attachments Energy Rating Council (AERC), a public interest partnership, was formed in 2015 with support from BTO/ET and the attachments industry. AERC consists of a broad range of public and private stakeholder representatives. Supported through a 3-year startup phase by DOE, the AERC seeks to certify, standardize, and disseminate rating information pertaining to a suite of interior and exterior attachment technologies. Because these technologies come in a wide range of shapes, sizes, materials, and operating strategies, it can be challenging to design and deliver systems that meet performance expectations, not only for energy and peak demand, but for thermal and visual comfort, which are key market drivers. Attachment technologies can be statically installed in place, but most are designed and configured for either daily or seasonal adjustment or real-time dynamic control to meet changing needs for energy and comfort. Dynamic control can be provided manually by occupants or via motorized and automated sensors and controls. This is the area of increased industry innovation and product development over the last few years, and provides the potential for much larger and more reliable energy savings.

Window treatments, as window attachments are sometimes referred to, have been shown to reduce summertime solar heat gain up to 65% on south-facing windows, and up to 77% on west-facing windows.[19] Systems may be coplanar to the facade (e.g., Venetian blinds and roller shades), or can be projecting, such as awnings, overhangs, and side fins. Operable systems can be manually operated by hand crank, or motorized and automated via multiple sensor input such as linkages to building automation systems and EMISs. Fixed horizontal overhangs and awnings block light from the high summer sun while admitting light from the lower winter sun, which can be beneficial for heating and lighting in colder climates, although glare must be managed.[20] Operable systems, depending on the level of sophistication, can be integrated with a central building-wide automation system to be operated automatically, or can have autonomous control at the zone or space level to provide the desired local functionality, usually with some provision for occupant override. Other benefits of the use of attachments include potential for HVAC system downsizing in new construction or in conjunction with planned upgrades or retrofits, enhancement of daylighting energy savings, and solar control if an appropriate system is selected. The February 2014 DOE BTO Windows and Building Envelope Research and Development Roadmap[21] estimates that inclusion of attachments in the U.S. building stock has the potential to save 461 TBtu of primary energy annually.

Figure 6-1 illustrates the wide range of attachment options that are available for commercial buildings.

Figure 6-1. Examples of Attachments

Sources: From left to right: 1 and 2, http://www.wbdg.org/resources/suncontrol.php 3, http://zwhcherry916.en.ec21.com/Aluminium_Architectural_Vertical_Louver_for--5732818_5744867.html 4, http://www.homedesignfind.com/green/exterior-sun-shades-reduce-energy-use/

6.1.2 Major Manufacturers

The commercial building attachment industry is highly fragmented, with suppliers having varying levels of vertical integration and different distribution channels. Table 6-1 provides a snapshot of representative industry players. These range from suppliers that produce only components and materials (films, fabrics, motors, etc.), to vertically integrated firms that source their own materials, produce the attachments, utilize in-house distribution networks to route

[19] Energy-Efficient Window Treatments, Department of Energy, Available at: http://energy.gov/energysaver/articles/energy-efficient-window-treatments
[20] Reducing Supplemental Loads, ENERGY STAR, Available at: http://www.energystar.gov/ia/business/EPA_BUM_CH7_SupLoads.pdf
[21] Available at: http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf

products to customers, include design services, and sometimes installation support and commissioning. Many of these products are either provided by local vendors (possibly part of a larger distribution network), are custom designed by an architect, or are provided by a construction materials supplier. The AERC will develop performance ratings including properties and annual energy impacts for interior and exterior attachment technologies. The first rollout of the ratings for residential attachments will occur in FY 2017, to be followed by ratings for commercial attachments. However, the simulation and measurement methods and product databases that already have been developed by LBNL will be useable in the commercial sector before the final ratings are completed.

Table 6-1. Representative Industry Players – Attachments

Company	Link
Allied Window	Link
Ametco Manufacturing Corp.	Link
Aristocrat Awnings	Link
Colt International	Link
Construction Specialties	Link
Draper Inc.	Link
Glen Raven	Link
Hansen Architectural Systems	Link
Hunter Douglas	Link
Alcoa/Kawneer	Link
Lutron	Link
MechoSystems	Link
MON-RAY	Link
Newell-Rubbermaid	Link
QMotion	Link
Renson	Link
Rollac	Link
Rollease-Acmeda	Link
Ruskin	Link
Solar Shading Systems	Link
Somfy	Link
Spring Window Fashions	Link
Sun Control	Link
Unicel Architectural	Link
Warema	Link
YKK Architectural Products	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

6.1.3 Relevant CBI Work and Resources

Owners and designers need objective, accurate performance data to help distinguish relative product performance. Recognizing the energy savings potentials of attachments and the lack of consistency and standardization of attachments energy performance characterizations, DOE's Windows and Building Envelope R&D team, through a competitive solicitation, issued a request for proposals to select an organization to create such a rating system. DOE selected a team assembled by the Window Covering Manufacturers Association (WCMA) to launch the AERC.[22] In 2015, the AERC established subcommittees to develop a comprehensive rating system for interior and exterior fenestration attachments; and pathways to increase awareness, understanding, and adoption of attachments as an effective solar and shading management option to reduce building energy use and improve human comfort. To ensure that attachment ratings are based on accurate, objective data, the AERC will build its rating system on the Complex Glazing Database (CGDB) initiated by LBNL several years ago. It also follows the model of the International Glazing Database (IGDB) LBNL developed with NFRC and now contains data on more than 5,000 product listings. In 2016, LBNL will release two updates to the CGDB and expects more frequent releases in the future. The AERC will launch development of a Certified Product Database (CPD) that will store the final attachment energy ratings. The certified products database will be completed in FY 2017 for selected classes of products. It will provide stakeholders, such as architects, energy modelers, manufacturers, code officials, and utility program managers, with credible, transparent, and actionable information to compare and select appropriate fenestration attachments for specific use cases. The AERC is initially focusing on development of ratings for residential products. The development of ratings for commercial building attachments will leverage many of the residential ratings.

Table 6-2 summarizes some of the relevant activities that BTO has supported for attachments in commercial buildings.

Table 6-2. DOE Efforts Supporting Market Adoption of Commercial Building Attachments

Provider	Program Highlights	Link
AERC	• Develops and promotes attachment ratings	Link
LBNL	• Advanced Windows Testbed: allows for side-by-side testing of window shading technologies and measurement of their effect on solar heat gain, daylight, and glare within a controlled office-like space. • FLEXLAB – allows for side-by-side outdoor testing of interactions of glazing and attachment configurations with lighting and HVAC at any building orientation, with office furniture and occupants if desired. •	Link (Windows) Link (Facades)
GSA GPG	• Conducts field tests of applied films and interior supplementary insulating glazings in GSA portfolio buildings.	Link

[22] Attachments Energy Rating Council, - Available at: http://energy.gov/eere/buildings/downloads/attachments-energy-ratings-council

Consortium for Building Energy Efficiency	• Organization to study and enable deep energy retrofits in small and medium-sized commercial buildings • Conducted market analysis of shading, films, and window attachments, providing recommendations for improving uptake of these technologies in the U.S. small- and medium-size commercial building market.	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

6.1.4 Technical and Market Barriers

Shading and insulating attachments for commercial buildings are fairly mature technologies, although still they are still evolving. As previously noted, attachments are extensively used in the United States as interior systems, but have very limited use as exterior systems, even while they are ubiquitous in European markets, where there are more product options, greater experience in design and installation, and lower costs. Both technical and market barriers have inhibited widespread adoption in the United States. Table 6-3 provides an overview of the technical and market barriers.

Table 6-3. Barriers – Attachments

ID	Barrier	Description
1	Complexity of dynamic shading systems	Dynamic systems employ sophisticated sensors and control systems to automate operation. In the United States, a shift to more open, interoperable systems will have the largest long-term benefit on cost and reliability; in the short term, more training and education is needed to ease installation, reduce cost and complexity, and enable the adoption of existing lower cost motors, sensors, and controls.
2	Maintenance challenges	On large commercial buildings that require window cleaning, certain types of external shades could impede window cleaning operations. Additionally, some external shading types may invite nesting birds, which bring another set of maintenance issues. Attachments need to be designed and installed with building maintenance practices in mind.
3	Lack of accessible modeling tools and design information	Accessible, functional energy assessment tools are needed to guide decision-making and selection from among the wide variety of systems. Architects are often forced to rely on general guidelines to design expensive custom systems. Designers need assistance in quantifying the relationships among shading, HVAC, and lighting energy use, and between energy use and comfort to properly quantify energy saving, acceptance, and return on investment.
4	Difficulty with code applications and lack	Building owners and architects have expressed concerns regarding the application of code requirements that may deter

ID	Barrier	Description
	of voluntary programs	the use of attachments, especially projecting attachments. Furthermore, major categories of attachments products with differing energy savings potential and tradeoffs are sometimes lumped into the same code or program category. Code officials need data to support savings generated by the automated dynamic systems.
5	Lack of energy impact awareness	Owners and designers need accessible and easy-to-understand information on the impact of solar heat gain to better quantify the cost-effective benefits of shading technologies. Window systems do not directly consume energy, so educating potential adopters on the synergies in energy savings possible through coordination of shading, lighting, and HVAC systems is critical to inform the business case for adopting the technology. Furthermore, comfort is a market driver that is understood by most owners and is getting increased attention with the growing emphasis on occupant well- being in voluntary programs like Leaders in Energy and Environmental Design (LEED) certification. Owners and facility managers need best practices and guidance on long-term phased asset replacement or retrofit strategies based on appropriate timing and budgeting, including systems tradeoffs, operations and maintenance requirements, and energy savings potential.
6	Impact on aesthetic appeal and consumer acceptance	Most shading systems are designed to be aesthetically pleasing as well as functional, and blend in with the overall design of the building. However, building owners may not care for the look of shading devices, particularly on a building that has a distinctive style. Automation can enhance the appearance of the building if all the shades are deployed uniformly.
7	Lack of architect understanding and acceptance	Designers can incorporate attachment technologies most cost effectively during new construction or major retrofit periods, such as window replacements. Properly designed systems can allow resizing of HVAC ducts and chillers, and in some cases, can eliminate fan coil systems adjacent to the window. If shading systems are not sized and positioned correctly for a given building's location and orientation, then they will not function correctly. In all climates, proper design is critical to ensuring that shading devices produce performance characteristics that increase comfort and provide desired energy savings outcomes.
8	Lack of standardization	The lack of standardization in product sizes, materials, and mounting methods adds cost complexity and makes design difficult and time consuming. In addition, barrier is the lack of interoperability between controls for these systems and controls serving other building systems, such as lighting and space conditioning, increases cost, complexity, and risk.

ID	Barrier	Description
9	Operation and occupant interaction	Most types of attachments may require some form of occupant operation or engagement. This is most commonly seen in the case of interior shading devices such as blinds, though it applies to some exterior technologies. In these instances, the level of engagement by occupants may be a barrier. Automation may improve these interface issues if executed properly, but requires adequate training of facility managers who may also need to override automation to address user specific needs. Devices may not be used for their optimal solar load mitigation because of the time and effort required to maintain automation along with occupant requirements.

Sources: Windows and Building Envelope Research and Development Roadmap, DOE BTO, http://energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf; Energy Efficient Building Envelopes Technology Roadmap, 2013, International Energy Agency, http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf ; Consortium for Building Energy Efficiency: Shading, Films, and Window Attachments Market Report. http://energy.gov/eere/buildings/downloads/shading-films-and-window-attachments-market-report. Additional material developed by Navigant, DOE national laboratory reviewers, and fall 2015 workshop stakeholder participants.

6.1.5 Other Focus Programs and Cross-Cutting Opportunities

In addition to DOE's efforts to support market adoption of attachments, many other organizations are also playing important roles. Table 6-4 summarizes some of the programs and activities by other government and non-government organizations.

Table 6-4. Other Efforts Supporting Adoption of Attachments

Provider	Program Highlights	Source
Sacramento Municipal Utility District (SMUD)	Energy efficiency measure demonstrations for: • Interior and exterior shading devices and window films • Photo- or time-activated awnings • Permanent shading devices	Link
Electric & Gas Industries Association	GEOSmart Residential and Commercial Energy Program is a low interest loan for building upgrades, including window shading technologies	Link
Northwest Energy Efficiency Council	Solar Gain Management Fact Sheet provides guidance on shading systems for mitigating solar heat gain within commercial buildings	Link
PG&E	Supporting field tests in LBNL FLEXLAB that include interior and exterior attachments	Link
European Solar Shading Organization	Develops guidelines, best practices, and ratings in Europe; many U.S. suppliers are global and members	Link

Purdue University	Facade Engineering Lab allows for testing of window shading technologies, including smart controls to operate shading attachments	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

6.2 Market Transformation Goals and Timeframe

CBI will work with key stakeholders and energy efficiency program sponsors to develop technical and market data that supports the inclusion of attachments as a measure within voluntary programs. This is expected to lead to supporting the improvement of current requirements (e.g., window-to-wall ratios and projection factors) from rating and standards organizations. Including provisions for this technology into voluntary programs will boost its visibility as an option for new construction and retrofits, which will drive implementation. Voluntary rating programs, such as the U.S. Green Building Council's (USGBC) LEED program, incentivize early adopters to incorporate technologies into high-performance new construction. The AERC will provide consistent, accurate, and objective performance data to enable "apples to apples" design and purchasing comparisons of attachment systems. Members of the AERC will use standardized energy labels and messaging across the industry to capture attention from market leaders and early adopters in existing buildings, and will work with DOE and other industry partners to carry out demonstration projects to support performance claims. More broadly within the BT Program, DOE will initiate a new Envelope Efficiency Solutions team through the Better Buildings Initiative.

Table 6-5. Key Attachments Deployment Partners

Key Attachments Deployment Partners		
American Architectural Manufacturers Association	American Institute of Architects	AERC
Consortium for Energy Efficiency (CEE)	ACEEE	NEEA
USGBC	IFMA	WCMA
Fraunhofer		

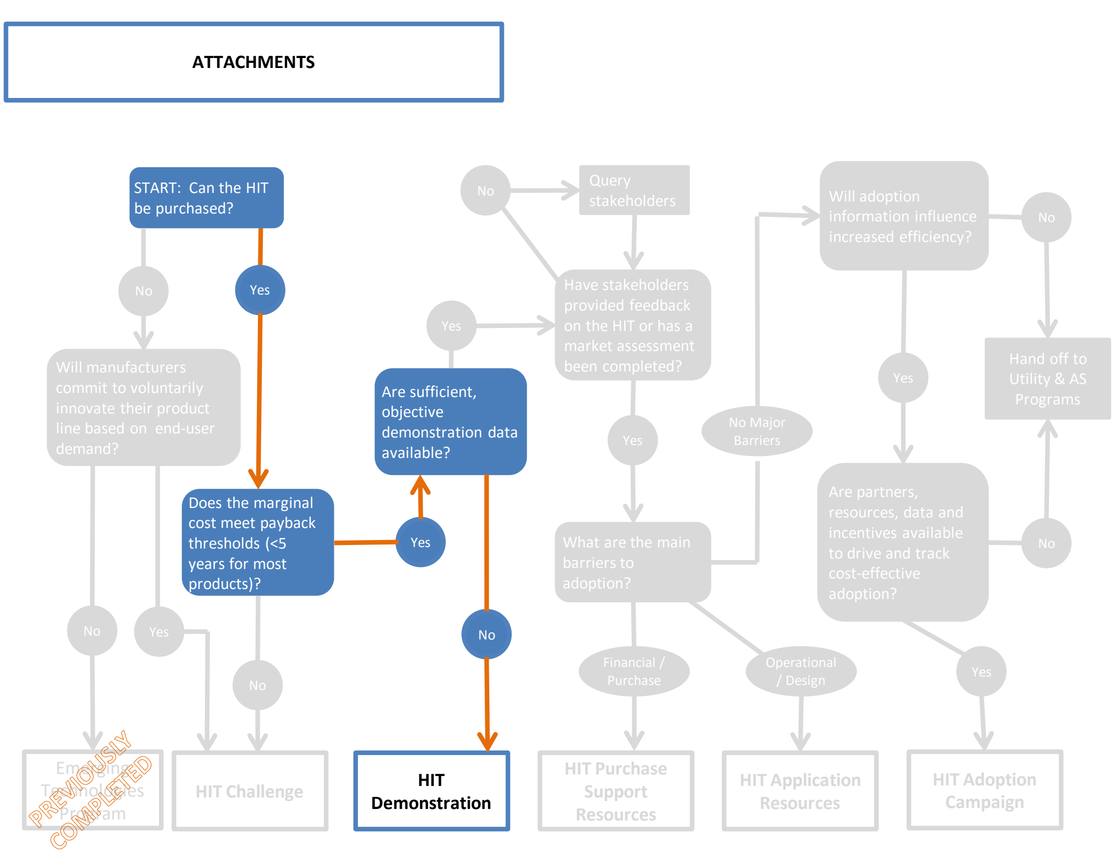
Source: Developed by Navigant based on DOE correspondence with partners and past activities.

