Northeast Energy Efficiency Partnerships

Emerging Technologies Incremental Cost Study Final Report

prepared for

Northeast Energy Efficiency Partnership

energy & resource solutions

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Contents

About NEEP and the Regional EM&V Forum

REGIONAL EVALUATION,
MEASUREMENT & VERIFICATION FORUM

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate energy efficiency in the building sector through public policy, program strategies, and education. Our vision is that the region will fully embrace energy efficiency as a cornerstone of sustainable energy policy to help achieve a cleaner environment and a more reliable and affordable energy system.

The Regional Evaluation, Measurement and Verification Forum (EM&V Forum or Forum) is a project facilitated by Northeast Energy Efficiency Partnerships, Inc. (NEEP). The Forum's purpose is to provide a framework for the development and use of common and/or consistent protocols to measure, verify, track, and report energy efficiency and other demand resource savings, costs, and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and the Mid-Atlantic region.

Energy & Resource Solutions (ERS)

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ERS was founded in 1995 to provide energy efficiency services and over the past 19 years has developed a consulting practice focused on energy efficiency, renewable energy, and emerging technologies. With offices in Massachusetts, Maine, Connecticut, New York, Texas, California, and Oregon, our staff of more than ninety professionals includes professional engineers, certified energy managers, and LEED-accredited professionals. ERS is involved in many diverse activities, including engineering analysis and modeling of energy efficiency measures, program process and impact evaluation, and program planning and delivery.

Final Report – Emerging Technologies Incremental Cost Study

Acknowledgments

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1 Executive Summary

This report presents the results of research and analysis of estimated incremental costs, including labor costs where appropriate, of several emerging technology categories. Efficiency program administrators rely on estimated and reported incremental costs for efficient technologies, compared with appropriate baselines, to assure that cost-effective technologies are supported. This provides value for the ratepayers as well as program participants.

1.1 Introduction

Northeast Energy Efficiency Partnerships (NEEP), and in particular the Evaluation, Measurement and Verification Forum (EM&V Forum or the Forum), has in the past produced several incremental cost reports for efficiency measures that are typically supported with efficiency program incentives. This report differs significantly in that it focuses primarily on technologies that have been identified as potential efficiency measures and have not yet been adopted as program-supported measures. Some of the technologies have been introduced to the marketplace recently, while others are still in pilot or research and development phases.

The Forum's member organizations have long offered residential and commercial sector energy efficiency programs. Many of these programs are recognized as "best practice" programs that are transforming markets and significantly reducing energy demand and consumption. However, the program administrators are fully aware that efficiency efforts cannot be stagnant. As markets are transformed, best practice becomes standard practice and new technology and programmatic developments offer new opportunities. This study provides solid incremental cost data for the studied technologies that can be used to support the introduction of innovative measures that are anticipated to be included as standard program offerings in the near future. It also demonstrates approaches that are useful for predictive estimations of incremental costs for technologies that have not yet reached full market status.

Although this study's focus is clearly on costs, the research team learned a great deal regarding technical aspects of the researched technologies, and that information is included in this report in order to assist in decision making regarding the inclusion of emerging technologies in efficiency program offerings.

Summary data is presented in this document. In addition, a set of worksheets accompanies this study and presents the data collected, the time frames, and the analysis details.

1.1.1 Study Methodology

The study team adopted a diverse set of strategies for estimating incremental costs that would likely be encountered as the technologies became more widely available. The strategies varied with the market status of each category, the willingness of market actors to share data, and the complexity and variability of installations. Recognizing these challenges, subject matter experts were engaged to perform the research, rather than utilizing general research staff. The researchers were all degreed engineers with expertise in the particular end-use category and exceptional industry contacts. In addition, the NEEP staff engaged subject matter experts from the study sponsor efficiency programs who were best able to provide data and industry contacts.

In addition to gathering hard data, the study team used professional judgment to interpret cost estimates gathered from market actor interviews. As many of the technologies covered have not yet come to market, or are in early market stages, interviewees were at times reluctant to provide cost information for competitive reasons, and/or were unable to predict the final cost to the end user once the products were introduced through distribution chains.

1.1.2 Regional Approach

The sponsor organizations for this study implement efficiency programs throughout the Northeast and Mid-Atlantic states. A regional approach is economical for the sponsors and also facilitates a wide range of input from program implementers and evaluators. The technologies selected represent their interest and intentions regarding future program prescriptive and custom measures. However, most if not all of the technologies covered are appropriate for gas and electric efficiency programs throughout the US and elsewhere. Other regional efficiency organizations are encouraged to work with NEEP to help keep this information current, and/or to broaden the technology coverage.

1.1.3 Use of this Study

This study is intended to be useful for many purposes, including program planning; cost-effectiveness testing; program evaluation; technology research; technical resource manual development; customer and market actor outreach; etc. The study strived for cost accuracy at the time of publication. However, some costs were changing even as final edits were being made. Given the nature of emerging technologies, costs should be updated frequently. It is also recognized that there will often be regional differences in project costs due to various market forces, including differences between rural and urban markets, and the experience of market actors, especially installers, with similar emerging technologies. Costing services such as RSMeans (https://www.rsmeans.com/) can be helpful in identifying regional differences in project costs.

1.2 Researched Technologies

NEEP assembled a project advisory committee with representatives from the sponsoring electric and gas efficiency programs that serve the majority of territories throughout the Northeast and Mid-Atlantic regions. ERS consulted with the advisory committee and NEEP staff to select technology categories that were identified as fitting into one or more of the following categories:

- Technologies approved for pilot programs
- Technologies considered for custom incentives
- Replacement technologies for measures transitioning to standard practice
- Technologies that promise wide market appeal
- Measures that may assist in reaching underserved markets

The selected technologies were then prioritized into two groups of five technology categories through a consensus process conducted with the advisory committee. The decision was made to research and report on the five priority technologies prior to making a final decision on the level of effort to place on lower-priority technologies. The final ten selected technologies are presented in Table 1-1, with brief descriptions following the table.

Table 1-1. Researched Technology Categories with Summary Incremental Cost Information

		Sector			Application*				
	Technology	RES	C&I	Category Range	NC	R	Approximate Incremental Cost	Report Section	Notes
1a	VRF heat pump – A/C	x	x	Multi-split and VRF systems – Single-family residential, multifamily, and small commercial units ≤ 16 ton	x		Variable from approximately $1,500 to $6,000 per ton - plus an additional 17% for cold climate performance	3.1	Single zone mini-split systems are covered in earlier NEEP incremental cost studies
1b	Multiple-zone variable capacity HP – modulating compressors	x	x		x			3.1	
2	Advanced LED lighting controls		x	Fixtures with integral controls and control systems designed for LED	x	x	Highly variable	3.2	Typically priced on a building area basis
3a	Home energy management products	x		"Smart" hubs and dedicated energy-impacting devices; appliances with communication capability for energy savings; power strips with logic beyond master/controlled operation	x	x	Highly variable cost, from $9 for "smart" lamps to $200+ for major appliances	3.3	Often referred to as "smart" products, the home energy management products category focuses on products with energy saving or load-shifting capabilities.
3b	Tier 2 power strips	x			x	x	$30-$70 depending on # of outlets and control features	3.3	
4	Advanced/ultra-high efficiency rooftop packaged A/C (SEER >18)		x	CEE size categories ≤ 65,000 Btu/hr and 65,000 to 135,000 Btu/hr include current packaged high efficiency units (15–18 SEER)	x		$360–$560/ton capacity	3.4	Limited reseach as deemed not cost-effective in the study region
5	Integrated heat pump multi-system thermostatic controls	x	x	Controls that are capable of controlling hp and additional heating system(s) typically via an interface with "smart" thermostats	x	x	$365–$660 per control	3.5	Ductless mini-splits are now controlled seperately from other heating systems, preventing automatic sequencing.
6	Advanced compressors for commercial refrigeration		x	Supermarket refrigeration systems for new construction of reconfiguration of existing systems	x		Highly variable from 0-55%	3.6	Current retrofit market dominated by compressor rebuilding and the retrofit of controls
7	Automatic compressed air system diagnostic monitoring		x	Focus on systems communicating with dashboard	x	x	Fullly installed cost; typical systems average $7,500–$17,500	3.7	Industrial measure – large savings potential
8	Improved HP water heaters	x		Residential systems offering higher-than-typical COPs at ambient temperatures below 68°F	x	x	$1,000–$2,100 compared with electric storage water heaters	3.8	Many heat pump water heaters as currently configured do not perform well in cool basements
9	Natural gas heat pump water heaters		x	Large-capacity commercial industrial systems	x	x	$176.50/MBtu/hr and $276.50/MBtu/hr	3.9	Limited market activity; commercial, municipal, and multifamily, large DHW loads
10	Q-Sync motors for evaporator fans (proprietary QM Power product)	x	x	Limited sizes and applications, further products under development; current market focus is small refrigeration fan motors	x		Estimated at $120–$230 for typical installed project cost	3.10	Proprietary - one supplier to date; currently available on a pilot basis - UL approved for some sizes

* Application: NC = New construction and end-of-life replacement; R = Retrofit applications

1.3 Technologies 1a and 1b – Residential and Commercial Variable Capacity and Variable Refrigerant Flow Air Source Heat Pumps and A/C

Inverter-driven air source heat pumps and air conditioning (A/C) systems utilize a variable frequency drive (VFD) to modulate the compressor output to match changing demand. Variable refrigerant flow (VRF) systems also utilize an inverter-driven compressor, but additionally have the capability to modulate the flow of refrigerant to each individual fan coil within the building. Some VRF systems also have the ability to provide simultaneous heating and cooling across zones through heat recovery at a central distribution point. This study covers inverter-driven multiple-zone systems for residential and small commercial applications, as well as VRF systems that have the capability of simultaneous heating and cooling. Single-zone "mini-split" heat pumps were included in earlier NEEP studies.

1.4 Technology Category 2 – Advanced LED Lighting Controls

Advanced LED lighting controls have the capability of responding to multiple signals in order to turn lighting off, and/or to dim lighting. Although there is no established industry definition, this study defines an "advanced" LED control system to be one that allows the use of a minimum of three of the following control strategies: occupancy sensing, daylight harvesting, task tuning, networking, and individual addressability (the ability to control single lights independently of the other lights in the zones).

1.5 Technology Category 3a & 3b – Home Energy Management Products and Smart Thermostats

Originally proposed as two categories, home energy management products, such as hubs that control lighting and other devices and smart thermostats, have been combined into one category, as they share many features. Furthermore, smart thermostats are beginning to be marketed as devices with the ability to control more than HVAC systems. In addition to thermostats and lighting products, tier-2 advanced power strips for plug load control and remote-controllable major household appliances are included.

1.6 Technology Category 4 – Advanced Rooftop Air Conditioning Units with SEER Ratings of 18 and Above

Rooftop air conditioning units (RTUs) are the most common systems for the conditioning of commercial buildings. Improved compressor, fan motor, evaporative coils, and control strategies have allowed the efficiency of these units to improve significantly over the last several years. Major manufacturers are now developing/introducing RTUs that represent the next step up in efficiency.

1.7 Technology Category 5 – Integrated Residential Multi-System Heat Pump Controls

This category includes controls that can be utilized to thermostatically control two heating systems – a heat pump and a furnace, boiler, or electric resistance – in order to maximize overall performance. Although heat pump manufacturers have been working on thermostats with this capability, their focus has now shifted to interfaces that allow existing "smart" thermostats such as Nest and Ecobee to control multiple heating sources.

1.8 Technology Category 6 – Advanced Compressors for Commercial Refrigeration

This category addresses improvements and alternatives to the centralized direct expansion (DX) systems that are used to provide cooling for nearly all grocery stores, supermarkets, and other commercial refrigeration applications in the United States. DX systems use a refrigerant vapor expansion/compression (RVEC) cycle to directly cool the supply air to the space. It is the same basic technology as that used for standard air conditioning systems. Advanced refrigeration compressor solutions are now available that offer efficiency improvements, reduced refrigerant leakage, and alternative refrigerants with lower greenhouse gas (GHG) impacts compared with standard practice equipment.

1.9 Technology Category 7 – Advanced Compressed Air Diagnostic Monitoring

Advanced compressed air system diagnostic monitoring is an industrial measure with large savings potential. While there are multiple compressed air diagnostic monitoring solutions available, the emerging technology option that this study focused on includes systems that communicate with a dashboard visible by either the company providing the service, the client, or both. These systems can automatically determine and adjust the number of compressors and storage tanks (receivers) in a plant that are operating, detect leaks, and improve pressure control through increasing the accuracy of the system pressure.

1.10 Technology 8 – Improved Efficiency Electric Heat Pump Water Heaters

This technology category is focused on residential and small commercial electric heat pump water heaters (HPWHs) that offer improved performance in installation environments that experience ambient temperatures below the standard testing/rating ambient temperature. The manufacturer published efficiency ratings for HPWHs are calculated at an industry standard ambient temperature of 68°F. Below that temperature, the performance deteriorates rapidly for most HPWHs. In the Northeast, most residential water heaters are installed in unheated or semi-heated basements with average temperatures below 68°F.

1.11 Technology 9 – Commercial Natural Gas Engine Powered Heat Pump Water Heaters

Natural gas engine powered heat pump water heaters (GHPWH) are heat pump water heaters that utilize an integral engine to power the system and typically recover heat from engine exhaust to increase operating efficiency. There are a number of different types of systems, including air to air, air to water, water to water, and variable refrigerant flow (VRF) type systems. This study focuses on systems designed to heat large quantities of water for large commercial, industrial, or institutional applications.

1.12 Technology Category 10 – Q-Sync Motors

Q-Sync motors are proprietary synchronous motors manufactured by QM Power. They are permanent magnet synchronous motors that directly utilize utility-supplied ac current. By contrast, synchronous electronically commutated (EC) motors require that the ac current be rectified to dc before it is applied to the motor windings, and rectifying electrical current produces some parasitic losses.

1.13 Summary of Incremental Cost Findings

Emerging technology, baseline, and resulting incremental cost estimates were developed for all of the selected technology categories. There are levels of variability in the estimates dependent upon several factors, including: current market status; market channels; measure complexity; market actor cooperation regarding providing cost information; etc. Table 1-1 above includes an abbreviated summary of the estimated incremental costs. Further incremental cost information is presented in the individual technology sections in this report. Excel workbooks with the data collected for this study are available at http://www.neep.org/initiatives/emv-forum/forum-products.

1.14 Research Challenges

Each technology presented particular challenges described below in summary and detailed within each technology section:

- **Variable capacity multi-split and VRF heat pumps** – According to our research, this is the fastest-growing area of the HVAC market, both in sales growth and competitive options. One manufacturer interviewed said that the market was "changing weekly." Especially in larger sizes, installed cost is highly variable and is highly dependent upon building and project configurations.