CBI will support deployment of attachment technologies and systems using a phased approach. The goal of the AERC activity by 2018 is to create consistent and accurate performance data and energy ratings, and to make that data and associated tools available for all products and building applications. Commercial attachment products are being evaluated, and properties of key components (e.g., fabrics) are being collected and entered into the CGDB. AERC expects that software tools will generate the analysis and/or optimization needed to adapt a shading solution to specific applications, such as orientation and climate. CBI and ET will partner with AERC to communicate the availability of this data and labeling system. Early demonstrations will help build confidence in the performance outcomes. Some products, such as screens and films, have completed demonstration results through the GPG and will be easier to implement sooner than more complex solutions, like louvered overhangs or motorized shades. CBI will collaborate with other industry partners, such as owners, designers and utilities, through the Better Buildings Envelope Efficiency team to assess which systems to promote or demonstrate as the supporting databases are developed and the calculation procedures are validated. Additionally, as appropriate and applicable, CBI will work with European partners to transfer lessons learned from the extensive application of envelope attachment technologies in Europe.

6.3 Market Transformation Activities

Figure 6-2 shows the planned market transformation pathway for exterior shading measures.

Figure 6-2. Pathway for Attachments



Source: Based on DOE internal strategy; figure developed by Navigant.

Over the last 5 years, BTO has begun to support applied research into shading technologies and rating procedures through the Emerging Technologies Program. In 2015, CBI began preliminary scoping of the market landscape for attachments with CBEI, LBNL, ORNL, and the AERC. CBI will begin scoping of further specific activities in FY 2017:

- Initiate case studies to develop independently collected data on real project savings, costs, installation, and operational factors to inform best practices and increase adopter confidence.
- Work with the organizers of the AERC to support development and deployment of tools and resources created through the organization and partners.
- Engage owners, designers, and utilities through the Better Buildings Initiative to share AERC rating development progress, uncover additional market barriers, and continue creating market interest and awareness.

- Coordinate with performers of activities for related technologies within the residential buildings sector to leverage momentum, data, and lessons learned, as applicable to commercial buildings. Specifically within envelope measures, much work has been done in residential buildings to transform the market for R-5 windows. This experience could be applied to CBI's efforts as well.

Additionally, CBEI[23] has conducted a market assessment covering a variety of attachment technologies in small commercial buildings. BTO (ET and CBI) will coordinate with the AERC to evaluate ways to take advantage of major opportunities and develop resources needed to overcome significant barriers to the adoption of attachment solutions. Based on the results of the CBEI assessment and AERC evaluations, DOE will adjust the scope and nature of its deployment activities to ensure optimal alignment with collaborators and maximal market impact.

[23] CBEI is an organization focused on generating impact in the small- and midsize commercial buildings retrofit market. CBEI develops and demonstrates systems solutions in a real-world regional context for future national deployment. More information is available at http://cbei.psu.edu/

7 Market Transformation Plan – Cold-Climate Heat Pumps

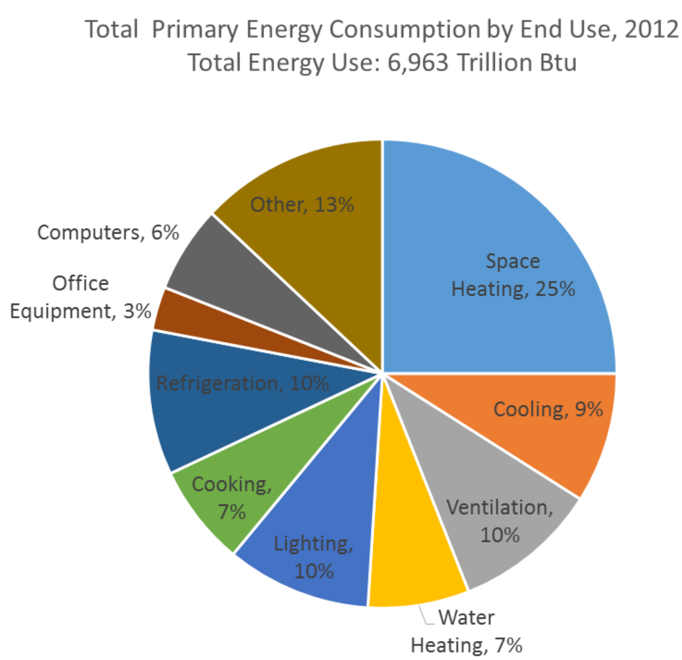
7.1 Evaluation of Current Market Landscape

7.1.1 Key Sectors and Applications

In recent years, electric utilities in the northwest and northeast have heavily promoted cold-climate air-source heat pumps (CCHPs) in the residential sector. Technology enhancements allow residential CCHPs to achieve superior heating performance (both capacity and efficiency) at low outdoor temperatures, compared to conventional residential heat pumps. This makes them more energy-efficient than competing space-heating technologies at most outdoor temperatures. Similar technology enhancements, mainly variable-speed compressors and fans with overspeed compressor operation in heating mode, are also being applied to commercial unitary air-source heat pumps, allowing these products to offer similar energy-efficiency benefits.

Figure 7-1 shows that space heating represents 25% (1.7 quads) of commercial building primary energy consumption.

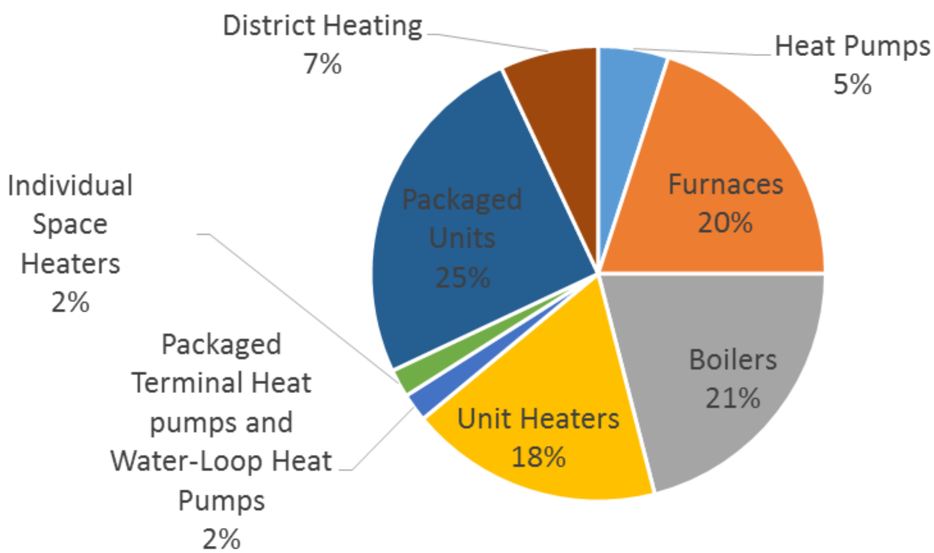
Figure 7-1. Commercial Sector Primary Energy Consumption



Source: EIA, 2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary, (March 18, 2016). https://www.eia.gov/consumption/commercial/reports/2012/energyusage/

Although more recent data are not available, a 2001 report estimated that heat pumps of all types account for only about 5% of commercial space-heating energy consumption (see Figure 7-2).

Figure 7-2: Commercial HVAC Equipment Primary Energy Consumption (2001)



Source: DOE, Arthur D. Little, Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume I: Chillers, Refrigerant Compressors, and Heating Systems, April 2001.

Three major types of commercial air-source heat pumps are available in the United States:

- Packaged rooftop heat pumps (see Figure 7-3)
- Split-system heat pumps (see Figure 7-4)
- Variable-refrigerant-flow (VRF) Heat Pumps (see Figure 7-5).

Packaged rooftop heat pumps currently dominate the market. VRFs are mainstream in major markets outside the United States, but have only a small share of the U.S. market, although their market share is growing quickly.[24] Split-system heat pumps are a relatively small player in the commercial market.

Figure 7-3. Commercial Packaged Heat Pumps

Source: 2015-06-09-10 Meeting Presentation: CUAC/CWAF ASRAC Working Group Fifth Meeting. https://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0091.

[24] http://www.achrnews.com/articles/131076-vrf-gaining-mass-appeal-in-the-us

Figure 7-4. Commercial Split-System Heat Pump

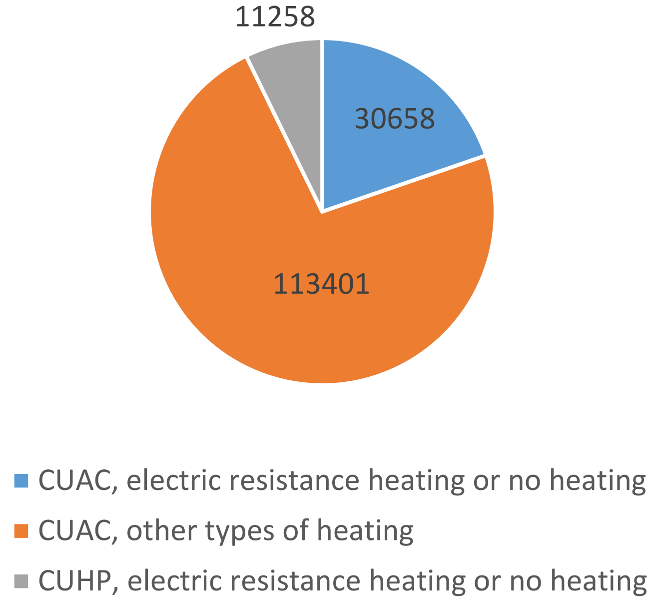
Source: Carrier Commercial. http://www.carrier.com/commercial/en/us/products/split-systems/split-systems/.

Figure 7-5. Variable-Refrigerant-Flow Heat Pumps

Source: Daikin VRV IV heat pump website. http://daikincomfort.com/products/vrvs/VRVIV-HeatPump.

Error! Reference source not found. shows that, in 2014, unitary heat-pump shipments were 11,258 units, or about 7% of the U.S. unitary air-conditioning market (these figures exclude VRFs).

Figure 7-6. Commercial Unitary Air Conditioner and Heat Pump Shipments, 2014



Based on data from 7 of 9 major U.S. suppliers. Source: 2015-12 Direct Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Small, Large, and Very Large Commercial Package Air Conditioning and Heating Equipment (2015), EERE-2013-BT-STD-0007-0105

7.1.2 Major Manufacturers

Unitary Packaged and Split-System Heat Pumps

Table 7-1 lists the major manufacturers of unitary heat pumps in the United States. Research found none that are specifically advertised as cold-climate heat pumps. However, there is evidence that at least some of these products are likely to have good cold-climate performance. For example, a linear extrapolation of Air-Conditioning, Heating, and Refrigeration Institute (AHRI)-certified capacity and power ratings at the 47°F and 17°F outdoor-temperature rating points shows that 8% of listed products would have a coefficient of performance (COP) of at least 1.75 at 5°F outdoor temperature.

Achieving a COP of 1.75 or higher at 5°F is a common criterion for utility incentive programs for residential cold-climate heat pumps (see section 0), and thus it follows that this target would be of analogous interest in the commercial sector. Of these product lines, the Daikin Rebel series of packaged rooftop heat pumps employs variable-speed compressors (a feature of virtually all residential CCHPs) and claims heat-pump operation down to 2°F outdoor temperature (at ambient temperatures below this value, a backup form of heating packaged with the unit, such as gas or electric resistance heating, would be activated).[25]

Another indicator of good cold-climate performance is the ratio of maximum heating capacity at 17F and/or 5F, if available, to rated cooling capacity. This ratio should be available for all commercial heat pumps for the 17F rating point. Units with the higher ratios will provide better

[25] http://lit.daikinapplied.com/bizlit/DocumentStorage/RooftopSystems/Brochures/ASP31-347_Rebel_Heat_Pump_Application_Brochure.pdf

seasonal performance in cold climates compared to units with similar, or moderately lower, COPs at 17F by reducing backup resistance heat use. Unitary units that have two-capacity or tandem compressors could provide higher ratios of maximum heating capacity at 17F compared to the rated cooling capacity, if such units are configured to be operated and rated in cooling mode only at the lower capacity stage. Tandem units have more potential in this regard than single two-capacity compressors due to the wider capacity difference and better low ambient performance. Such units could provide low ambient capacity ratios and COPs similar to overspeed variable-speed units at lower cost. However, there appear to be no commercial CCHP product offerings of this type at this time.

Table 7-1. Major Industry Players – Commercial Unitary Heat Pumps

Company	Heat Pump Product Offering
Aaon	Packaged and Split
Lennox	Packaged and Split
Carrier	Packaged and Split
Daikin	Packaged and Split
Goodman (member of Daikin group)	Packaged
Johnson Controls	Packaged and Split
Nortek	Packaged
Rheem	Packaged and Split
Trane	Packaged and Split

Source: Table developed by Navigant and DOE national laboratory subject matter experts.

VRF Heat Pumps

Table 7-2 lists the major manufacturers of VRF heat pumps sold in the United States. There is evidence that many of these products are likely to have good cold-climate performance. Manufacturers list minimum operating temperatures ranging from -4°F to -13°F, although at least some of these temperature limits are based on wet-bulb temperature rather than dry-bulb temperature. A linear extrapolation of AHRI-certified capacity and power ratings at the 47°F and 17°F outdoor-temperature rating points shows that close to 80% of listed products would have a COP of at least 1.75 at 5°F outdoor temperature.[26]

Table 7-2. Major Industry Players – Commercial VRF Heat Pumps

Company	Heating-Mode Minimum Operating Temperature (°F) *
Daikin	-13 (wet bulb)
Fujitsu	-4
GD Midea	-4
Gree	-4
Johnson Controls	-4
Lennox	-13

[26] Most or all VRF products use variable-speed compressors. Extrapolating performance for variable-speed products introduces many uncertainties. However, given that a large percentage of the extrapolations suggest good cold-temperature performance, it's likely that many of these products can actually achieve good cold-temperature performance.

Company	Heating-Mode Minimum Operating Temperature (°F) *
LG Electronics	-13 (wet bulb)
Mitsubishi	-13
Panasonic	-4
Toshiba Carrier	-5
Trane	-13
Samsung	-13

* Based on manufacturer published product literature. Unless indicated otherwise, the manufacturer did not specify whether the minimum operating temperature is dry-bulb or wet-bulb.

Navigant research found no VRF products offered in the United States that are specifically marketed as cold-climate heat pumps. However, on its global product Website, one manufacturer advertises an outdoor unit for low outdoor temperature use that uses two-stage compression technology to improve performance at low outdoor temperatures—as low as –13°F.[27]

7.1.3 Relevant CBI Work and Resources

Table 7-3 lists five DOE programs under which CCHPs (both commercial and residential) are being (or have been) developed. Using one project as an example, the high-efficiency commercial cold climate heat pump, United Technologies Research Center demonstrated through laboratory testing that this packaged rooftop heat pump can achieve a 1.8 COP at -13°F with a capacity that is within 15% of the capacity at the 47°F rating point.[28]

Table 7-3. DOE Efforts Supporting Market Adoption of Commercial and Residential Cold Climate Heat Pumps

Project Title	Target Market	Report Link
High-Efficiency Commercial Cold Climate Heat Pump	Commercial	Link
Natural Refrigerant High-Performance Heat Pump for Commercial Applications	Commercial and Industrial	Link
Split System Cold Climate Heat Pump	Residential	Link
Low-Cost Gas Heat Pump for Building Space Heating	Residential and Commercial	Link
The Natural Gas Heat Pump and Air Conditioner	Residential and Commercial	Link

Source: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

7.1.4 Technical and Market Barriers

Table 7-4 lists the key barriers to widespread adoption of commercial CCHPs in the United States. The barriers are primarily market-related; there are few technical barriers to achieving good cold-climate performance, as has been demonstrated by the many residential CCHPs available.