- **Advanced LED lighting control systems** – Many different systems with various pricing strategies are entering the market, making it difficult to predict future market directions.
- **Home energy management products** – Thermostats and lighting are now well established with consistent pricing. However the "smart" large appliance market is unstable with products being introduced and then discontinued on a regular basis.
- **Advanced ultra-high efficiency RTUs** – After initial research the advisory committee determined that, for the Northeast, these systems cannot meet program cost-effectiveness requirements. As a result, further research was restricted.
- **Integrated multi-system heat pump thermostats** – Initial research determined that the market direction was trending toward heat pump interfaces that are designed to work with "smart" thermostats and facilitate the control of both the heat pump and an additional heating system.
- **Advanced refrigeration compressors** – This is a complex category with several different control strategies. The study focused on projects that represent alternative system configurations and refrigerant specifications, rather than the simple retrofit of compressor controls.
- **Automatic compressed air diagnostic systems** – With limited and competitive systems, market actors were reluctant to share pricing strategies.
- **Improved heat pump water heaters** – Our research identified a cold climate specification under development by the Northwest Energy Efficiency Alliance that has potential for improving performance in the sponsor territories. Much of the improvement involves control strategies rather than equipment component upgrades.
- **Natural gas heat pump water heaters** – These systems are very rare in the United States and require highly custom installation. Incremental cost needs to be determined on an individual project basis. Since the existence of these systems is relatively unknown by the sponsor organizations, the study focused on technology research while presenting limited cost information.
- **Q-sync motors** – This is a patent-protected proprietary product that is just beginning to be piloted in refrigeration applications. However, preliminary pricing information was provided, as was the pricing strategy of the manufacturer.

2 RESEARCH METHODOLOGY

Emerging technologies require different approaches in order to estimate incremental costs. For mature technologies, research focuses primarily on actual invoices submitted to document successful installation. With truly emerging technologies, these data sets are not available, and therefore other approaches must be adopted. For this study ERS adopted a diverse set of strategies for predicting estimated incremental costs that would likely be encountered as the technologies became more widely available and accepted. The strategies include:

- **Pilot project research** – Some of the technologies are being piloted by efficiency programs, but limited cost data was available.
- **Web research** – Some products such as residential smart hubs and lamps have readily researchable pricing obtainable on the web. However, as is typical of many emerging technologies, the availability of products and the costs are both very volatile. Using multiple online retailers as well as brick-and-mortar retailers with websites, we identified real selling pricing rather than simply manufacturers' suggested retail pricing.
- **Cost service research** – Services such as RSMeans maintain databases of equipment and installation costs. RSMeans proved usable mostly for baseline pricing.
- **Vendor and customer interviews** – Vendor and customer interviews were used to identify real-world installed costs, as well as projected costs for products still in R&D phases.
- **Overseas market investigation** – For products emerging first and/or gaining faster acceptance overseas, markets outside the U.S. were consulted for comparative pricing.
- **Application of product pricing strategies** – When little or conflicting cost data was available we applied market pricing strategies to cross-reference pricing. This included comparing pricing in similar product categories as well as consulting market pricing strategies published by 360pi, a market channel research service.
- **Product cost-effectiveness strategies** – When very little cost data was available, we utilized assumptions regarding energy savings to estimate cost-effectiveness in order to generate reasonable cost predictions based on marketability within the efficiency program space. Historically, emerging technologies in the efficiency and renewable energy fields are often introduced at pricing that is somewhat above a

cost-effective basis, and as the early adopter phase fades, those technologies conform to cost-effectiveness standards to survive. Accepting a loss on these products during the emerging phase is often deemed acceptable. This methodology played a role in estimating costs for Qsync motors as well as heat pump multiple system controls as the market actors reported pricing their products to meet cost-effectiveness and competitiveness requirements during this emerging stage, at times subsidizing their introduction.

Research strategies varied by technology category depending upon market status and the cost data available through conventional research techniques. The strategies employed for each technology category are detailed in Table 2-1.

Table 2-1. Cost Research Strategies by Technology Category

	Technology Category	Program Project Data	Web Based Research	Cost Service Research	Market Actor Interviews	Overseas Market Research	Market Pricing Strategies	Cost-Effectiveness Model
1a	VRF heat pump – A/C	√	√	√	√			
1b	Multiple-zone variable capacity HP – modulating compressors	√	√	√	√			
2	Advanced LED lighting controls	√	√		√			
3a	Home energy management products		√		√			
3b	Tier 2 power strips	√	√		√			
4	Advanced/ultra-high efficiency rooftop packaged A/C (SEER >18)	√	√	√	√			
5	Integrated heat pump multi-system thermostatic controls		√		√		√	
6	Advanced compressors for commercial refrigeration	√	√		√		√	
7	Automatic compressed air system diagnostic monitoring		√		√	√		
8	Improved HP water heaters	√	√		√	√		
9	Natural gas heat pump water heaters	√	√		√	√		
10	Q-Sync motors for evaporator fans (proprietary QM Power product)		√		√		√	√

3 Technology-Specific Estimated Costs and Market Information

The following sections detail this study's finding for each one of the technology categories. This includes baseline identification and costs, emerging technology costs, and the resulting incremental costs. Except for products that are typically end-user installed, the costs include installation costs broken out as appropriate. In addition, we have included the results of limited market research regarding the current market status for each, and have reported on technology cost trends.

Although this study's focus is clearly on costs, the research team learned a great deal regarding technical aspects of the researched technologies, and that information is included in this report in order to assist in decision making regarding the inclusion of emerging technologies in efficiency program offerings.

3.1 Technology Categories 1a and 1b – Residential and Commercial Variable Capacity and Variable Refrigerant Flow Air Source Heat Pumps and A/C

Inverter-driven air source heat pumps (ASHPs) and air conditioning (A/C) systems utilize an inverter and variable frequency drive (VFD) to modulate the compressor output to match changing demand. Variable refrigerant flow (VRF) systems also utilize an inverter and VFD-driven compressor, but additionally have the capability to modulate the flow of refrigerant to each individual fan coil, or indoor unit, within the building. Depending on manufacturer and model, some VRF systems over 10 tons that are designed for commercial buildings with variable conditioning loads offer simultaneous heating and cooling depending on the conditioning demands of the individual zones. Simultaneous heating and cooling is provided through heat recovery (HR) at a refrigerant distribution point, which improves the efficiency of these systems.

The HVAC industry categorizes the different types of HP systems as mini-split, multi-split, or VRF, the differences between which are illustrated and described in Figure 3-1. This study covers multiple zone (multi-split and VRF) HP systems for residential and small commercial applications, as well as VRF systems that have HR capability.

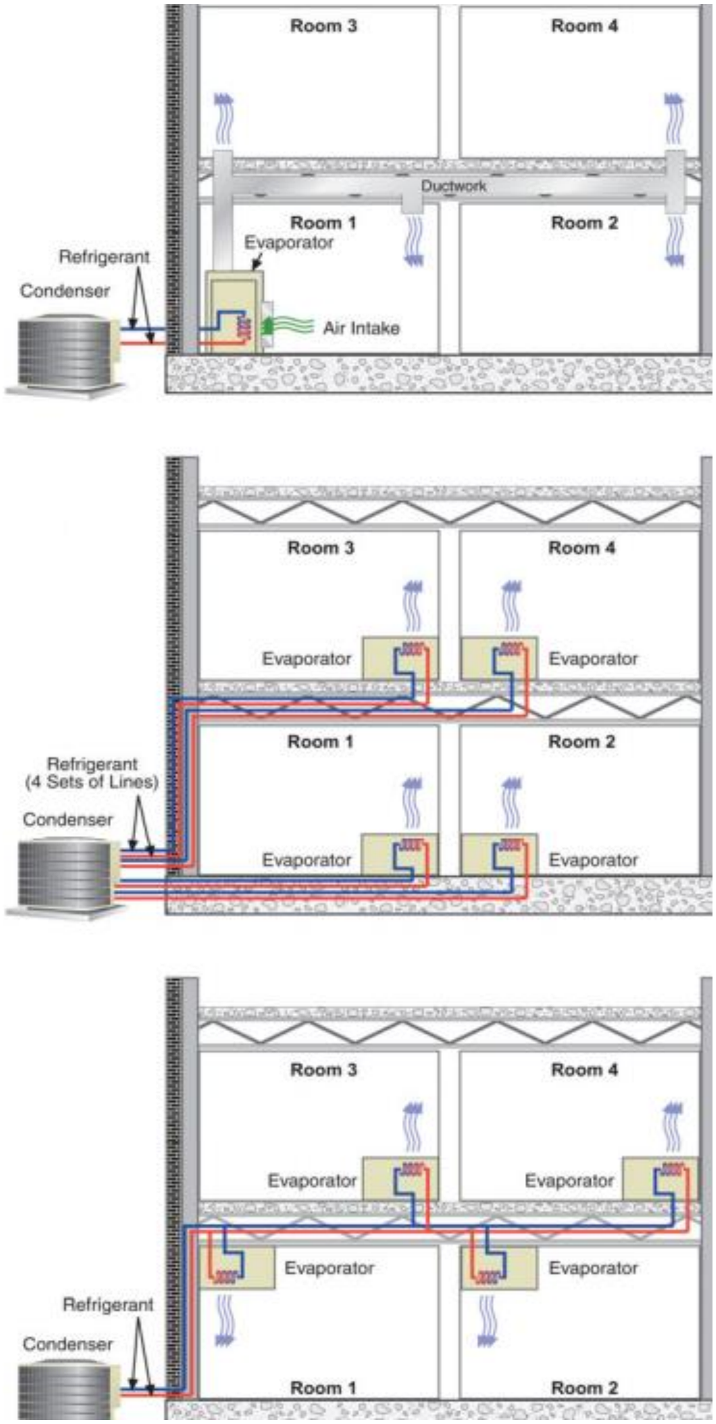
Single-zone mini-split HPs were included in earlier NEEP studies and are not covered in this study[1].

Multiple-zone inverter-driven and VRF systems offer several advantages over standard ASHPs and A/C systems, including the following attributes:

- High efficiency, inverter-controlled compressors
- Individual zone comfort controls
- Potential for HR in buildings requiring simultaneous heating and cooling
- Appropriate for retrofits in buildings without existing ductwork
- Require no ducting in new construction, thus increasing the useable square footage and reducing total installed cost

[1] 2009 KEMA Ductless Mini Pilot Study:
http://www.energizect.com/sites/default/files/Final%20DSHP%20Evaluation%20Report%20ver3%20(2).doc
2012 Northwest Ductless Heat Pump Initiative: http://neea.org/docs/reports/northwest-ductless-heat-pump-initiative-market-progress-evaluation-report-2.pdf?sfvrsn=6
2014 Northeast/Mid-Atlantic Air-Source Heat Pump Market Strategies Report:
http://www.neep.org/sites/default/files/resources/NortheastMid-Atlantic%20Air-Source%20Heat%20Pump%20Market%20Strategies%20Report_0.pdf

Figure 3-1. Schematic of Split, Multi-Split, and VRF Systems[2]



Definitions:

Split system – Single-zone residential-sized split systems served by a single outdoor unit. These systems may use ducts to distribute conditioned air to multiple zones. Or they may be ductless, in which case they are commonly referred to as "mini-split" systems,

Multi-split – Multiple-zone split (sometimes referred to as multi-head) systems for residential and small commercial applications served by a single outdoor unit. Each indoor unit is connected directly to the outdoor unit via refrigerant lines.

VRF – Commercial multiple-zone systems with or without the capability of simultaneous heating and cooling. Each indoor unit is connected to a central refrigerant distribution point that allows variable refrigerant flow to each individual zone.

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[2] ACEEE 2008 proceedings – Variable Refrigerant Flow: An Emerging Air Conditioner and Heat Pump Technology by Amarnath: http://aceee.org/files/proceedings/2008/data/papers/3_228.pdf

Manufacturers we interviewed report that these types of systems are not well suited to large open spaces or big box-type stores. VRF and multi-split HP systems are most effective when installed in buildings with multiple zones with divergent conditioning needs and are especially cost-effective when HR is possible. In buildings with open floor plans and homogeneous heating and cooling demands, there is little opportunity to exchange energy between zones, limiting the HR potential of VRF systems.

3.1.1 Baseline Description

Because multi-split and VRF systems are so versatile, there is a broad range of baseline technologies these systems can replace. Potential baseline systems for multi-split and VRF systems are:

- Packaged, code-compliant ASHP, or AC systems
- Rooftop units (RTUs) with multi-zone VAV and hot water reheat
- Hot water baseboard systems with window A/C units

As a general guideline, the baseline is considered the system that most likely would have been installed without the influence of the incentive program. Following discussions with market actors and efficiency program representatives sponsoring the study, the decision was made to adopt non-modulating code-compliant ASHP systems as the baseline. However, for larger and more complex buildings and systems, both the proposed and baseline systems will be specific to the installation. Incremental cost studies previously completed by NEEP also identified ASHPs as the baseline and provided useful baseline data that helped inform the study.

Although there are practical overlaps, our research confirms that residential system capacities are typically identified as 65,000 Btu/hr (5.4 tons) or less, while multifamily and small commercial systems are rated from 65,000 to 135,000 BTU/hr (11.25 tons), and larger commercial VRF systems are typically rated at up to 192,000 Btu/hr (16 tons). US Department of Energy (DOE) equipment standards and international energy code (IECC) provisions assist in characterizing baseline equipment efficiency. Current standards and minimum efficiency requirements for ASHPs and VRF HPs are presented in Table 3-1.

Table 3-1. Standards and Certifications for HPs and VRF HPs[3]

Split System and VRF HPs			
Standard or Certification	**Residential (<5.4 tons)**	**Small Commercial (5.4 to 11.25 tons)**	**Commercial (11.25 to 20 tons)**
DOE equipment standard	SEER = 13 HSPF = 7.7	EER = 10.8 COP = 3.3	EER = 10.4 COP = 3.2
IECC 2012	SEER = 13 HSPF = 7.7	EER = 10.8 IEER = 11 COP = 3.3 at 47°F COP = 2.25 at 17°F	EER = 10.4 IEER = 10.5 COP = 3.2 at 47°F COP = 2.05 at 17°F

3.1.2 Market Status as of April 2016

Manufacturers and contractors interviewed for this study report that VRF and multi-split technologies represent the fastest-growing segment of the commercial HVAC market. A recent study by Transparency Market Research found that VRF technology is expected to grow at a compound annual growth rate of 5.2% through 2019[4].

VRF and split system HP technologies were first developed and marketed in Asia, and the market is still dominated by Asian companies, such as Mitsubishi, Daikin, Fujitsu, LG, Panasonic, Samsung, and Sanyo, although several domestic manufacturers, including Lennox, Trane, Carrier, and York, have begun to offer similar systems. Indian and Chinese manufacturers also list website availability of these systems, although these are not included in our study because they do not typically meet performance standards established by the DOE, Consortium for Energy Efficiency (CEE), and efficiency program implementers. Research also indicates that they have not gained significant US market share and are not offered by professional HVAC installers.

The major manufacturers have all introduced systems for the residential, multifamily, and small commercial markets, and many anticipate taking advantage of the modular nature of VRF systems to expand into the medium and large commercial markets, where

[3] https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/77
http://publicecodes.cyberregs.com/icod/iecc/2012/icod_iecc_2012_ce4_sec003.htm

[4] The study is discussed here: http://www.prnewswire.com/news-releases/us-commercial-air-conditioning-systems-vrf-market-to-reach-usd-102513-million-by-2019-transparency-market-research-265514851.html, but the actual study can be purchased here: http://www.transparencymarketresearch.com/commercial-air-conditioning-systems-market.html

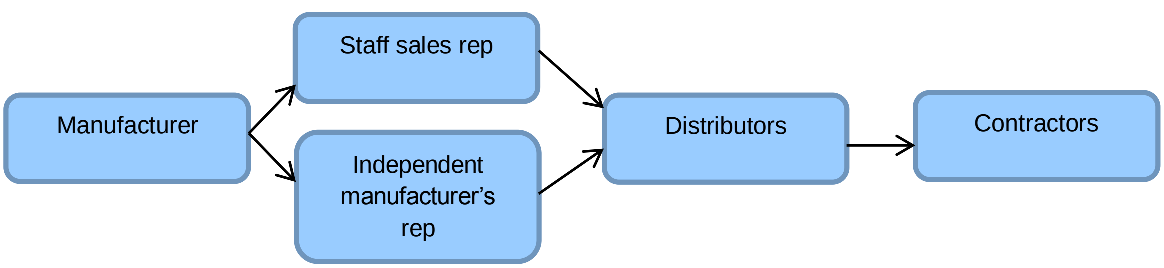
it is anticipated that VRF systems will progressively compete with RTUs in some commercial markets.