[27] http://www.daikin.com/products/ac/lineup/vrv/
[28] As presented at the 2016 DOE BTO Peer Review: http://energy.gov/eere/buildings/downloads/high-performance-commercial-cold-climate-heat-pump

Table 7-4: Barriers – Cold-Climate Heat Pumps

ID	Barrier	Description
1	Capital Cost Premiums	CCHPs can have a substantial first-cost premium compared to conventional heat pumps. VRFs, which tend to have superior cold-climate performance compared to conventional packaged or unitary split-system heat pumps, are significantly more expensive than these conventional products.
2	Purchaser First-Cost Sensitivity	Exacerbating Barrier 1 above, packaged RTUs, which represent the bulk of the unitary heat-pump market, tend to be used in applications where low first costs are of paramount importance to the purchaser (such as emergency replacement).
3	Retrofit Challenges	VRFs can be difficult and expensive to install in retrofit situations where conventional unitary equipment was originally installed. This may indicate a market need for low-cost ducted CCHP solutions.
4	Limited Documentation of Cold-Climate Performance	Manufacturers are not required to rate heat pumps at temperatures below 17°F, and very few publish detailed performance information at colder temperatures. Demonstrations completed for small commercial and/or residential applications has produced inconsistent data.
5	Limited Product Offerings	Based on available performance data, less than 10% of packaged rooftop heat pumps, which represent the bulk of the unitary heat-pump market, are likely to achieve good cold-climate performance

Sources: Table developed by Navigant and DOE national laboratories, and fall 2015 workshops stakeholder participants.

On the positive side, CCHPs generally offer superior comfort and indoor-air-quality benefits compared to conventional heat pumps. The variable-capacity capabilities of CCHPs allow them to maintain very uniform indoor air temperatures and humidity levels year 'round compared to conventional products. This can be a significant non-energy benefit in some applications.

7.1.5 Other Focus Programs and Cross-Cutting Opportunities

Table 7-5 lists examples of non-DOE efforts to promote residential CCHPs. Research was unable to identify any current, non-DOE programs to promote commercial CCHPs, but it is conceivable that the residential programs could potentially be expanded into the commercial space.

Table 7-5: Other Efforts Supporting Market Adoption of Residential Cold-Climate Heat Pumps

Provider	Program Highlights	Source
NEEP	• Focuses on residential single-zone and multi-zone air source heat pump units. • Requires COP>1.75 at 5°F ambient.	Link
Massachusetts Clean Energy Center	• Rebate for residential single head and central/multi-head heat pump systems • Requires COP>1.75 at 5°F ambient.	Link

Provider	Program Highlights	Source
	• Requires system deliver 100% of rated 47°F or 17°F capacity at 5°F	

Source: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

7.2 Market Transformation Goals and Timeframe

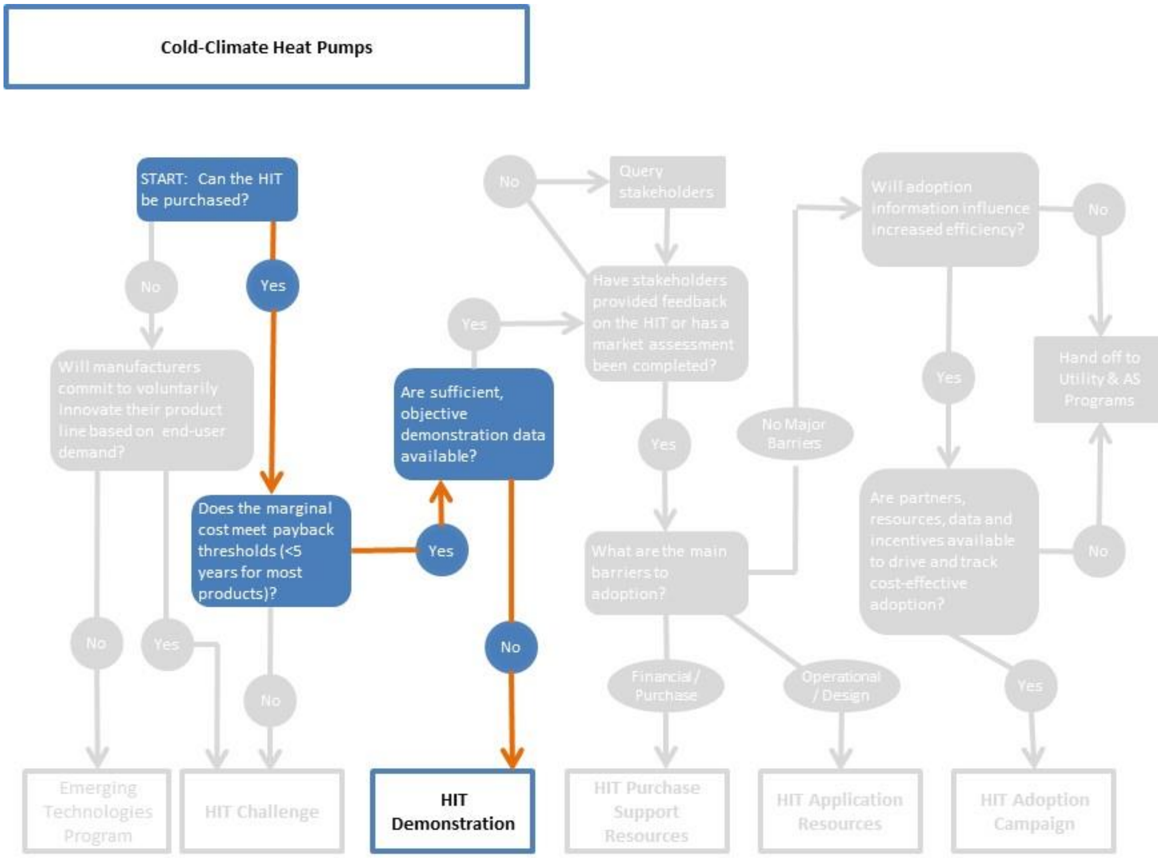
CBI will conduct additional market evaluation to better understand the existing installed base, definitional needs, recent demonstration results, and market factors impacting performance (training for design, installation and commissioning, product lead time and/or availability, operation and warranty). In coordination with the GSA GPG, FEMP, Department of Defense Environmental Security Technology Certification Program, utilities, professional societies (ASHRAE and AHRI in particular), and other organizations, BTO will identify opportunities to field-demonstrate CCHPs in commercial building applications in northern U.S. locations. CBI will ensure that demonstration results are published and distributed broadly to encourage broad market adoption of commercial CCHPs. Further, working with utilities and supporting organizations such as the CEE, CBI will encourage utilities to develop incentive programs targeted at commercial CCHPs.

CBI plans to begin market transformation activities in 2017, starting with additional market research. That will be followed by discussions with utilities and/or CEE to identify products appropriate for field demonstration, identify appropriate field-demonstration sites, and initiate demonstrations.

7.3 Market Transformation Activities

Figure 7-7 shows the planned market transformation pathway for CCHPs.

Figure 7-7. Pathway for Cold-Climate Heat Pumps



Source: Developed by Navigant based on DOE internal strategy.

The market evaluation for these technologies shows that the key barriers include the lack of field demonstration data documenting cold-climate performance, energy consumption, reliability, and other key factors integral to supporting market adoption. Additionally, the lack of consistent definition of a cold-climate heat pump, and thus a lack of manufacturer representation of units as such, deters adoption in applicable regions.

To address these barriers, CBI will work to identify applicable units, whether on the market today or in the first phases of commercialization. CBI will coordinate with other programs, such as Bonneville Power Administration and the Northeast Energy Efficiency Partnerships, to conduct field studies of the performance of the units. Focus will be placed on gathering field performance data and market factors to elevate the confidence of building owners, utilities, and voluntary programs in the potential of these technologies. As the technology progresses, DOE may transition to development of supporting application resources, including best-practice materials, to ensure that equipment achieves its performance potential when deployed in the field.

Additionally, much work has already been performed to demonstrate and deploy cold-climate heat pump technologies within the residential buildings space. This includes development and testing of prototype systems by laboratories, as well as market transformation programs sponsored by utilities to accelerate consumer purchase of more mature designs already on the market. CBI will work with performers who have experience in this space, including major utilities and national laboratories, to leverage their lessons learned and data.

In the long term, CBI seeks to partner with utilities, REEOs, and voluntary certification programs to drive adoption and track adoption metrics. These organizations are well-positioned to partner with CBI to create this data through existing member and partner bases. These entities are also positioned to provide incentives to members/customers, which will help lower costs and hasten large-scale adoption of viable products.

8 Market Transformation Plan – Automated Fault Detection and Diagnostic Systems for Rooftop Units and Air Handlers

8.1 Evaluation of Current Market Landscape

8.1.1 Key Sectors and Applications

Satisfying the comfort and air quality demands while minimizing energy waste in commercial buildings requires the precise interaction HVAC system components. HVAC systems must function in several operating modes and use numerous sensors and controls to coordinate the actions of different heating and cooling subsystems and their various moving parts (e.g., fans, motors, and dampers). Whether as a standalone packaged RTU or part of a larger distributed system using AHUs, the performance of HVAC systems often deviates from design performance due to system malfunctions, equipment wear, manual controls overrides, and other causes. These faults often begin with little or no noticeable change in system performance or operation, but over time can lead to decreased capacity, efficiency, comfort, reliability, and longevity.[29] Semi-annual maintenance inspections often fail to identify faults due to the limited time the technician can observe the system and test individual components.

Table 8-1 and Table 8-2 highlight the potential efficiency degradation of RTUs caused by common system faults, such as low refrigerant charge and condenser or evaporator airflow reduction. While individual faults can cause moderate performance and efficiency decreases, the presence of multiple faults can have a substantial impact even for small fault levels. As Table 8-2 shows, even a collection of relatively small faults can reduce RTU efficiency by 15%, and several moderately severe faults reduce efficiency by 26%.

Table 8-1. Example Performance Degradation from Common Single-Faults for RTUs

Fault Type	Fault Levels	EER Degradation	Notes
Low Refrigerant Charge	Low: -10% Med: -20% High: -30%	Low: +2% Med: -3% High: -25%	Slight EER increase based on relative drop in cooling capacity and electrical consumption
Condenser Airflow Reduction	Low: -16% Med: -37% High: -58%	Low: -17% Med: -24% High: -36%	Air-side EER
Evaporator Airflow Reduction	Low: -23% Med: -46% High: -67%	Low: -2% Med: -10% High: -23%	Air-side EER

Source: Southern California Edison. "Evaluating the Effects of Common Faults on a Commercial Packaged Rooftop Unit." ET13SCE7050. July 2015. http://www.etcc-ca.com/reports/evaluating-effects-common-faults-commercial-packaged-rooftop-unit?dl=1461105088.

[29] See for example, the ACEEE report outlining common economizer faults and prevalence at http://aceee.org/files/proceedings/2014/data/papers/3-1007.pdf

Table 8-2. Example Performance Degradation from Common Multiple-Faults for RTUs

Fault Levels	Low Refrigerant Charge	Condenser Airflow Reduction	Evaporator Airflow Reduction	EER Degradation
Low	-10%	-17%	-23%	-15%
Medium	-23%	-37%	-46%	-26%
High	-30%	-58%	-67%	-52%

Source: Southern California Edison. "Evaluating the Effects of Common Faults on a Commercial Packaged Rooftop Unit." ET13SCE7050. July 2015. http://www.etcc-ca.com/reports/evaluating-effects-common-faults-commercial-packaged-rooftop-unit?dl=1461.105088.

To address this issue, manufacturers, service providers, and researchers have developed AFDD systems to provide greater insight into RTU and AHU operations and improve maintenance practices. AFDD systems consist of a suite of sensors, communication systems, and analytical algorithms that perform the following functions:

- Monitor various performance indicators
- Benchmark performance over time
- Detect when performance changes, indicating a fault
- Alert building staff when indicators suggest a fault
- In some cases, provide building staff with likely causes for the fault so that they can be readily addressed through maintenance and repair.

AFDD systems provide energy savings and other comfort and operational benefits by increasing the likelihood and restorative impact of system maintenance. AFDD systems can quickly alert building staff or service technicians when a fault occurs, sometimes quantify the fault priority, impact, and/or savings opportunity, and then direct technicians to likely problem areas so that issues can be inspected and repaired rapidly. This reduces the amount of time the RTU or AHU operates below optimum efficiency and performance, and could provide up to 30% energy savings compared to common seasonal or annual maintenance. In addition, AFDD systems could reduce maintenance and repair costs by catching small issues before they cause catastrophic damage over time. Some AFDD systems even can verify that the repairs and maintenance solved the issue and returned performance.[30] The non-energy benefits of AFDD, including building comfort and increased equipment reliability, are particularly valuable in applications where minimization of downtime is essential, such as hospitals.

AFDD systems must balance the number of monitoring points, sensor types, diagnostic capabilities, sensitivity, accuracy, and other attributes with the product cost and installation complexity to ultimately meet the needs of the building staff. For this reason, AFDD systems for smaller buildings using RTUs commonly have fewer sensors than those for larger buildings with

[30] Katipamula et al. 2016. "Sensors & Advanced Building Controls Project: Task 2: Develop, Test, and Validate Diagnostic and Self-Aware Concepts for Small Commercial Buildings." Presentation to DOE/BTO. February 10, 2016.

distributed and built-up AHUs and duct systems. Table 8-5 in Section 8.1.2 compares the features of several AFDD systems on the market today. However, the AFDD requirements for California Title 24 Building Energy Efficiency Standard[31] highlights the capabilities of many systems:

- Temperature sensors to monitor: outside air, supply air, return air
- Operational status for economizers, cooling system, heating system, mixed air system.
- The FDD system shall detect the following faults:
  - Air temperature sensor failure/fault;
  - Not economizing when it should;
  - Economizing when it should not;
  - Damper not modulating; and
  - Excess outdoor air.

AFDD systems are available for both new and existing HVAC equipment. The California Building Code requirements apply to new RTUs with cooling capacities greater than 4.5 tons, and manufacturers have incorporated these AFDD capabilities into their products. Additionally, many vendors and researchers have developed retrofit AFDD systems that can cost-effectively integrate with existing RTUs and AHUs. Section 8.1.2 discusses various AFDD vendors and offerings in greater detail.

The market for AFDD systems will continue to grow as more manufacturers introduce products that provide onboard AFDD capabilities and as vendors increasingly offer retrofit AFDD analytics. Table 8-3 provides key information on HVAC energy consumption for small, medium, and large buildings. Generally speaking, smaller buildings are primarily served by RTUs, large buildings by distributed systems with AHUs, and medium-size buildings with a mix of these technologies. Combined, these building types can potentially save 500 to1,000 TBtu of site energy savings by using HVAC AFDD.

Table 8-3. HVAC Consumption in U.S. Commercial Building Stock

Characteristics	Small Buildings	Medium Buildings	Large Buildings	Total
Floor space Range (thousand sq. ft.)	≤ 50	>50 and ≤ 100	>100	–
Number of Buildings (thousands)	4,604	147	108	4,859
Total Floor space (billion sq. ft.)	36	10	25	71
Total Site Energy Consumption (TBtu)	2,889	913	2,722	6,524

[31] California Energy Commission. 2015. “Building Energy Efficiency Standards for Residential and Nonresidential Buildings for the 2016 Building Energy Efficiency Standards.” Title 24, Part 6, and Associated Administrative Regulations in Part 1. CEC-400-2015-037-CMF June 2015. Available at: http://www.energy.ca.gov/2015publications/CEC-400-2015-037/CEC-400-2015-037-CMF.pdf

Total Expenditures ($B)	51	15	42	108

Source: Katipamula et al. 2016. "Sensors & Advanced Building Controls Project: Task 2: Develop, Test, and Validate Diagnostic and Self-Aware Concepts for Small Commercial Buildings." Presentation to DOE/BTO. February 10, 2016.

As discussed previously, installation cost and complexity is a key consideration for the value proposition of AFDD systems. Several recent technology and market trends have helped improve the capabilities and reduce the upfront cost of installing and configuring AFDD systems, including:[32]

- Open-source standards for building and HVAC control systems (e.g., BACnet) allow for easier integration and communication than previous proprietary systems (though issues remain with proprietary implementations of open-source standards)
- Communication and IT costs have decreased substantially in recent years
- Title 24 requirements for RTUs (greater than 4.5 tons in capacity) obligated manufacturers to respond to major market mandates, reducing the incremental cost.
- Research into low-cost sensors, advanced communication platforms, and analytic software, has a compounding effect of reducing the size, cost, and complexity of AFDD installations.