The 2014 NEEP Market Strategies Report[5] and interviews indicate that the largest share of the US market is represented by Mitsubishi, Daikin, Fujitsu, LG, Lennox, and Carrier. ERS was able to obtain interviews with four of these manufacturers for this study. There is some understandable reluctance to share performance and market information that might be viewed as challenging to market competitiveness, but in general, market actors provided valuable assistance.

3.1.3 Market Chains Identified

The market chains for advanced heat pumps vary by manufacturer. Mitsubishi does not utilize independent manufacturer representatives in the Northeast, instead relying on staff sales representatives to specify projects with design teams and sell products to stocking distributors. This is in contrast to other manufacturers, such as Fujitsu, that utilize independent manufacturer representatives to market their products to distributors. In either case, contractors purchase equipment from distributors, or for large projects, directly from factory representatives who execute the transaction through distributors. A schematic of the market chains identified is shown in Figure 3-2.

Figure 3-2. Market Chains Identified



3.1.4 Sources of Data

Early data on VRF incremental costs was presented in a 2002 Department of Energy (DOE) publication on emerging HVAC technologies[6], which reported an incremental cost of 5% to 20% compared to chilled water systems with equivalent capacity. This

5 http://www.neep.org/northeastmid-atlantic-air-source-heat-pump-market-strategies-report

6 http://apps1.eere.energy.gov/buildings/publications/pdfs/commercial_initiative/hvac_volume3_final_report.pdf

study was later referenced by several other key studies we reviewed, including a 2007 ASHRAE Journal article by Goetzler, and a 2008 ACEEE article by Amarnath[7]. Additional cost and market data was gathered from a 2012 General Services Administration (GSA) report by Pacific Northwest National Laboratory (PNNL)[8] and a 2011 study for the Bonneville Power Administration prepared by EES Consulting[9].

Other studies contributing data for this report are the NEEP Incremental Cost Study Phase 3 Report[10], the Northeast Mid-Atlantic Air-Source Heat Pump Market Strategies Report[11] NEEP Ductless Heat Pump (DHP) Meta-Study[12], the Efficiency Maine Technical Reference Manual[13], case studies gathered by Energy Management Solutions (EMS)[14], and the California DEER database with associated Southern California Edison Company Work Paper SCE13HC036[15].

Market Actor Installed Cost Data

In addition to secondary research and market actor interviews, we sought and received cooperation from manufacturers, distributors, and contractors in developing incremental installed costs. Four manufacturers and a Massachusetts HVAC contractor provided installed project cost data and participated in follow-up interviews to develop a full understanding of the pricing strategies for purposes of consistency and accuracy. All market actors stress, however, that as the size of the installed systems increases, the installations become more complex and highly customized to the application.

Two of the manufacturers were able to provide installed costs for a set of prototypical scenarios that represent commonly installed zone configurations for the size units. Two other manufacturers provided data in the form of verbal responses on a per-ton basis. A

7 http://aceee.org/files/proceedings/2008/data/papers/3_228.pdf
8 http://www.gsa.gov/portal/mediaId/197399/fileName/GPG_Variable_Refrigerant_Flow_12-2012.action
9 http://rtf.nwcouncil.org/subcommittees/vchp/BPA_VRF_Measure_Report_Final_R1.pdf
10 http://www.neep.org/incremental-cost-study-phase-3-report
11 http://www.neep.org/northeastmid-atlantic-air-source-heat-pump-market-strategies-report
12 http://www.neep.org/ductless-heat-pump-meta-study-2014
13 http://www.efficiencymaine.com/docs/EMT-TRM_Commercial_v2016_2.pdf
14 http://www.emsenergy.com/uploads/pdfs/West-Energy-Management-Congress-VFD-Can-Save-30-of-Your-HVAC-Cost-June-2013.pdf
15 http://www.deeresources.com/index.php/deer-versions/deer-2016/deer2016-technology-costs (login information is required for access)

summary of these costs is provided in Table 3-2. It is notable that the data gathered independently from the manufacturers was surprisingly consistent, particularly for multi-split systems, which helps to validate the data collected.

Table 3-2. Summary of Installed Costs Provided by Manufacturers

Manufacturer	Multi-Split ($/ton)	VRF ($/ton)	VRF w/HR ($/ton)
1	$3,330	$8,800	$10,600
2	$4,000	$5,000	$7,000
3	$3,780	$5,480	$10,330
4	$3,800	$6,120	$8,860

The prototypical costs for Manufacturer 1 are shown in Table 3-3 and give additional detail to the costs shown in Table 3-2.

Table 3-3. Manufacturer 1 Installed Costs

System Type	Size (Tons)	Zones	Installed Cost ($/ton)
Multi-split	1.7	2	$3,750
Multi-split	4.0	3	$2,900
Multi-split w/ cold weather capability	1.7	2	$4,560
Multi-split w/ cold weather capability	4.0	3	$3,290
VRF	N.D.	N.D.	$8,800
VRF with HR	N.D.	N.D.	$10,600

Manufacturer 3 was able to provide costs further broken down by labor and equipment costs, which are shown in Table 3-4.

Table 3-4. Manufacturer 3 Installed Costs

System Type	Tonnage	Zones	Equipment Cost ($/ton)	Labor cost ($/ton)	Installed Cost ($/ton)
Multi-split	3	3	$1,751	$2,028	$3,780
VRF	4	4	$2,811	$2,064	$4,875
VRF	10	6	$2,612	$3,462	$6,075
VRF with HR	16	14	$3,717	$6,612	$10,330

3.1.5 Incremental Costs

End-user installed costs were tabulated from eleven studies and interviews for this study, including the data from the four manufacturers listed above. Several of these sources represent a calculation of VRF and baseline system costs based on other studies and/or summaries of collected case study data. Some of these studies varied greatly in their costs. For example, the CA SCE13HC036 work paper reported installed costs as $2,100/ton, for VRF systems, which is significantly lower than the manufacturer-reported costs, which averaged $6,350/ton. Four outlier data points were excluded from the analysis as they were not consistent with the majority of verifiable data.

In addition, some of the costs were reported on a $/sq ft basis rather than on a $/ton of cooling basis. In these cases, the costs were converted to a $/ton basis by applying a typical industry assumption of 400 sq ft/ton[16]. Sources report that older existing buildings require somewhat more capacity per area, and that recent improvements in higher performance building construction require less capacity per building area. But, all are in agreement that 400 sq ft/ton is the appropriate average for the Northeast climate. The incremental costs were calculated by first summarizing the costs from each source. In some cases, this meant averaging costs among case studies, or several referenced publications, and then averaging the summarized costs together to obtain an overall average per ton. We further investigated referenced studies embedded in specific sources to ensure that an individual data point was not being counted multiple times, thereby skewing the results.

The results of this analysis are shown in Table 3-5.

[16] Interview with Greg Hasselback of Mitsubishi, and data sourced from: http://www.greenbuildingadvisor.com/blogs/dept/musings/calculating-cooling-loads, http://www.sawnee.com/content/hvac, http://www.achrnews.com/articles/86221-rules-of-thumb-for-troubleshooting

Table 3-5. Summary of Installed Costs by Technology

System Type	Average Costs per Ton	Notes
Baseline	$2,270	Average from case study and published data
Multi-split	$3,830	Average from manufacturer data
VRF	$6,640	Average from manufacturer, and secondary data
VRF with heat recovery	$8,600	Average from manufacturer data, and case studies

The resulting estimated incremental costs are presented in Table 3-6. Note that adding HR to a VRF system represents a cost increase of approximately 30%. As presented in Table 3-3, adding cold weather (typically described as full capacity heating below 17°F) capability was found to represent an additional cost of approximately 17%[17] for manufacturers offering this capability. Since not all manufacturers offer this capability, the associated added cost is not included in the overall average or incremental costs. These incremental costs are inclusive of both labor and equipment costs for both the baseline and split/VRF HP technologies.

Table 3-6. Summary of Incremental Equipment and Labor Cost by Technology

System Type	Incremental Costs per Ton	Cold Weather Performance
Multi-split	$1,460	$2,090
VRF	$4,370	$5,500
VRF with heat recovery	$6,330	$7,790

Labor costs were not separately identified for all sources, but the average of two key sources indicated that the installation cost for VRF systems is $2,160/ton. Interviews and literature indicated that labor costs will be highly dependent both on geographic location and building type.

Market actor interviews indicate that the biggest factors affecting installation costs are:

[17] The 17% cold weather adder was calculated from the difference in manufacturer quotes for identical systems with and without cold weather capabilities.

- The familiarity/experience of the contractor with the installation of multi-zone ductless heat pump systems. It is reported that installation labor time is reduced significantly with system experience. Efficiency Maine reported that installation times have been reduced significantly in their multifamily DHP program as the result of a limited number of contractors installing multiple systems.
- The number of zones per ton of the system being installed increases the labor and miscellaneous materials costs.
- The type of indoor fan coil units installed. It was reported that surface-mounted wall fan units (cassettes) are easier to install than ceiling or floor units and result in less disruption that might require carpentry skills to complete a successful installation.

3.1.6 Cost Trends

All manufacturers interviewed reported that over the past year, prices for all larger multi-zone DHPs have been coming down due to increased competition. They predict that this trend will continue, with 5% to 15% further reduction predicted over the next 1 to 2 years before stabilizing. It was noted that to remain competitive in a market with low gas prices, system costs must remain reasonable and the advantages of cooling and heating with a single system need to be emphasized. Additional factors that were cited as contributing to recent and current cost reductions include:

- Contractors' increasing familiarity with the installation of heat pump systems.
- Heat pump manufacturing transitioning from overseas to domestic production.
- Advancements in the combination of ducted and ductless heat pump systems.

3.1.7 Additional Market Insights

Although the study focus was on incremental costs, the interviews gathered additional market insights that are potentially helpful to program planners, as follows:

- DHPs including VRF systems represent the fastest-growing segment of the HVAC industry but currently are only a very small portion of the total industry (approximately 3% based on a 2014 IHS study[18]).

[18] https://technology.ihs.com/527236/does-the-vrf-market-in-the-united-states-deserve-the-buzz

- The largest potential market for VRF systems is seen to be colder climate zones where increasing cold weather capabilities will enable market penetration.
- The high cost of electricity versus the low cost of natural gas has depressed heat pump sales in recent months.
- Multi-zone DHPs and the soon-to-be-introduced "micro-VRF" systems[19] are seen as growth areas.
- One of the incremental cost drivers identified was the use of flared connections in multi-split systems versus brazed connections for VRF systems. Brazed connections are more expensive due mostly to labor costs, but are more durable than flared connections. This is seen as an important consideration, as properly brazed connections will prevent inadvertent refrigerant leakage that mechanical flared connections are prone to.

The most significant barriers currently preventing larger DHP systems from becoming more widespread were identified as:

- The cost premium of these systems and the need for incentives.
- Lack of public and contractor knowledge of how heat pump systems operate and the benefits they provide.
- The US legacy of ducted systems, which is ingrained through manufacturers and their support of traditional HVAC approaches.

3.2 Technology Category 2 – Advanced LED Lighting Controls

Advanced LED lighting controls have the capability of responding to multiple signals in order to turn lighting off and/or to dim lighting. Based on discussions with Gabe Arnold (Manager of the NEEP/DesignLights Consortium [DLC] Lighting Controls Project), ERS is considering an "advanced" LED control system to be one that allows the use of three overlapping control strategies – at a minimum occupancy sensing, daylight harvesting, and task tuning – along with networking and individual addressability (the ability to control single lights independently of the other lights in the zone). Many advanced LED controls come with more features than just the minimum features described. Multiple sources showed a wide array of different advanced LED control features available in

[19] Residential multi-zone DHPs that include the heat recovery functionality of larger VRF systems.

today's marketplace. The features listed in Table 3-7 were found by researching the DLC and MassSave Networked Lighting Controls qualified products lists, Internet research, and conversations with key market actors. This is not an exhaustive list, but it contains features that are found in multiple product lines.

Table 3-7. Identified Advanced LED Control Features Available on the Market

Advanced LED Control Features Available on the Market
Zoning – reconfigurable with layering
Occupancy sensing
Daylight harvesting
Task tuning
Continuous dimming
Autonomous/distributed processing scheduling
Luminaire integration
Scheduling
Personal control
Load shedding/demand response
Plug load control
EMS/BMS integration
Energy performance monitoring
Device monitoring/remote diagnostics
Operational and standby power
More than 150 fixtures controlled
Automatic demand response capability
Ability to modify operating schedules for fixtures within each zone via internal and external means (software interface, web, smartphone, etc.)
Ability to modify time delays and operating schedules for occupancy sensors within each zone via the software interface
Display near real-time status of the lighting fixtures (i.e., on, off, dimmed mode) on a floor plan

3.2.1 Baseline Description

The relevant state's energy code for commercial buildings is considered to be the applicable baseline for projects that would trigger code, as is the case in new construction and some renovation projects. NEEP keeps an updated listing of applicable lighting codes in each Northeastern state on their website[20]. For most code jurisdictions,

[20] http://www.neep.org/initiatives/energy-efficient-buildings/codes-tracker

occupancy/vacancy sensors or scheduling controls are required for most office and educational type spaces, with automatic daylight sensors required for some specific daylit zones.

For the incremental costs calculated in this section, baselines were often already included in the project documentation and thus baseline values were not determined separately in order to find the incremental cost. For example, a number of projects reviewed retrofit advanced controls onto existing lighting fixtures. In this case, the baseline is considered the preexisting condition. Another scenario showed the cost of an adequate but less advanced system on the invoice for the advanced LED controls. In this case, the less advanced, project-specific alternative that was considered on the invoice was used as the baseline cost from which incremental cost was calculated. On a per-fixture basis, the baseline would be the same light fixture that is used in combination with the advanced LED controls, without the controls.

3.2.2 Sources of Data

We conducted Internet research, looked at advanced LED controls projects previously reviewed by ERS, communicated with other ERS staff who have recently attended related conferences or who have been involved with advanced LED control projects in the recent past, and completed five interviews with key market actors and manufacturers about their product offerings and general sense of the advanced LED marketplace. Unfortunately, none of the manufacturers provided equipment and installation invoices for past projects. We collected rough estimates of cost from these interviews and project-specific cost information from already installed projects in order to validate the cost estimates provided by the manufacturers and ensure accurate cost reporting. Manufacturers generally reported that they initially estimate control system costs on a per-square-foot basis. The cost information that manufacturers provided includes cost per square foot, percentages of total project cost for commissioning, cost of integration with other systems, and material cost, along with the total cost of a system.