8.1.2 Major Manufacturers

Table 8-4 highlights the variety of manufacturers, service providers, and researchers that have developed AFDD systems for RTUs and AHUs. Most systems are designed as add-ons or retrofits to existing building systems, but many RTU manufacturers now offer at least some factory-installed AFDD capabilities in their products to comply with California Title 24-2016 standards.

Table 8-4. System Providers – AFDD Systems for RTUs and AHUs

Company	Product / Service
Many RTU manufacturers	On-board AFDD systems
Emerson	HCBDM
Belimo	ZIP Economizer
Field Diagnostics Inc.	FDSI Insight / Sentinel
ClimaCheck	ClimaCheck
Transformative Wave	Catalyst eIQ
Philips	Teletrol
Effec	EffTtrack
Facility Dynamics	PACRAT
UCtriX	DABO
SkyFoundry	SkySpark
KGS	Clockworks

[32] Katipamula et al. 2016. "Sensors & Advanced Building Controls Project: Task 2: Develop, Test, and Validate Diagnostic and Self-Aware Concepts for Small Commercial Buildings." Presentation to DOE/BTO. February 10, 2016.

Iconics	Energy Analytix
Johnson Controls	Metasys Enterprise
McKinstry	EEM Suite
Ezenics	Optimized Operational Readiness
CopperTree	Kaizen
Cimetrics	Analytika
Virtjoule	Virtjoule

Sources: Katipamula et al. 2016. "Sensors & Advanced Building Controls Project: Task 2: Develop, Test, and Validate Diagnostic and Self-Aware Concepts for Small Commercial Buildings." Presentation to DOE/BTO. February 10, 2016; New Buildings Institute. 2013. "Rooftop Units Fault Detection and Diagnostics – Part of the Evidence-based Design and Operations PIER Program." Prepared for California Energy Commission. March 2013. Available at: https://newbuildings.org/wp-content/uploads/2015/11/RooftopUnitsFDD_FinalResearchSummary1.pdf

The capabilities of available AFDD products can vary substantially, especially since many offerings are customizable to fit the system design, equipment types, and other attributes of the specific building.[33] Table 8-5 highlights some of the capabilities offered by several AFDD systems for RTUs, including those that are basic product capabilities and those premium cost-added features that can be added for the specific application. Discussed above, AFDD products must balance the value that additional features offer with their additional cost and complexity. Some products, such as the Low-Cost SMDS developed by PNNL, offer fewer number of features to lower costs, but can still provide the core functionality necessary to improve maintenance practices and achieve energy savings.

Table 8-5. Example Capabilities of Select AFDD Systems for RTUs

AFDD Capability	FDSI Insight / Sentinel	Clima-Check	Low-Cost SMDS	Low-Cost NILM	Virtjoule
Low Airflow	O	O		O	O
Low/High Charge	O	O		O	O
Sensor Malfunction	O	O			X
Economizer Fault	O	X			O
Compressor Cycling	O	O	O	O	O
Excessive Operating Hours	O	O	O		O
Performance Degradation	O	O	O	O	O
Insufficient Capacity	O	O	O		X

33 Katipamula, Srinivas, and Michael R. Brambley. 2005a. "Methods for Fault Detection, Diagnostics and Prognostics for Building Systems – A Review Part I." International Journal of Heating, Ventilating, Air Conditioning and Refrigerating Research, 11(1):3-25. Pacific Northwest National Laboratory, Richland, WA. Katipamula, Srinivas, and Michael R. Brambley. 2005b. "Methods for Fault Detection, Diagnostics and Prognostics for Building Systems – A Review Part II." International Journal of Heating, Ventilating, Air Conditioning and Refrigerating Research, 11(2):169-188. Pacific Northwest National Laboratory, Richland, WA.

Incorrect Control Sequence	O	O		O	O
Lack of Ventilation	O				X
Excess Outdoor Air	O	X			X
Control Problems	O	O			O
Failed Compressor	O	O		O	O
Stuck Damper	O	O			X
Slipping Belt	O	O			O
Leaking Valves	O	O			X
Failed Unit	O		O	O	O

Note: O represents basic product capability X represents premium product capability
Source: New Buildings Institute. 2013. "Rooftop Units Fault Detection and Diagnostics – Part of the Evidence-based Design and Operations PIER Program." Prepared for California Energy Commission. March 2013. Available at: https://newbuildings.org/wp-content/uploads/2015/11/RooftopUnitsFDD_FinalResearchSummary1.pdf

AFDD vendors offer a variety of hardware, software, and services to their customers, similar to EMIS vendors. Hardware typically includes one or more sensors (wired or wireless) and communication equipment (e.g., WiFi, cellular, Ethernet). Monitoring software may be located onsite or through cloud computing systems. In addition, many offerings include remote monitoring for both the building staff and service provider, and may connect directly to the service technician to expedite the repair process.

8.1.3 Relevant CBI Work and Resources

Various CBI and ET projects have developed and demonstrated AFDD systems for RTUs and AHUs over the last several years. Table 8-6 summarizes CBI's and ET's AFDD-related projects, while Table 8-7 summarizes BTO Emerging Technology Sensors and Controls Projects, which will ultimately support AFDD systems.

Table 8-6. DOE Efforts Supporting Development and Demonstration of AFDD Systems for RTUs and AHUs

Title	Lead Performers	Overview	Report Link
AHU FDD in Small and Medium Sized Commercial Buildings	CBEI-Drexel University, PNNL	Develop and demonstrate cost-effective and VOLTTRON-compatible AFDD for AHUs	Link
Fault Detection and Diagnostics (FDD) for Advanced RTUs	CBEI-URTC, CBEI-Purdue	For advanced RTUs, implement and assess low-cost, embeddable AFDD systems	Link
Pre-Commercial Demonstration of Cost-effective Advanced HVAC Controls and Diagnostics for Medium-size Buildings	CBEI-UTRC	Demonstrate cost-effective, scalable installation of advanced building and HVAC control and AFDD solutions.	Link
Virtual Refrigerant Charge Sensing and Load Metering	CBEI-Purdue, CBEI-UTRC, Lennox	Extend RTU virtual sensor methods for refrigerant charge, cooling capacity, and unit	Link

		power to RTUs having micro-channel condensers	
Demonstrations of Integrated Advanced Rooftop Unit Controls and Automated Fault Detection and Diagnostics	PNNL, Transformative Wave, NorthWrite Universal Devices	Show that integrating advanced controls and AFDD systems could result in significant savings and persistence for RTUs at low cost	Link
VOLTTRON Analytics for RTUs and AHUs	PNNL	Open source algorithms for RTUs and AHUs and also automated continuous commissioning algorithms for AHUs; RTU AFDD algorithms meet CA Title 24 requirements	Link

Source: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

Table 8-7. DOE Efforts Supporting Sensors, Controls, and Transactional Networks

Title	Lead Performers	Report Link
VOLTTRON	PNNL	Link
BEMOSS	Virginia Tech Advanced Research Institute	Link
Controls and Communication Integration	LBNL, U.S. India Joint CBERD	Link
Sensors, Controls, and Transactive Energy Research	PNNL	Link
University-Industry-National Laboratory Partnership to Improve Building Efficiency by Equipment Health Monitoring with Virtual Intelligent Sensing	ORNL	Link
Low-cost Wireless Sensors for Building Monitoring Applications	ORNL	Link
Building Re-tuning	PNNL	Link
Smart Buildings Equipment Initiative	PNNL, NREL	Link
Transforming Ordinary Buildings into Smart Buildings via Low-Cost, Self-Powering Wireless Sensors and Sensor Networks	Case Western Reserve University, Cleveland, OH	Link
Retro-commissioning sensor suitcase commercialization pilot project	PNNL, LBNL, ORNL	Link

Source: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

8.1.4 Technical and Market Barriers

AFDDs systems for RTUs and AHUs emerging onto the market today could greatly ease maintenance practices and improve the performance and efficiency of commercial HVAC systems, but several barriers exist before widespread adoption. Table 8-8 highlights several key technical and market barriers.

Table 8-8. Barriers – AFDD Systems for RTUs and AHUs

ID	Barrier	Description
1	Lack of availability and awareness	While several manufacturers and vendors offer AFDD products today, most are not widely available as a simple add-on for most equipment purchases or tune-ups. Many manufacturers, even within California, may not highlight the AFDD features of their products, and may not offer AFDD capabilities in other regions. In addition, HVAC contractors may not be aware of system capabilities or communicate the value of potential retrofit AFDD systems to customers.
2	Difficulty quantifying benefits	AFDD can provide benefits over the life of equipment, but forward-looking energy savings and non-energy benefits are difficult to predict for different equipment types, operating conditions, etc.
3	Lack of understanding of AFDD capabilities	Within the HVAC industry, standard definitions and test methods for various AFDD features are still under development. In addition, building owners and staff have low tolerance for false alarms or frequent faults and may not understand what the AFDD system is providing through faults.
4	Difficulty of integration with legacy systems	Especially for AHUs that operate throughout medium-to-large buildings, the buildings already have some building automation features in place, and integrating with the existing system or adding additional sensors can be difficult in retrofit situations.
5	Perception of high costs	AFDD systems carry steep upfront costs for hardware, software, installation, etc., in the range of several hundred dollars for RTUs, to several thousand dollars for AHU systems. These upfront costs are significant relative to a single service call for maintenance.
6	Limited time and resources for building operators	Especially for small commercial buildings, the transition from seasonal maintenance to periodic monitoring and more intermittent maintenance with AFDD systems adds another responsibility to already limited and stretched resources.
7	Alters traditional maintenance practices	Building owners, maintenance staff, and HVAC technicians are accustomed to the predictability of a seasonal or annual maintenance schedule, and AFDD could alter the timing and scope of maintenance calls significantly. While the net outcome will be beneficial, this still moves building owners and operators out of their established zones of comfort and predictability.
8	Data integration challenges	For many systems, especially those that rely on BAS sensor data, data integration is costly and time consuming, which makes the value proposition much more challenging. Even for

ID	Barrier	Description
		systems that use their own sensors, integrating AFDD output with systems that the building operators already use can be challenging and costly to train operators to consult yet another information system during their daily routine.
9	System Security	Wireless sensor technologies, including those incorporated into AFDD systems, may pose security issues. Some building managers mistrust wireless systems in environments that require extremely high levels of system reliability.
10	Lack of contractor training	Strong contractor engagement is vital to successful deployment of AFDD, but has been lacking in utility efficiency programs. To a great extent, this seems to be due to a lack of training on the technology. Utility efficiency program experience suggests that many lack the technical knowledge to optimally install equipment and guide users on operation. Further, the business model for selling AFDD retrofit equipment is distinct from their normal model of selling equipment and they may also lack the comprehensive understanding of the value proposition to be able to sell the product effectively.
10	Incentive structures	Current downstream (direct-to-customer) incentives are seemingly insufficient to motivate contractors to engage. Their involvement is vital to successful deployment. Midstream- or upstream-rebate delivery channels may be considered to help drive contractor engagement.

Source: Material developed by Navigant, DOE National Laboratory reviewers, and fall 2015 workshop stakeholder participants.

8.1.5 Other Focus Programs and Cross-Cutting Opportunities

In addition to CBI and ET activities, a multitude of researchers, standards organizations, and other stakeholders across the HVAC and commercial building industries have identified the need for widespread adoption of AFDD systems for RTUs and AHUs. The organizations support initiatives to further develop the AFDD algorithms that could be used similar to an application, lower installation cost and complexity, demonstrate AFDD benefits, and incentivize adoption. Table 8-9 highlights some of the organizations and activities that other government and non-government organizations have conducted in support of AFDD for RTUs and AHUs.

Table 8-9. Other Programs Supporting Adoption of AFDD Systems for RTUs and AHUs

Provider	Program Highlights
Universities	R&D for AFDD systems, sensors, and algorithms • Massachusetts Institute of Technology • Purdue University • Texas A&M • University of Nebraska • Drexel University
National Laboratories	AFDD system development and demonstration, with several projects highlighted in Table 8-4 • PNNL • LBNL • National Institute of Standards and Technology • ORNL
Western HVAC Performance Alliance (WHPA)	Developed FDD Industry Roadmap developed by WHPA Fault Detection and Diagnostics Committee
Western Cooling Efficiency Center (WCEC)	University of California Davis WCEC provides support to IOU HVAC Technology and System Diagnostics Advocacy Program and to the WHPA FDD Subcommittee
ASHRAE	• TC 7.5 – The Smart Buildings Technical Committee of ASHRAE is responsible for programs, standards, research, and handbook related to FDD. • SPC 207P– The Standards Project Committee is tasked with developing the “Laboratory Method of Test of Fault Detection and Diagnostics Applied to Commercial Air Cooled Packaged Systems” • SSPC 90.1 – The Mechanical Subcommittee RTU Working Group has been focused on RTU issues as they relate to the 90.1 Standard • SSPC 189.1 – This standard for high-performance buildings could be a tool for disseminating information about FDD and encouraging adoption • Guideline 36P – High-Performance Sequences of Operation for HVAC Systems
California Energy Commission Electric Program Investment Charge	• Title 24-2016 building energy codes require RTUs >4.5 tons to have AFDD systems covering airflow, economizer operation, and sensor failure. • Automated HVAC FDD Commercialization Program ○ Project team works with major manufacturers to develop systems and controls

Provider	Program Highlights
	○ Includes field demonstrations to document energy performance and cost advantages of the systems ○ HVAC FDD Tool marketed by Architectural Energy Corporation was demonstrated at UC and CSU sites
California IOUs	California Investor-Owned Utilities (IOUs) conduct research into energy efficiency issues through field studies, support for emerging technologies, and other activities, and promote adoption through incentive programs and stakeholder outreach.
IEA Annexes	The International Energy Agency has sponsored a set of research programs or annexes to develop, implement, and test FDD algorithms
ESource	ESource has conducted a review of program participation for advanced RTU controllers to elucidate specific barriers to the adoption of these controllers in utility service areas.

Source: WHPA. 2013. "Onboard and In-Field Fault Detection and Diagnostics—Industry Roadmap." Western HVAC Performance Alliance. July 10, 2013. Available at: http://www.performancealliance.org/Portals/4/Documents/CommitteeWorkspace/AFDD/WHPA%20Fault%20Detection%20and%20Diagnostics%20(FDD)%20Roadmap.pdf

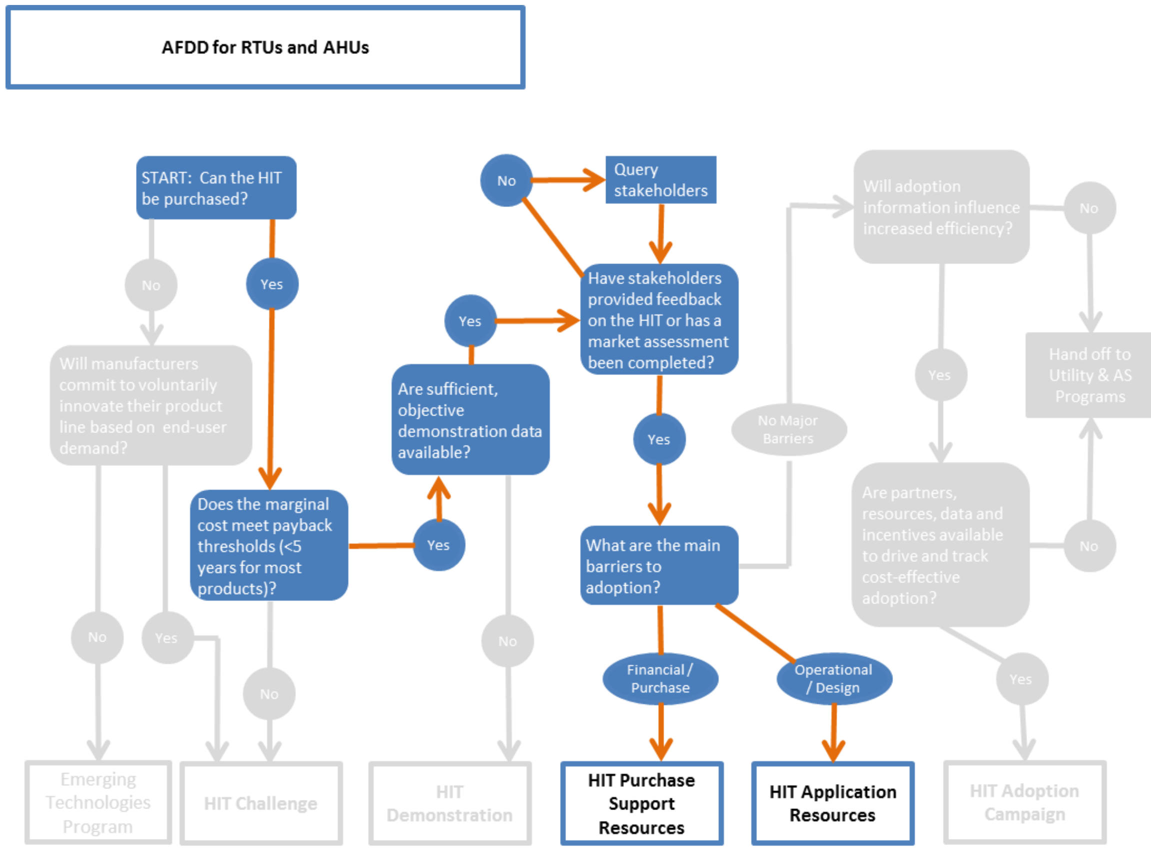
8.2 Market Transformation Goals and Timeframe

CBI will coordinate with utilities, professional societies, industry groups, and other stakeholder organizations to develop procurement and best-practice guidance for use by building owners and operators. Deployment through trusted channels will drive market uptake by end-user organizations. CBI plans to focus on the consolidation and development of application resources through FY 2018 and will collect and deploy additional new real building demonstration performance information as that becomes available or as late as 2019. DOE will track uptake and usage of new resources and information based on efficiency program participation and best practices as supplied by building owners, designers, and other stakeholder partners. If, in its ongoing evaluation of the market conditions and adoption, CBI determines that there is an opportunity to further accelerate market transformation for RTU/AHU AFDD, CBI will evaluate possible options and initiate support as appropriate.