Additionally, ERS reviewed one study[21] that focused on the cost-effectiveness of a variety of lighting control strategies over a 10-year period, and another[22] that discussed

[21] Sanders, Dane and Chinnis, Darcie. “Wireless Lighting Controls: A Life Cycle Cost Evaluation of Multiple Lighting Control Strategies.” Prepared by Clanton & Associates, Inc. for Daintree Networks.

advanced LED control cost trends. ERS also reviewed the DLC's draft qualified product list requirements for advanced LED control features, the qualified products list for the MassSave Networked Lighting Controls, and the Sacramento Municipal Utility District's Advanced Lighting Controls (ALC) program requirements for features that are required by these programs in order to be considered a qualified product.

3.2.3 Market Status as of April 2016

Advanced LED controls are readily available and have penetrated roughly 2% of the market, according to L.J. Eldredge, an advanced LED control subject matter expert at ERS. ERS has reviewed a number of projects with advanced LEDs controls installed. As shown below, these products were available on the market 3 or more years ago.

3.2.4 Product Lines

We investigated twenty-one different product lines from twenty different manufacturers to determine whether each product's control system qualifies as advanced control. Table 3-8 includes a number of leading products on the market, although it is not meant to be a complete list of all advanced LED control products available at the time of this writing.

[22] Rubinstein, Francis. "Wireless Advanced Lighting Controls Retrofit Demonstration." Prepared for the General Services Administration by the Lawrence Berkeley National Laboratory.

Table 3-8. Advanced LED Control Products

Manufacturer	Product Name
Cree	Smartcast
Plimoth Bay Controls, LLC	SunSense
Lutron	Quantum
Osram Sylvania	Encelium
Enlighted	Enlighted Room Control
Philips	Dynalite
Cooper Controls	Fifth Light
Autani, LLC	LightCenter
Acuity	nLight
legrand	WattStopper
Digital Lumens	LightRules
Daintree	ControlScope
Dimonoff Inc	Lite node
Delta Controls	DDM-880, DLC-G1212, DLC-Pxxxx
Exergy Controls	XRG-1000
Fulham Controls	ROOM SOLUTION
Eaton Cooper Industries	Metalux Encounter
Eaton Cooper Industries	Sky Ridge LEDs
Dialight	SafeSite
Philips	Spacewise
Crestron	Crestron Lighting Control & Fusion

3.2.5 Market Chains Identified

ERS identified two product categories available in today's marketplace for advanced LED controls: fixtures marketed to end users with integrated controls, and networked lighting control systems that are marketed for their features and which can be installed with a variety of fixture types. The fixtures with integrated controls are typically marketed through normal lighting distribution chains, while networked lighting control systems are more often specified by factory representatives and are incorporated into project designs by lighting designers and/or electrical engineers.

3.2.6 Incremental Cost

As mentioned, the interviews provided a variety of different presentations of cost information, which included percentages, price ranges, and general prices per square foot. Applying a degree of professional judgment, we used only invoiced or quoted costs of actual installed projects for calculating incremental costs. See Table 3-9 for the pricing information collected through manufacturer interviews and project document reviews. Manufacturers were understandably reluctant to release individual project information.

Table 3-9. Cost Information from Manufacturer Interviews

Cost	Amount	Description	Notes	Source	Date
Incremental	$15-20	Incremental cost/fixture for manufacturer to add adv. LED ctrls	High estimate. Likely to decrease w/ volume increase. Value confirmed below.	Interview with Manufacturer A	Nov 2015
Incremental	$50-75	Incremental cost to add advanced LED controls to fixtures in the field	≈3x the cost to integrate controls into the fixture at the manufacturer	Interview with Manufacturer A	Nov 2015
Incremental	65%	Estimated incremental cost of an advanced LED control solution	50% material cost, 10-15% labor cost	Interview with Manufacturer A	Nov 2015
Full	$250	Full cost of installing adv LED ctrl solution in private office	Likely around 200 sq ft	Interview with Manufacturer B	Nov 2015
Full	$50,000–$200,000	Cost of installing adv LED ctrls in typical commercial office space	Varies based on finished desired and many other factors	Interview with Manufacturer B	Nov 2015
Full	$500,000	Price of an adv LED ctrl solution for 10 story commercial office building	Estimated, not based on specific project data	Interview with Manufacturer C	Nov 2015
Full	$5,000	Price/room of installing adv LED ctrls in 80 rooms in healthcare facility, with identical operation in each room	Commissioning is simpler when all rooms operate identically.	Interview with Manufacturer C	Nov 2015
Full	$6,000–6,500	Price/room of installing adv LED ctrls in 80 rooms in a healthcare facility, treating each room individually.	Incremental price/room of individual operation is ≈$1,250 per room compared to identical operation of all rooms.	Interview with Manufacturer C	Nov 2015
Full	10%	Percent of project cost that typically goes to commissioning and setup	Commissioning will be required with any adv LED ctrl solution	Interview with Manufacturer C	Nov 2015
Full	25-35%	Percent of project cost that for integration with other systems	For retrofit or new construction scenarios with different brands of equipment	Interview with Manufacturer C	Nov 2015
Full	$1.50/sq ft	High bound of advanced LED control solution	Includes 1 day of commissioning and 1 day of end user training.	Interview with Manufacturer C	Nov 2015
Full	$1.10-$1.20	Average cost per square foot of advanced LED control solution	Includes 1 day of commissioning and 1 day of end user training.	Interview with Manufacturer D	Dec 2015
Baseline	$0.90	Cost of a minimally code compliant solution supplied by Manufacturer D	Estimated, not based on specific project data	Interview with Manufacturer D	Dec 2015
Incremental	$16.88	Cost/fixture to add adv LED ctrls to LED troffer at the time of manufacture	Installation was in a conference room in an office building in California	Invoice for 535 sq ft room w/ 8 fixtures.	Oct 2015

Cost	Amount	Description	Notes	Source	Date
Full	$257.63	Cost/fixture of LED troffer with an integrated adv ctrl solution	Total fixture cost including control. Installation was in a conference room in an office building in California	Invoice for 535 sq ft room w/ 8 fixtures.	Oct 2015
Incremental	$0.25	Cost per square foot of advanced LED control solution	Installation was in a conference room in an office building in California	Invoice for 535 sq ft room w/ 8 fixtures	Oct 2015
Incremental	$1.36/ sq ft	LEDs with advanced controls compared to T5HO baseline	Part office space, part manufacturing. Baseline used was alternative proposal	Project documents from study sponsor	2013
Incremental	$2.34/ sq ft	Incremental cost of adding advanced LED ctrls to current system	This is for a large office building. Baseline is current system.	Eversource	Oct 2015
Incremental	$3.55/ sq ft	Cost to add advanced LED controls to existing fixtures	Large office building in NYC. Baseline is current system.	ERS project document review	2015
Incremental	$2.89/ sq ft	Cost to add advanced LED controls to existing fixtures	Large office building in NYC. Baseline is current system.	ERS project document review	2015
Incremental	$2.36/ sq ft	Cost estimate to add advanced LED controls to existing fixtures	Lab space in NYC. Baseline is current system.	ERS project document review	2016
Incremental	$2.78/ sq ft	Cost estimate to add advanced LED controls to existing fixtures	Lab space in NYC. Baseline is current system.	ERS project document review	2016
Full	$6.69/ sq ft	Retrofit existing fixtures to LEDs with advanced ctrls	Average cost of 25 projects at 25 stores in a Northeastern grocery store chain	ERS project document review	2016

Table 3-10 isolates the incremental costs of installed or quoted project documentation and excludes ballpark figures that were self-reported by manufacturers, which is the most accurate information available. Averaging these incremental costs shows an overall incremental cost of $2.22/ft^2 for advanced LED control solutions.