8.3 Market Transformation Activities

Figure 8-1 shows the planned market transformation pathway for AFDD systems and controls for rooftop AC units and AHUs.

Figure 8-1. Pathway for AFDD for RTUs and AHUs



Source: Figure developed by Navigant based on DOE internal strategy.

To help focus CBI efforts, DOE may explore bringing together a group of stakeholders as part of a new AFDD-focused working group. This may include key stakeholders involved in efficiency program implementation and contractor training programs, among others. A key topic for discussion is workforce development and training approaches via contractor unions, nationwide associations, and other groups. Lack of engagement from contractors is sufficiently vital to AFDD deployment for focused dialogue on the topic. This working group can also be a forum for discussion of the other challenges to help guide CBI efforts.

The market assessment for this technology has shown that other key barriers lie in the awareness, procurement and integration, and operations spaces, and that major energy savings opportunities can be obtained through proper selection and use of equipment. There are numerous options available to end users, and data supporting the attributes and performance of these options, but little aid available for building owners or operators seeking to select the offering that best suits their needs. CBI will work with building owners, equipment suppliers, and other relevant stakeholders to develop and deploy these resources and demonstration data in the form of an index of available resources, solutions, and accompanying validation data. This activity will help to elevate the level of awareness and education with respect to equipment selection. DOE may also develop supporting application resources, including best-practice materials, to ensure that equipment is utilized to its optimal performance potential once deployed in the field.

DOE will continue to work with the engaged entities listed in Table 8-9. These organizations are well aligned to collaborate on the development and dissemination of useful information developed through the HIT Catalyst to assist large target existing member/customer bases in adopting the best RTU/AHU AFDD solutions for their buildings. Some of these entities may also be positioned to provide incentives to adopters, which will help to hasten large-scale adoption.

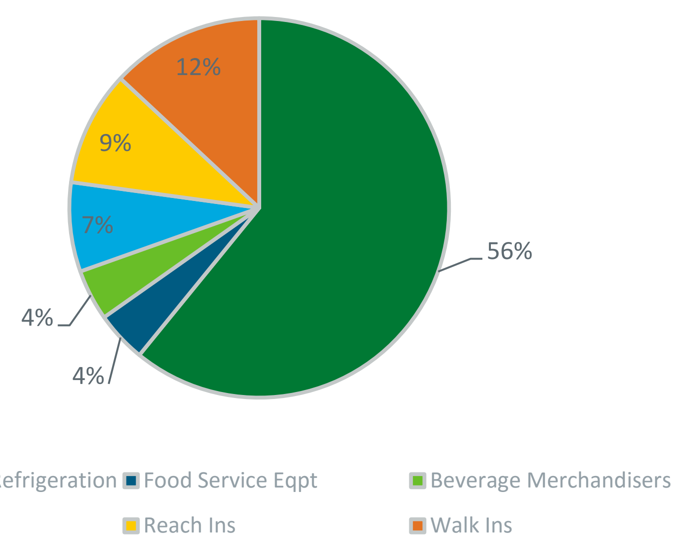
9 Market Transformation Plan – Alternative Refrigerants for Supermarket Refrigeration Systems

9.1 Evaluation of Current Market Landscape – Alternative Refrigerants

9.1.1 Key Sectors and Applications

Several major commercial building types commonly use field-erected refrigeration systems, including food sales (grocery stores, supermarkets, etc.) and food service establishments. A majority of the installed base of refrigeration systems in commercial spaces is in food sales applications.[34] Commercial refrigeration consumes significant energy, making food retail establishments very energy-intensive building types. Annual energy use values range from approximately 100,000 kilowatt-hours (kWh) per year to 1.5 million kWh/year, depending on store size and location. Within those buildings, it is estimated that refrigeration system energy use comprises 30%-50% of the whole-store energy consumption.[35] While commercial refrigeration equipment can be split into several major types, the bulk of the energy use is attributed to supermarket refrigeration. Figure 9-1 shows a breakdown of commercial refrigeration energy use by system type.

Figure 9-1. Commercial Refrigeration Energy Use



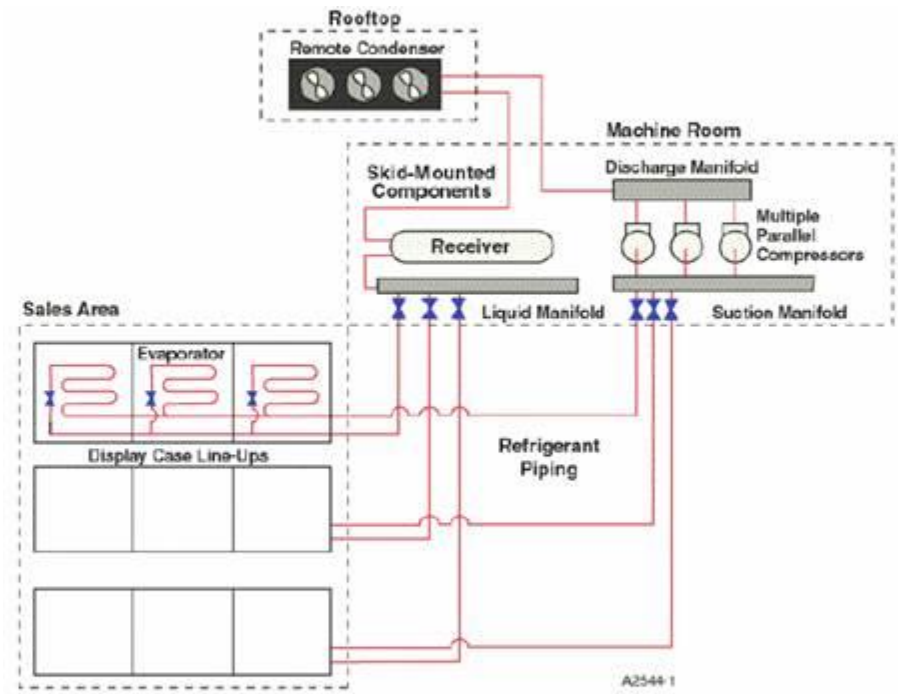
A typical supermarket with roughly 50,000 square feet of floor area uses about 60 display cases to display fresh and frozen food products, which account for between 30% and 50% of the store's total electricity consumption. These cases may be open (typically used for fresh produce, dairy, etc.) or closed (typically used for frozen food). With the exception of some small,

[34] Navigant Consulting. "Energy Savings Potential and R&D Opportunities for Commercial Refrigeration." (2009): US Department of Energy, 23 Sept. 2009. <http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_refrig_report_10-09.pdf>.

[35] ICF International, Revised Draft Analysis of U.S. Commercial Supermarket Refrigeration Systems Available at: https://www.epa.gov/sites/production/files/documents/EPASupermarketReport_PUBLIC_30Nov05.pdf

standalone display cases, a large majority of supermarket cases are remote-condensing units, wherein a bank of refrigerator and freezer units share a common rack of compressors and condensers that distribute refrigerant through the various cases. Figure 9-2 shows a representative schematic of a typical supermarket refrigeration system.

Figure 9-2. Typical Supermarket Refrigeration System Configuration



Source: Image courtesy EPA GreenChill Partnership. http://www2.epa.gov/greenchill/advanced-refrigeration.

The working fluids utilized in the majority of supermarket refrigeration systems today consist of hydrofluorocarbons (HFCs) or blends thereof. These refrigerants are known as third-generation refrigerants,[36] and are not harmful to the Earth's ozone layer, but possess high global warming potential (GWP) values. The arrival of HFCs as the dominant family of refrigerants came about as a result of regulatory action stemming from the need to reduce the emission of ozone depleting substances (ODSs) due to stratospheric ozone depletion identified in the mid-1980s. Within the United States, this mandate was driven by the Clean Air Act, section 612 of which established the U.S. Environmental Protection Agency's (EPA) Significant New Alternatives Policy (SNAP) program, as well as by the inclusion of the United States as a signatory on The Montreal Protocol on Substances that Deplete the Ozone Layer.[37,38]

EPA's SNAP is the governing program which maintains authority over the acceptability of substances for use across a number of end-use applications. These applications include refrigeration, and it was this program that was responsible for the phase-out of the last generation of ODS refrigerants, including HCFC-22. This triggered the transition to the HFC refrigerants

[36] The first generation of refrigerants consisted of volatile fluids such as ethers, alongside some natural compounds such as propane, while the second generation consisted of synthesized fluorochemicals, most notably chlorofluorocarbons.
[37] https://www.epa.gov/snap
[38] http://ozone.unep.org/en/treaties-and-decisions/montreal-protocol-substances-deplete-ozone-layer

used today. However, recently, EPA SNAP has used its authority under the Clean Air Act to initiate further transitions away from substances with high GWP values, the use of which is seen as a secondary consequence of the elimination of ODSs. The most notable SNAP action today has been the publication of a final rule in July 2015 removing a number of high-GWP HFCs, including several commonly used in commercial refrigeration applications, such as R-404A and R-507A, from acceptable use as soon as 2017.[39] More aggressive action has been taken in the European Union, in the form of F-Gas (fluorinated gas) regulations, which will stringently curb the use of HFCs.[40]

The recent regulatory action on high-GWP refrigerants, coupled with an increasingly environmentally conscious consumer base, has motivated equipment manufacturers and store operators to seek lower-GWP alternatives that still allow them to maintain necessary levels of temperature control and energy performance. As such, a number of emerging refrigerants, in different stages of commercialization in the U.S. market, have been identified. These include:

- **Transcritical carbon dioxide:** Carbon dioxide was one of the very first working fluids to be used in a vapor-compression refrigeration cycle, but was largely displaced by synthetic refrigerants with more desirable thermophysical properties. The defining operating characteristic of transcritical CO_2 systems is the high head pressure, more than 1,000 psia, which motivates a need for a robust system architecture including welded steel piping and valves rated for the high pressures encountered. Additionally, head pressures grow significantly at higher heat rejection temperatures, resulting in significant compressor power draw increases in warm climates. This refrigerant is attractive due its heat transfer capacity, low GWP (1, by definition), and widespread availability at high purity. Transcritical CO_2 systems produce large amounts of high-quality waste heat, which can be recovered for use in space-heating and water heating applications. The good low-ambient performance and heat recovery opportunity has made these systems the near standard in northern Europe, with significant market penetration in Canada as well. Transcritical CO_2 is also prevalent in Japan. Within the United States, the first such system was commissioned in Maine in 2013, with additional systems since having been placed in New York, Northern California, and elsewhere.[41,42]

- **Hydrofluoroolefins (HFOs) and HFO blends:** HFOs are a family of synthetic refrigerants which have been under development by major international chemical companies over the past number of years. The most widely known HFOs are HFO-1234yf and HFO-1234ze, which are manufactured and distributed by various suppliers under several different trade names. These substances were developed as substitutes (in some instances, drop-in replacements) for legacy HFC refrigerants and possess GWP

[39] EPA SNAP: "Change of Listing Status for Certain Substitutes Under the Significant New Alternatives Policy Program; Final Rule"
Available: https://www.gpo.gov/fdsys/pkg/FR-2015-07-20/pdf/2015-17066.pdf
[40] European Commission, Climate Action – Fluorinated Greenhouse Gases.
Available: http://ec.europa.eu/clima/policies/f-gas/index_en.htm
[41] DOE Better Buildings Alliance: "Case Study: Transcritical Carbon Dioxide Supermarket Refrigeration Systems"
Available:
http://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Transcritical_CO2_Supermarket_Refrigeration_Systems.pdf
[42] Emerson Climate Technologies: "Commissioning a CO_2 System"
Available: http://www.emersonclimate.com/en-us/About_Us/News/Events/E360-Annual-Conference/Documents/MAGA-Tuesday-1100-Kolstad.pdf

values in the single digits. HFOs are also sold blended, generally with HFCs, producing mixtures that have intermediate aggregate GWP values between those of the pure HFOs and the HFCs, but more closely mimic the thermophysical properties of HFCs than would a pure HFO. These refrigerants have broad application to a wide variety of end uses, including motor vehicle air conditioning, stationary air conditioning, and refrigeration. However, their use to date in commercial refrigeration applications has been limited. In Europe, only a few stores employ HFO systems in customer-facing applications, while in the U.S. market, exploration of these working fluids has been limited to laboratory tests.[43,44,45]

- **Ammonia:** Ammonia has been used in industrial applications such as process chilling and cold storage warehouses for decades. The supplier and technician communities are strong, costs are low, and energy performance is excellent. However, the main deterrent to the use of ammonia is its toxicity, mitigation of which requires implementation of numerous safety measures and clearance of regulatory hurdles. This is amplified in a consumer-facing application such as a retail store. There is an anecdotal aversion to the refrigerant's use in public areas by many in the refrigeration community due to past incidents in industrial settings. One method to minimizing the risk of using ammonia has been to utilize the refrigerant in a "cascade" configuration, in which all of the ammonia is kept outside of the building in a close loop, and a secondary loop (generally of carbon dioxide) is used for the heat transfer out of the store. Ammonia-CO_2 cascade systems have been successfully piloted in several commercial settings in the United States, including a grocery store in California and a commissary on a U.S. Air Force base in Texas.[46,47]

No single, clear, long-term solution has yet emerged for the U.S. market. Different retailers have piloted projects using one or more of these options on the store level, but few large-scale trends have yet become evident. Thus there is room for continued governmental support of the development and deployment of these technologies.

9.1.2 Major Manufacturers

A range of domestic and global manufacturers offer systems or components utilizing alternative refrigerants. Due to the custom nature of supermarket-scale refrigeration systems, the means of sourcing of these systems and their necessary components can vary widely from customer to customer. Typically, larger players in the market provide complete refrigeration systems, engineered on a site-specific basis to fit the customer's needs and including compressor racks,

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[43] *ACHR News*: "Italian Supermarket Claims Big Energy Gains from HFO/CO2 Cascade and Heat Recovery" Available: http://www.achrnews.com/articles/131939-italian-supermarket-claims-big-energy-gains-from-hfoco--cascade-and-heat-recovery

[44] United Nations Environmental Programme: *Low-GWP Alternatives in Commercial Refrigeration: Propane, CO_2, and HFO Case Studies*
Available: http://www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf

[45] U.S. Department of Energy: "Working Fluids: Low Global Warming Potential Refrigerants"
Available: http://energy.gov/sites/prod/files/2014/10/f18/emt13_abdelaziz_042414.pdf

[46] EPA GreenChill Partnership, "Ammonia Cascade Systems"
Available: https://www.epa.gov/sites/production/files/documents/GC_Webinar_AmmoniaCascade_2012.11.15.pdf

[47] EPA SNAP, "Low-GWP Alternatives in Commercial Refrigeration"
Available: https://www.epa.gov/sites/production/files/2015-10/documents/deca_commercial_refrigeration_case_study.pdf

condensers, display cases, and associated controls. These players in turn source from other component-level suppliers.

Due to the prevalence of some kinds of alternative refrigerant technology, particularly transcritical carbon dioxide, in Europe and Asia, manufacturers from these regions possess significant technical knowledge bases that they have begun to export to the North American market. This has been accelerated by consolidation and acquisition within the industry. Advansor, a Danish company and major supplier of transcritical carbon dioxide systems in Europe, was acquired by Hillphoenix in 2011, and their technology has been implemented in numerous North American installations (many in Canada) in the time since. More recently, Hussmann, a major domestic refrigeration equipment manufacturer, was acquired by Panasonic in late 2015. Given Panasonic's longstanding experience with transcritical carbon dioxide refrigeration in Japan and other Asian markets, coupled with the increased interest in the technology in the United States, it would seem likely that that this acquisition could result in technology transfer to the domestic market in the foreseeable future. Within North America, Carnot Refrigeration, a Quebec-based company, has made significant inroads in the Canadian grocery market, and began placing systems in the United States in 2013.

Table 9-1 lists major suppliers within the alternative refrigerant supermarket system market. These include manufacturers of components, entire systems, and the refrigerants utilized in those systems.

Table 9-1. Major Industry Players – Alternative Refrigerant Systems

Company	Products	Sectors	Target Markets
Hillphoenix	Compressor racks, condensers, display cases, integrated systems,	Commercial	Global – domestic focus
Emerson Climate Technologies	Compressors, refrigeration controls	All	Global
Hussmann*	Compressor racks, condensers, display cases, integrated systems	Commercial	Global – domestic focus
Bitzer	Compressors	Commercial	Global – historical European focus
Danfoss	Compressors, refrigeration controls, refrigeration equipment,	Commercial	Global
Carnot Refrigeration	Transcritical carbon dioxide refrigeration systems	Commercial	North America
Panasonic*	Compressors, condensing units, display cases, integrated systems	All	Global – Asian focus
Honeywell	Synthetic refrigerants, refrigeration controls	All	Global

DuPont	Synthetic refrigerants	All	Global

*In December 2015, Panasonic agreed to purchase Hussmann Corp.; however the company still operates as an independent brand and is thus listed as such here.
Source: Navigant Consulting. "Energy Savings Potential and R&D Opportunities for Commercial Refrigeration." (2009): US Department of Energy, 23 Sept. 2009.
http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_refrig_report_10-09.pdf.

9.1.3 Relevant CBI Work and Resources

Table 9-2 lists CBI activities supporting alternative refrigerants for supermarket applications.

Table 9-2. DOE Efforts Supporting Alternative Refrigerant Systems

Project Title	Report Link
ASHRAE Refrigeration System Commissioning Guide	Link
Hannaford Transcritical Carbon Dioxide Refrigeration Case Study	Link
ORNL: High-Efficiency, Low-Emission Refrigeration System	Link
Grocery Store Advanced Energy Design Guide	Link
Refrigerant Playbook: Natural Refrigerants	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

9.2 Technical and Market Barriers

While new refrigerant options provide promise and opportunity, as with all emerging technologies these are accompanied by barriers. In the case of alternative refrigerants, many of the barriers pertain to the relative newness of the technologies to the U.S. market and the uncertainty surrounding this industry. The technical and market barriers known to CBI are described in more detail in Table 9-3.

Table 9-3. Barriers – Alternative Refrigerant Systems

ID	Barrier	Description
1	Limited number of system and component suppliers	For the refrigerants that are new to the domestic market, most specifically transcritical carbon dioxide and HFOs, the number of suppliers of systems and replacement components is limited, and production volumes are comparatively low. This provides buyers with limited options, constraining their ability to apply price pressure or request specific custom features.
2	Lack of service infrastructure	There is a significant shortage of qualified technicians to service even legacy, established HFC systems. Introduction of new refrigerants heightens this barrier, as existing service technicians do not have experience with the systems, and training services may yet not have developed curricula for use in educating technicians on these emerging technologies.

ID	Barrier	Description
3	First cost	These systems incur a significant first-cost premium over legacy HFC systems. This is due to a number of factors, including low production volume on the supplier side, a need for specialized engineering resources when specifying systems, and inherently costlier componentry within the systems themselves. In industries with extremely low margins and limited operating capital, such as food retail, first-cost sensitivity is high.
4	Prioritization of energy vs. climate impacts	To date, much of the focus on system design within the commercial refrigeration sector has been on improving energy performance. This is due to factors including regulatory pressure, operator economics (energy being one of the largest variable costs in food retail), and the presence of incentives from utilities and other organizations. Climate performance, namely the mitigation of direct impacts due to refrigerant emissions, has been of largely secondary importance.
5	Variability of performance with climate zone (transcritical CO_2)	Due to the very high head pressures inherent in the transcritical CO_2 working cycle, systems utilizing this refrigerant are very sensitive to ambient heat rejection temperatures, with compressor power draw increasing greatly at high ambient temperatures. This has historically made such systems unattractive for warmer climates. While much recent work has been done to improve this performance and systems now being used in warm climates of Southeast Asia and the Mediterranean, more work needs to be done to dispel this longstanding belief regarding poor warm-ambient performance.
6	Regulatory and market uncertainty	The past years have seen a number of changes in the regulatory landscape surrounding refrigeration equipment, both on the energy and GWP impact fronts. Having been affected by multiple rounds of refrigerant transitions and energy conservation standards, operators are seeking solutions with stability and long-term viability. Because no single alternative refrigerant has emerged as the ideal solution, many potential adopters pause for fear of potentially making the “wrong” choice and being saddled with obsolete equipment for a generation.
7	Toxicity concerns (ammonia)	While ammonia is a mature, well-understood refrigerant with a very capable manufacturing and service infrastructure, it is a toxic substance, the use of which to date has been largely in industrial settings. End-users in customer-facing sectors, such as food retail, are highly sensitive to the possible ramifications of potential ammonia discharge, both in terms of health risks to their customers and associated negative publicity.
8	Flammability concerns (HFOs)	HFO refrigerants are classified as ASHRAE designation A2L, meaning that they are mildly flammable with a maximum burning

ID	Barrier	Description
		velocity of less than 10 cm/second. While they are less flammable than refrigerants such as hydrocarbons, use of HFOs still requires that suppliers and end users take additional precautions in the development and operation of systems utilizing these refrigerants. Because HFOs are not yet in widespread use in the United States, implementation of these refrigerants would require the development of established protocols and training relating to their safe use.

Source: Material developed by Navigant, DOE national laboratory reviewers, and fall 2015 workshops stakeholder participants.

9.2.1 Other Focus Programs and Cross-Cutting Opportunities

During the development of this plan, DOE was not able to identify any significant efforts to date by third-party programs (utilities, REEOs, etc.) in studying, promoting, or incentivizing these technologies within the domestic marketplace. There exist manufacturer literature and case studies developed by manufacturers and/or market research firms. However, energy-efficiency organizations and utilities appear to be taking a wait-and-see approach. This also highlights the degree of uncertainty and hesitation in the market surrounding these technologies, and the extent to which independent work by DOE and other parties may be able to aid the market in identifying viable and trusted solutions.

9.3 Market Transformation Goals and Timeframe

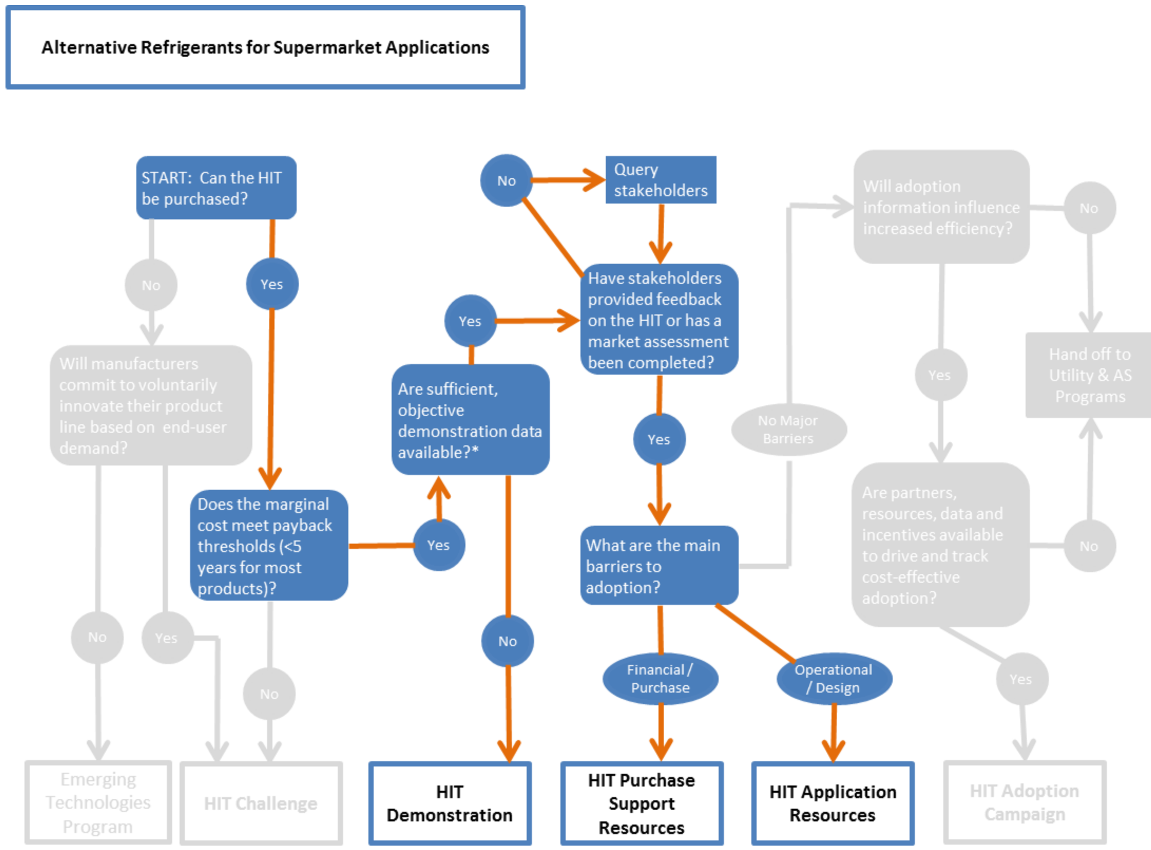
CBI will coordinate with professional societies (such as ASHRAE), REEOs, early adopters, and other organizations to assist in the deployment of materials pertaining to the installation, commissioning, and operation of alternative refrigerant systems. CBI will also continue its ongoing demonstration work, in laboratory and/or field-installed settings as appropriate and applicable. Further down the line, CBI may work with utility incentive programs and other broad-reaching voluntary programs to help drive uptake and acceptance of the technologies.

CBI also plans to maintain an awareness of any developing interagency and intergovernmental activities related to the refrigerants landscape, including any possible action with respect to EPA SNAP or the Montreal Protocol. Should any developments of significance occur, CBI will adjust its deployment trajectory and goals accordingly in line with these additional regulatory changes.

9.4 Market Transformation Activities

Figure 9-3 shows the planned market transformation pathway for alternative refrigerants for supermarket refrigeration applications.

Figure 9-3: Pathway for Alternative Refrigerants



*While preliminary demonstrations and field studies are underway, there is need for additional continuing demonstration data concurrent with the development of purchase and application support resources.

Source: Figure developed by Navigant based on DOE internal strategy.

The market assessment for these technologies shows that the key barriers include the lack of independent field data (or in the case of HFO refrigerants, laboratory data) documenting savings, capital costs, and owner satisfaction; concerns over performance of transcritical systems in warm climates; and lack of available support in the form of qualified technicians and replacement parts. To address these barriers, CBI will continue its work to support independent demonstrations of alternative supermarket refrigeration technologies in both laboratory and field settings, ideally across a range of regions and climates throughout the United States. This may include gathering field performance data to elevate the confidence of building owners, utilities, and voluntary programs in these technologies. DOE will also continue to develop and promote supporting application resources for both engineers, installation and service providers, including best-practice and operations materials, to ensure that equipment achieves its performance potential when deployed in the field. Specifically, through its Tech to Market program, DOE will focus on developing a refrigeration toolkit, containing bundled application resources targeted at potential adopters. Work in this area is multi-faceted and includes:

- expansion of refrigeration system analysis tools to evaluate market adoption scenarios as well as building-level energy impacts
- demonstrations of retrofit and new system refrigerants
- demonstration of refrigeration system analytics and commissioning platforms
- consolidation of existing available resources into one webpage.

As alternative refrigerant performance is verified and begins to gain traction in the market, CBI will seek to partner with other agencies, utilities, REEOs, or voluntary certification programs to drive adoption and track adoption metrics. These organizations are well-positioned to partner with CBI to create this data through existing member and partner bases. These entities are also positioned to provide incentives to members/customers, which will help to lower costs and hasten large-scale adoption.

10 Appendix A: 2015 Market Transformation Plan – Commercial Fans

10.1 Evaluation of Current Market Landscape

10.1.1 Key Sectors and Applications

Fans are used across all sectors of the commercial building industry to provide supply, return, and exhaust air for building ventilation systems. Commercial fans are also used in process-specific applications, such as commercial kitchen exhaust hoods, and as part of cooling towers and air-cooled condensers supporting building HVAC systems. They are also embedded in packaged HVAC equipment such as RTUs, as well as in air-handling units. Ventilation-related energy consumption, of which fan energy is the primary component, accounted for approximately 6% of commercial building energy consumption in 2010.[48] DOE estimates that commercial fans consume 139 billion kWh of electricity annually.[49] There are energy savings opportunities available through improvements in fan selection, fan system design practices, and operational practices. Because fan power decreases as the cube of the operating speed, and the maximum output of a given fan is not necessarily needed at all times of operation, the increased use of speed control has a large potential for energy savings.[50]

10.1.2 Major Manufacturers

The commercial fan market consists of a range of different industry players, from large multinational corporations to very small companies. The market is fragmented and competitive.[51] Fan manufacturers generally consider fans to be commodity items, with some competitive advantages based around durability, support, and fulfillment time, depending on the application.[52] Many manufacturers offer fan selection guides, fan selection software, and/or engineering capabilities to assist customers in making energy-efficient fan selections. Table 10-1 lists some of the major industry players in the commercial space.

Table 10-1. Major Industry Players – Commercial Fans

Company	Link
Acme Engineering & Manufacturing Corporation	Link
American Coolair Corporation	Link
CaptiveAire	Link
Carnes Company	Link
Chicago Blower	Link
Cincinnati Fan	Link
ebm-papst	Link
Greenheck Fan Corporation	Link
Hartzell Air Movement	Link
Howden American Fan Company	Link
Lau Fan (Subsidiary of Ruskin)	Link

48 http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.4
49 NOPD 2011 (Link)
50 *Fan and Pump Systems* ACEEE white paper 2002 (Link)
51 *Fan and Pump Systems* ACEEE white paper 2002 (Link)
52 DOE/AMCA publication: Improving Fan System Performance (2003) (Link)

Company	Link
Loren Cook Company	Link
Morrison Products	Link
New York Blower	Link
PennBarry	Link
Soler & Palau USA Ventilation Systems	Link
Twin City Fan and Blower	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

10.1.3 Relevant CBI Work and Resources

CBI works to support market adoption of high-efficiency commercial fan technologies. Table 10-1 lists some of the efforts in this area to date.

Table 10-1. DOE Efforts Supporting Market Adoption of Efficient Fan Systems

Project Title	Lead Performer	Report Link
Higher Efficiency HVAC Motor Research	QM Power	Link
Improving Fan System Performance: A Sourcebook for Industry	LBNL, Resource Dynamics Corporation	Link
Fan System Assessment Tool	ORNL, AMCA	Link
Advanced Rooftop Unit Campaign	ASHRAE, Retail Industry Leaders Association, DOE	Link
Advanced Rooftop Control Retrofit Field Study	PNNL	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

10.1.4 Technical and Market Barriers

Highly efficient fans are available today for commercial applications; however, they still face significant barriers to adoption. The technical and market barriers known to CBI are described in more detail in Table 10-2Table 10-2 below.

Table 10-2: Barriers – Fans

ID	Barrier	Description
1	Sound level constraints	Commercial applications can have stringent sound level requirements set by building codes, project requirements, or both, especially in facilities such as schools and hospitals. In some cases, a tradeoff must be made between selecting the most efficient fan and ensuring that the system is able to meet these sound level requirements.

ID	Barrier	Description
2	Size constraints	In cases where there is a choice between a larger fan operating at a lower speed using less energy and a smaller fan operating at a higher RPM using more energy, building owners may opt for the smaller fan to decrease the space, weight, and capital cost. This is especially true in replacement and retrofit situations where larger fans that may be more efficient may not fit in the available footprint. Additionally, there may be weight constraints based on the load-bearing capacity of the desired installation location.
3	Suboptimal system design	A fan must work against the system pressure to deliver the desired airflow in a commercial building. Suboptimal system designs not properly tailored to the specific building that they serve lead to much higher pressures than necessary, which in turn lead to fans that consume more energy. These include design practices based on estimation rather than calculation, or utilizing rules of thumb which may no longer be appropriate. Good system designs informed by the latest design practices and tools will enable energy saving fan specifications and installations.
4	Inconsistent installation and maintenance practices	Fan system installation and maintenance and operating practices can have a considerable effect on fan system energy use. Leaky or damaged ducts, clogged filters, or poor system balancing will increase system pressure, resulting in an increase in energy use to maintain the airflow. Loose belt drives or unlubricated bearings will increase the power required by the fan.
5	Upfront cost	The difference in cost between the lowest upfront cost fan options and higher efficiency fan options can be considerable, as the higher efficiency options may be larger fans or more complex styles of fans (e.g., a mixed flow fan instead of a centrifugal inline fan). The upfront cost is a part of the capital budget allocated for the project, which often undergoes strict scrutiny before a project is started. In contrast, longer term energy and operations and maintenance factors are less often considered when deciding whether to move forward with a project.
6	Lack of awareness and information	Lack of awareness and technical understanding, along with lack of access to clear and concise information to drive sound purchasing decisions, are key barriers to adoption of higher efficiency fans.
7	Differing incentives for system designers and owners	Specifying engineers typically define the requirements for equipment in a particular commercial building, often competing for jobs based on first cost. This creates an incentive to design for the lower first cost, which may preclude optimized fan system design for dynamic loads or space conditions. The design of systems for lowest first cost may include added safety factors to lower the risk of missing design requirements due to uncertainties in system design, or in later operation due to fouling effects or future capacity increases.

ID	Barrier	Description
8	Time Investment	System startup, optimization, adjustment, and maintenance can be a time-consuming process. Many site operators have a strong focus on minimizing downtime and installation time, and thus may prioritize having the system running over having it running optimally.
9	Industry inertia	Decades-old rule of thumb fan system design and fan selection practices are still in use in many applications. These practices, including assumed static pressure loss, equal friction method duct design, and fitting loss estimation, overlook efficiency potential from technical improvements and project particulars.

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

10.1.5 Other Focus Programs and Cross-Cutting Opportunities

Table 10-3 summarizes programs that support the market adoption of high-efficiency fan technologies and practices by other organizations outside of DOE.

Table 10-3. Other Efforts Supporting Adoption of Efficient Fans

Provider	Program Highlights	Source
GSA GPG	Conducted field research comparing the installed performance and payback period of cogged V-belts and synchronous-drive fan belts	Link
PG&E	Offers several rebates for fans and fan system measures, including variable frequency drive (VFD) for HVAC fans, specific belt replacements, and certain types of demand control ventilation	Link
Efficiency Vermont	• Offers several rebates for fans and fan system measures, including VFD and ENERGY STAR ventilation fans	Link
Focus on Energy	• Offers several rebates for fan and fan system measures, including demand control ventilation and VFDs	Link
FEMP	• FEMP's Promising Technologies List includes: CAV to VAV installation and auto sash fume hoods	Link
NYSERDA	• Offers incentives for VFDs and demand-controlled ventilation sensors	Link
Air Movement and Control Association, International (AMCA)	• Certified Ratings Program (CRP) assures that a fan product line has been tested and rated in conformance with AMCA International's test standards and rating requirements ○ Certification label on certified equipment and its literature ○ Challenge testing from competitors	Link

Provider	Program Highlights	Source
	• Provides articles, education, and research papers to its members and the public • Maintains and supports industry codes and standards on fan testing and performance ○ Drafted fan performance requirements for ASHRAE 90.1, the IgCC, etc.	
Greenheck Fan Company	Provides in-person, online, and instructor-led courses on fan fundamentals and components	Link
SCE	Field survey of RTU Fan Efficiency and Operation Patterns, 2011-2012 Demand control ventilation for commercial kitchen hoods project	Link Link
PennBarry	Provides how-to guides and in-person training opportunities	Link
Twin City Fan	Provides in-person fan engineering seminars, as well as online fan engineering reference materials	Link
Chicago Blower	Offers onsite in-person seminars as well as a range of online fan engineering materials	Link

Sources: Provided in individual links; table developed by Navigant and DOE national laboratory subject matter experts.

10.2 Market Transformation Goals and Timeframe

CBI will coordinate with utilities, professional societies, industry groups, and other stakeholder organizations to encourage the use of best-practice guidance or procurement specifications by end users. Deployment through trusted channels will drive market uptake by end-user organizations. Potential deployment partners are listed in Table 10-4.

Table 10-4. Potential Fan Deployment Partners

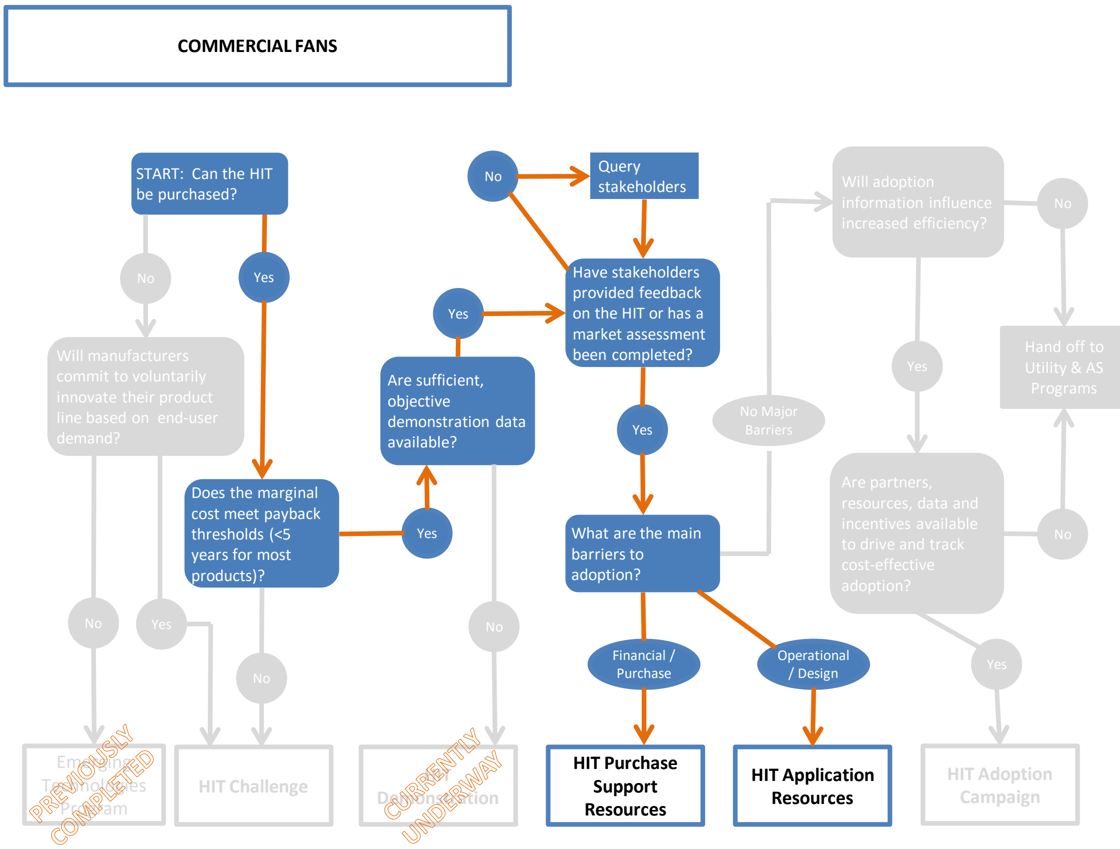
Potential Fan Deployment Partners		
ASHRAE	AMCA	Air Conditioning Contractors of America (ACCA)
State and municipal utilities	Sheet Metal and Air Conditioning Contractors' National Association	AHRI

CBI plans to focus on the development of application and procurement resources through FY 2017 and will collect and deploy new real building demonstration performance information as that becomes available or as late as FY 2018. DOE will track uptake and usage of new resources and information based on efficiency program participation and best practices as supplied by building owners, designers, and other stakeholder partners. DOE will track deployment of real building demonstration data based on the efficiency levels supported by utilities for small fan motor replacements. If, in its ongoing evaluation of the market conditions and adoption, CBI determines that there is an opportunity to further accelerate market transformation for commercial fans, CBI will evaluate possible options and initiate support as appropriate.

10.3 Market Transformation Activities

Figure 10-2 shows the planned market transformation pathway for commercial fans.

Figure 10-2: Pathway for Commercial Fans



The market assessment for this technology has shown that current barriers lie in the procurement and operations spaces, and that major energy savings opportunities can be obtained through proper selection, design, and use of equipment. However, new R&D of fan motor technology will likely drive additional cost-effective savings in upcoming years. CBI will work with building owners, equipment suppliers, and other relevant stakeholders to develop and deploy these resources and demonstration data, helping to elevate the level of awareness and education with respect to equipment selection. DOE will also develop supporting application resources, including best-practice materials, to ensure that equipment is utilized to its optimal performance potential once deployed in the field.

After the HIT Catalyst activities are complete, CBI will hand off the technology support resources to parties that will oversee the next stage of that technology's development and deployment in the marketplace. In the case of commercial fans, the ideal partners for this stage will include REEOs, industry groups, voluntary certification programs, utilities, and federal sector deployment partners. These organizations are well aligned to disseminate the information that CBI will have developed to large target audiences utilizing their existing member/customer bases. Some of these entities may also be positioned to provide incentives to adopters, which will help to hasten large-scale adoption.

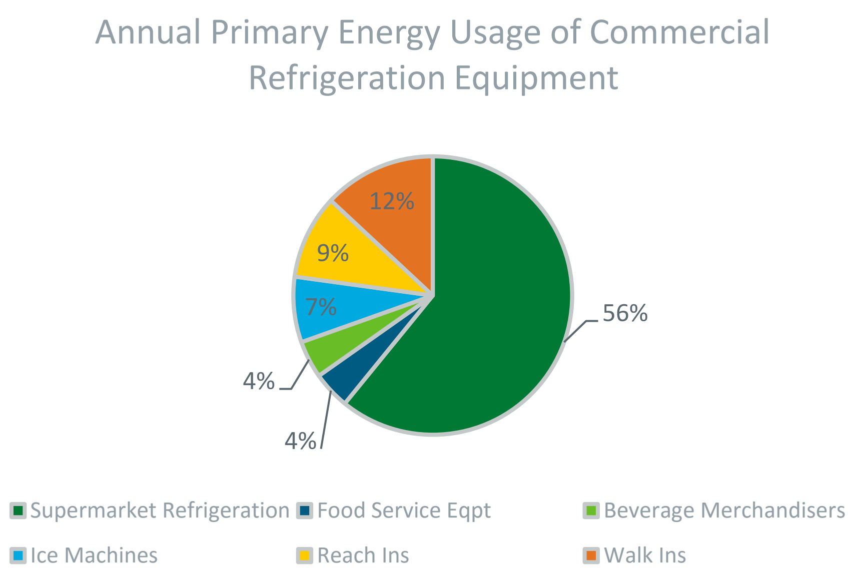
11 Appendix B: 2015 Market Transformation Plan - Refrigeration Controls and Display Case Retrofits

11.1 Evaluation of Current Market Landscape – Refrigeration Controls

11.1.1 Key Sectors and Applications

Refrigeration controls may find application in commercial buildings that use field-erected refrigeration systems, including food sales (grocery stores, supermarkets, etc.) and food service establishments. A majority of the installed base of refrigeration systems in commercial spaces is in food sales applications.[53] Evidence suggests that a majority of new refrigeration systems installed at commercial establishments in the last decade have come with refrigeration controls included in the package. However, the nature of these controls varies widely from simple mechanical control valves to more modern digital and solid state systems.

Figure 11-1. Breakdown of Refrigeration Energy Use

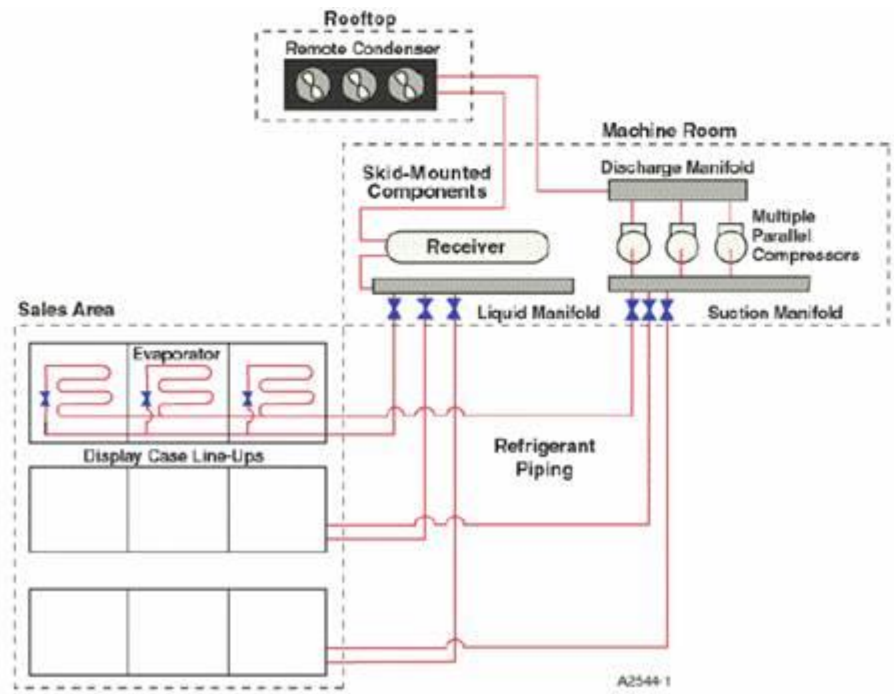


A typical supermarket with roughly 50,000 square feet of floor area has about 60 display cases to display fresh and frozen food products, which account for between 30% and 50% of the store's total electricity consumption. These cases may be open (typically used for fresh produce, dairy, etc.) or closed (typically used for frozen food). With the exception of some, self-contained display cases, and small remote condensing units a large majority of supermarket cases are served by multiplex rack systems. Multiplex rack systems in conjunction with CPU-based controllers provide a desirable matching of refrigeration load and capacity. In a multiplex configuration, typically, a group of un-evenly sized compressor serves medium and low temperature suction groups. For each suction group, a common suction manifold feeds

[53] Navigant Consulting. "Energy Savings Potential and R&D Opportunities for Commercial Refrigeration." (2009): US Department of Energy, 23 Sept. 2009.
<http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_refrig_report_10-09.pdf>.

refrigerant to the compressors. Compressors discharge refrigerant to a common discharge header and then to a large remote condenser.

Figure 11-2: Typical Supermarket Refrigeration System Configuration[54]



A variety of refrigeration control options are available to consumers. The most basic controls for a refrigeration unit make use of a single thermostat within the interior of the case to switch on or off the compressors as needed to maintain temperature. The thermostat controls the discharge air temperature, using a temperature sensor located at the exit of the honeycomb diffuser or discharge plenum. However, this basic system can limit control flexibility and increase energy consumption compared to more advanced systems that map control logic to desired temperature performance and changing conditions. Such basic systems are generally only seen on standalone or self-contained refrigeration equipment. Large multiplex systems use more complex controls. More accurate temperature control may be achieved by using solid-state controlled suction valves, evaporator pressure regulator (EPR), and electronic expansion valves. Adaptive controllers used in conjunction with electronic valves can offer a tight and dynamic operation. The CPU-based rack controllers programmed with adaptive logic and algorithm function as an EMS for the entire refrigeration system. They monitor case load and constantly adjust system parameters, such as superheat temperatures and suction pressures, and accordingly, modulate the operation of electronic valves. CPU-based controllers can also further optimize the efficiency of the system by controlling discharge or head pressures. Several manufacturers also offer speed controllers for evaporator and condenser fans. Evaporator fan controllers slow down or temporarily shut off evaporator fans if they are not required to maintain cabinet temperature. Condenser fan controls allow for variable speed of the condenser fans as needed to maintain the setpoint compressor discharge head pressure.

[54] Image courtesy EPA GreenChill Partnership. Available at: http://www2.epa.gov/greenchill/advanced-refrigeration

Timers, motion controls, and dimmers for display case lighting systems are simple but under-used. These systems are currently available on the market and have significant energy savings potential, especially when combined with LED technology to replace legacy fluorescent lighting. They allow display case lights to be switched off or dimmed automatically based on the time of day, customer proximity, or the ambient lighting level. Display cases also have anti-sweat heaters to prevent condensation from forming on the display case doors, frames, and walls. Monitors and control systems that run these heaters only based on the conditioned space dew point, as opposed to continuously, not only reduce heater electricity consumption by the heaters themselves, but also lower refrigeration electricity consumption, as less heat is emitted into the refrigerated space. Additionally, several products allowing for defrost control are available in the marketplace, with additional R&D underway. Furthermore, refrigerant flow controls, water regulating valves (for systems utilizing water as a heat rejection medium), and refrigerant leak detection systems may also be deployed.

11.1.2 Major Manufacturers

A range of domestic and global manufacturers offer refrigeration controls. Typically, larger players provide complete refrigeration systems. Over the last decade, controls have increasingly been factory-installed with new refrigeration units and compressor racks. As such, many independent manufacturers of controls—such as Carel—typically produce equipment that refrigeration system manufacturers rebrand and offer either as a part of a new refrigeration system or as a retrofit through their dealer network. Due to the lack of standardization in this market, consumers may often purchase controls through the same vendor as the compressor racks and/or display cases.

Table 11-1: Major Industry Players – Refrigeration Controls

Company	Products	Sectors	Target Markets
Johnson Controls	Refrigeration and air conditioning controls	All, but predominantly commercial	Global, strong U.S. focus
Honeywell	Refrigeration controls	All	Global
Emerson Climate Technologies	Refrigeration controls, liquid line filters and driers, compressors for refrigeration units	All	Global
Carel	Refrigeration controls, humidifiers	Commercial	North America
Danfoss	Refrigeration controls, compressors, refrigeration equipment, HVAC equipment	Commercial	Global
GEA Refrigeration Technologies	Refrigeration controls, compressors, HVAC equipment	Commercial	Global, very strong Europe/SE Asia presence

11.1.3 Relevant CBI Work and Resources

Table 11-2 lists CBI activities focusing on refrigeration controls.

Table 11-2: DOE Efforts Supporting Market Adoption of Refrigeration Controls

Project Title	Report Link
Refrigerated Display Case Controls (Webinar)	Link
ASHRAE Refrigeration Systems Commissioning Guide, contains information on setting up and commissioning refrigeration systems with controls	Link
Grocery Store Advanced Energy Design Guide	Link
Commercial Buildings Resource Database - Commercial Building Partnerships	Link

11.1.4 Technical and Market Barriers

The market for refrigeration control systems has grown quickly, and most new refrigeration system installations now include a variety of controls. Even so, consumers face barriers to adoption. The technical and market barriers known to CBI are described in more detail in Table 11-3.

Table 11-3: Barriers – Refrigeration Controls

ID	Barrier	Description
1	Compatibility and interoperability	Often controls are sold as Original Equipment Manufacturers (OEM)-branded products along with refrigeration systems. Adding or replacing controls as part of a retrofit or specifying controls separately from refrigeration racks can result in compatibility issues between the various pieces of equipment. Further complicating the issue is an absence of standardized communication protocols in this space.
2	Downtime	In some cases, adding controls to existing units requires refrigeration systems to be shut down for the duration of the installation. Any downtime presents a significant barrier for consumers. Downtime also can risk perishable products if those products are not relocated.
3	Quantification of benefits	Owners and designers may find it difficult to evaluate the actual energy and cost savings that would result from installing refrigeration controls on a refrigeration system. While substantial academic literature is present, this material is often not presented in a manner in which the key takeaways are easily accessible to consumers. Furthermore, cost savings and project economics can vary significantly depending on site-specific factors.

ID	Barrier	Description
4	Settings & optimization	The optimization of refrigeration control settings for energy savings and performance requires trained technicians to monitor and periodically refine each setting.
5	Lack of applicable information	Designers find it hard to obtain and compare quantitative data on specifications, costs, and complete product information regarding controls systems. Typically, refrigeration equipment manufacturers provide turnkey systems with embedded controls. Furthermore, these systems are usually custom-built for a given user and application. This makes it very difficult for widely applicable and publicly available information to be developed and disseminated.
6	Capital cost	The cost of installing refrigeration controls includes not just the cost of the control systems and associated hardware, but also technical experts to evaluate, install, and monitor the equipment. Capital costs may be prohibitive, especially for small grocery store owners.
7	Complexity	The number of products, control schemes, configurations, and interactivity levels available on the market can be confusing and intimidating for prospective adopters. This may lead to suboptimal system implementation or decisions not to utilize advanced controls at all.

11.1.5 Other Focus Programs and Cross-Cutting Opportunities

Table 11-4 provides a snapshot of some of the programs and activities that support market adoption of refrigeration controls.

Table 11-4. Other Efforts Supporting Adoption of Refrigeration Controls

Provider	Program Highlights	Source
PG&E	• Refrigeration Rebate Catalog for businesses includes refrigeration control systems. • Focus on adaptive refrigeration controls.	Link
SMUD	• Energy Efficiency Measures Demonstrations for Refrigeration Controls. • Incentives covering up to 80% of installation cost.	Link
Baltimore Gas and Electric	• Small Business Energy Solutions program provides refrigeration measures and financial incentives up to 80% of refrigeration control retrofits for customers who have billing demand of 60 kW or less.	Link
Connecticut Light and Power	• Small Business Energy Advantage Program offers an energy assessment, and incentives for control retrofits.	Link

Provider	Program Highlights	Source
SCE	• Existing Building Direct Install Program provides consultation with an energy efficiency contractor to recommend refrigeration upgrades, including appropriate controls.	Link
Arizona Public Service (APS)	• Express Solutions program offers incentives of up to 90% of project costs for refrigeration upgrades including controls.	Link

11.2 Evaluation of Current Market Landscape – Open Case Retrofits

11.2.1 Key Sectors and Applications

Most of the more than 37,000[55] supermarkets and grocery stores in the United States use vertical, open display cases for fresh produce and dairy, in addition to other refrigerated beverages and products. These cases typically come in a range of standard integral lengths, between 8 and 12 feet long and featuring 3 to 5 decks for product display. Cases are often connected without internal partitions, forming a long, continuous bank. These banks of cases are generally served by a remote-condensing unit that supplies liquid refrigerant and discharge waste heat to the ambient environment.

Open cases have no physical barrier between the refrigerated space and the store ambient air. Hence, they not only require more electricity to maintain temperatures than doored cases, but also affect the energy usage needed for space conditioning. It is estimated that a little over 10%[56] of the current installed base of commercial refrigeration cases are of the medium-temperature, open type. To save energy and cut costs, stores may choose to install transparent doors on existing open cases. DOE estimates that door retrofits on existing open cases will save between 50% and 80%[57] of system electricity consumption, not including any savings in space conditioning energy use. Additionally, this technology incurs additional non-energy-related benefits, such as increased product lifetimes due to tighter temperature control.

11.2.2 Major Manufacturers

Display case door retrofit hardware is produced by a wide variety of small and large manufacturers. The market can be divided into two broad segments: 1) refrigeration system and display case OEMs that also market door retrofit components, and 2) third parties such as door manufacturers and retrofit kit manufacturers and contractors. Table 11-5 lists the major U.S. manufacturers of door retrofit systems.

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[55] "Supermarket Facts." *Food Marketing Institute*. <http://www.fmi.org/research-resources/supermarket-facts>.
[56] [56] Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment; Final Rule, 79 FR 17725 (March 23, 2014) (codified at 10 C.F.R. 431.66)
[57] Navigant Consulting, Inc. "Guide for the Retrofitting of Open Refrigerated Display Cases with Doors." November 2012, Updated June 2013. Better Buildings Alliance, Buildings Technology Office, US Department of Energy. <http://www1.eere.energy.gov/buildings/commercial/pdfs/cbea_open_case_retrofit_guide.pdf>.

Table 11-5. Major Industry Players – Door Retrofits

Company	Products	Sectors	Target Markets
REMIS	Retrofit Kits	Commercial	United States
Hillphoenix	Display Cases, Doors, and Retrofit Kits	Commercial	Global
Anthony International	Doors and Retrofit Kits	Commercial	Global
Hussmann	Display Cases, Doors, and Retrofit Kits	Commercial	Global

11.2.3 Relevant CBI Work and Resources

BTO has supported a range of efforts to help inform potential adopters of open case retrofit technology. Table 11-6 summarizes some of the most relevant activities supported by CBI and the BBA Team for open case door retrofits.

Table 11-6. DOE Efforts Supporting Market Adoption of Door Retrofits

Project Title	Report Link
Guide for Retrofitting of Open Refrigerated Display Cases with Doors	Link
Open Case Retrofit Savings Case Study: Fresh & Easy	Link
Open Case Retrofit Savings Calculator	Link
Door Retrofits for Open Display Cases: Webinar	Link
Grocery Store Advanced Energy Design Guide	Link
Case Study: Walmart — Saving Energy, Saving Money Through Comprehensive Retrofits	Link

11.2.4 Technical and Market Barriers

Many large grocery and multi-line retain chains have already started chain-wide installations of door retrofits for open cases and are minimizing the number of open cases in new installations. Even so, there remains a significant installed base of open cases with a large associated energy savings potential. Open case door retrofit technology is mature, and thus significant technical barriers are not often cited. Instead, the major remaining barriers to mass adoption are market-focused. A summary of these barriers is provided in more detail in Table 11-7 below.

Table 11-7. Barriers – Open Case Retrofits

ID	Barrier	Description
1	Initial Cost	While the lifetime energy cost savings from door retrofits typically exceed the installation costs, some operators—often small chains with limited budgets—are deterred by the high initial cost of installing door retrofits.
2	Performance Concerns	Due to the lack of standardization, both for installation and for measurement of savings, some owners have achieved energy savings that are lower than expected.
3	Concerns Over Impacts on Sales	Some supermarket operators believe that installing glass doors on open cases will make merchandise less visible and less accessible to customers, thereby affecting product sales. This belief lingers despite the fact that some studies have shown the sales impact to be minimal or even positive, particularly when considering the value of conserved energy.[58]

Sources: Table developed by Navigant and DOE national laboratories, and fall 2015 workshops stakeholder participants.

11.2.5 Other Focus Programs and Cross-Cutting Opportunities

Table 11-8 provides a snapshot of the programs and activities that support the adoption of open case door retrofits.

Table 11-8. Other Programs Supporting Adoption of Open Case Retrofits

Provider	Program Highlights	Source
AVISTA Utilities	• EnergySmart Grocer Rebate including a rebate of $85/linear ft. for retrofit door installations.	Link
Bonneville Power Administration	• EnergySmart Grocer Rebate including a rebate of $60/linear ft. for retrofit door installations.	Link
PG&E	• EnergySmart Grocer Rebate including a rebate of $70/linear ft. for retrofit door installations.	Link
SCE	• Express Energy Management Solutions incentives, offered to consumers planning to install retrofit doors, as well as those who have done so recently	Link

[58] *ASHRAE Journal*, "Doored Display Cases – They Save Energy, Don't Lose Sales". Fricke, Brian A. and Bryan R. Becker. September 2010.

11.3 Market Transformation Goals and Timeframe

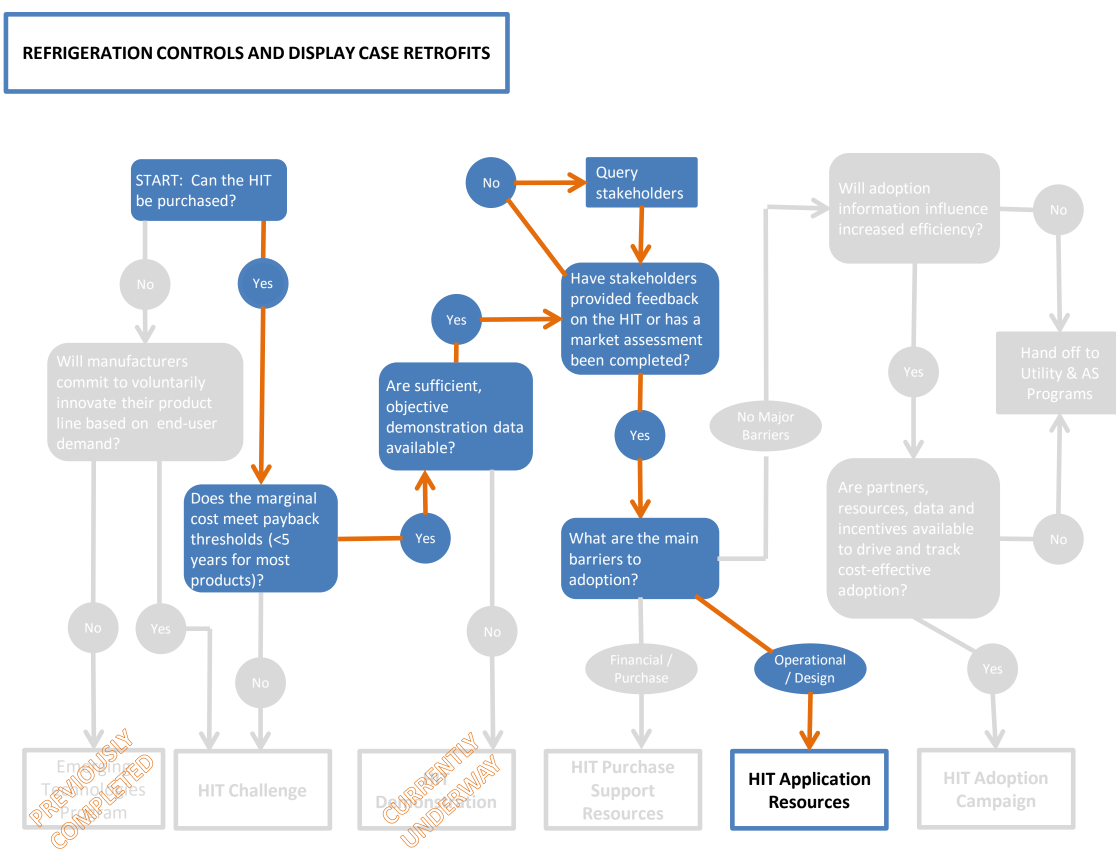
CBI will coordinate with utilities, REEOs, professional societies (such as ASHRAE), and other organizations to assist in the deployment of refrigeration controls and display case door retrofit technologies through voluntary programs and/or certification. Utility incentive programs will influence retrofit and technology adoption decisions. Including these technologies within well-respected voluntary programs will help broaden outreach and acceptance of the technologies.

CBI plans to continue its current market stimulation activities in 2016. These activities will include creation of a refrigeration toolkit through the Tech to Market program, publication of demonstration results where appropriate, further deployment of the ASHRAE commissioning guide, and, as applicable, partnering with incentive or voluntary certification programs to develop data to support the expansion of efficiency programs.

11.4 Market Transformation Activities

Figure 11-3 shows the planned market transformation pathway for refrigeration controls and open case door retrofits.

Figure 11-3. Pathway for Refrigeration Controls and Display Case Retrofits



The market assessment for these technologies shows that the key barriers include the lack of independent field data documenting savings, capital costs, and owner satisfaction; information overload; and operational issues. The lack of field data is particularly evident with respect to control technologies, where it is exacerbated by the extremely high amount of variation in the marketplace. To address these barriers, CBI will work to incorporate refrigeration controls as part of parallel EMIS work with building owners, equipment suppliers, and other relevant stakeholders. Activities may include gathering field performance data to elevate the confidence of building owners, utilities, and voluntary programs in these technologies. DOE will continue to develop supporting application resources, including best-practice materials, to ensure that equipment achieves its performance potential when deployed in the field.

CBI seeks to partner with utilities, REEOs, or voluntary certification programs to drive adoption and track adoption metrics. These organizations are well-positioned to partner with CBI to create this data through existing member and partner bases. These entities are also positioned to provide incentives to members/customers, which will help to lower costs and hasten large-scale adoption.

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