Table 3-10. Incremental Advanced LED Control Costs from Reviewed Project Documentation

Incremental Cost/sq ft	Description	Notes	Source	Date of Data
$0.25	Cost per square foot of advanced LED control solution	Installation was in a conference room in an office building in California	Invoice for a 535 square foot room with 8 integrated fixtures installed	October 2015
$1.36	Incremental cost of LEDs with advanced controls compared to T5HO as baseline	Part office space, part manufacturing space. Baseline used was alternative proposal	Project documentation from study sponsor	2013
$2.34	Cost to add advanced LED controls to existing fixtures	Large office building	Project documentation from study sponsor	October 2015
$3.55	Cost to add advanced LED controls to existing fixtures	Large office building in NYC	ERS project document review	2015
$2.89	Cost to add advanced LED controls to existing fixtures	Large office building in NYC	ERS project document review	2015
$2.36	Cost estimate to add advanced LED controls to existing fixtures	Lab space in NYC	ERS project document review	2016
$2.78	Cost estimate to add advanced LED controls to existing fixtures	Lab space in NYC	ERS project document review	2016
$2.22	**Average incremental cost per square foot**			

While this information indicates that there is still a premium cost associated with advanced LED controls, it's worth noting that one study, which investigated the total life cycle cost of a variety of lighting control systems over 10 years[18], found that wireless advanced controls provide the lowest life cycle cost of any control strategy available today, due to the reduced energy costs and labor costs, as installation of wireless systems is reported to be less labor-intensive than that of wired systems.

3.2.7 Cost Trends

Two of the interviewees mentioned that they predicted the cost of their product would either remain the same while the number of features increased, or go up slightly. One cited that raw material costs could easily rise, and that is not something that manufacturers have control over. The other three interviewees predicted that costs would decrease over time as volume and innovation increase. This downward trend is consistent with that mentioned in Francis Rubinstein's Wireless Advanced Lighting Controls Retrofit Demonstration[18], which states that "costs are projected to decrease with technology maturation, increased sales volume, and the embedding of sensors and controls directly into fixtures." It's also worth noting that the market appears to be moving towards controls integrated into fixtures, as their ease of installation reduces both headaches and labor costs. They can reduce the price of labor enough that that cost benefit can outweigh the increased equipment and commissioning costs.[18]

Additional Market Insights

The customer's understanding of the total value proposition offered by these control systems came up repeatedly as a barrier to market adoption in the manufacturer and key market actor interviews conducted. One advanced LED control subject matter expert had visited multiple sites that had installed advanced LED controls where the facility managers in charge of operating the lights did not know how to adjust the task tuning and had not bothered to take advantage of that feature. Additionally, Gabe Arnold mentioned that the complexity of these systems leads to the lack of standardization, which can lead to high costs and thus uncertainty of savings and value. If a potential customer is not confident in the achievable energy and cost savings and other less tangible benefits, his or her uncertainty can easily make the customer unlikely to decide to install the controls. Gabe also mentioned that in general, utility program design has not done well to support this technology, and improving the process of and/or the money available for these products is likely to increase market adoption of advanced LED controls. A prescriptive approach may be one solution to increase market friendliness of these utility programs.

3.3 Technology Category 3a and 3b – Home Energy Management Products, Smart Thermostats, and Advanced Power Strips

Originally proposed as two separate measure categories, this section includes residential energy management products, such as "smart" thermostats, lighting hubs and lamps, appliances that offer controllability features beyond those of standard products, and Tier 2 advanced power strips that offer multiple automatic control functions for the control of plug loads for home entertainment systems or office equipment.

Smart phone controllable outlet

3.3.1 3a: Home Energy Management Products

Home energy management products are often referred to as "smart" products. For purposes of this study, the category includes products that facilitate the enhanced control of energy usage either through automatic means based on a set of programmable protocols responsive to user behavior patterns or through connectivity with communication devices such as smartphones, tablets, or personal computers. Products that focus specifically on security, user convenience, or other non-energy related benefits have been intentionally excluded from this research, as have products that simply monitor power and provide feedback on a user's energy consumption.

Technology Overview

This category covers a broad range of product lines from a variety of manufacturers and is rapidly expanding as more products are introduced on a continual basis. While many products have the potential to offer considerable energy savings to end users as control interfaces and protocols are developed, there are a limited number of devices that offer immediate energy savings opportunities as currently configured. A major challenge associated with this category has been containing the research to a scope that is representative of current markets, as well as predictive of what product types and/or lines are likely to achieve market success. As previously agreed, the research in this section will focus on products that demonstrate the ability to achieve cost-effective energy savings. This includes:

1. Smart hubs/gateways that connect enabled devices such as lamps and electrical outlets
2. Smart lighting (mainly LED lamps) that can connect to hubs or include integral controllability
3. Smart thermostats that adapt to occupant behavior patterns, and/or are controllable from smartphones/tablets/PCs
4. Major household appliances with integral communication chips for demand response or other energy related controllability

Communication Protocols

Before discussing the specific technologies, this section provides an overview of the means by which devices communicate with each other and respond to user input. There are multiple communication protocols that facilitate wireless communication. The radio frequency transceiver chips embedded within smart devices are configured to use one or more of these protocols. Some are proprietary to the device manufacturer, and others are open source and available to all manufacturers. Z-Wave and ZigBee are the two most common communication protocols. They are both termed "mesh" type networks, which allow each device to act as a node playing the role of both a wireless data source and a repeater. This feature allows the devices to communicate in lieu of a Wi-Fi network. The Bluetooth communication protocol is a mesh type network that has been in use for several years and is capable of connecting a variety of devices.

Z-Wave and Zigbee are two leading standards for household applications and facilitate interoperability among products from many different manufacturers. Z-wave is frequently used for security systems as well as energy management products, and there is a consortium of over 300 companies called the Z-Wave Alliance, which includes LG, D-Link, ADT, Bosch, Samsung and many others. ZigBee is similar to Z-Wave, but is used less in security systems and is often adopted for larger commercial applications in addition to household consumer products.

Thread is the communication protocol for Google's "Works with Nest" that was introduced after the kick-off of this study as a system approach for communicating with Nest thermostats. Google is actively soliciting manufacturers to produce or adapt products to use their communication protocol, and has branded the name Nest Weave as a software platform for interconnectivity across brands.

At the time of this writing it was not clear if the industry will standardize on one communication protocol. However, as more products are introduced there is a clear trend toward connectivity across manufacturers' product lines and the ability to interact with multiple communication protocols.

Smart Hub Systems

Smart hub systems have been entering the marketplace rapidly, and our research has identified several marketed systems. These products do not directly reduce a household's energy consumption; they act as a gateway for products so an end user can control multiple smart devices. For example, smart hubs have the capability of controlling multiple lighting fixtures and plug loads through a single interface/application thus providing the control to reduce consumption.

Smart hub systems are being actively marketed through existing online and brick-and-mortar retail market chains. To date, they have not been marketed by dedicated online energy efficiency retailers such as Energy Federation Inc. (EFI).

Product Lines

The following product lines and associated market actors have been identified as having significant current or potential market activity. Table 3-11 summarizes the product lines that market research identified as being currently and widely available. Additional descriptive information follows the table.

Table 3-11. Smart Hubs

Manufacturer	Product Name	Base Hub Cost*	Average Controlled Outlet Cost	Open Compatibility	Notes	Cost Source
Samsung	Smart Things	$99	$50	Yes	Comprehensive product line with broad compatibility. Currently marketed primarily as a security product with energy savings as a secondary goal.	Multiple retailers (Home Depot, Best Buy, Sears, etc.)
Wink	Wink	$70	$35	Yes	Wide product compatibility	Home Depot
D-Link/Staples	Connect Hub	$60	$35	Yes	Marketed primarily as computer device networking	Amazon
Lutron	Smart Bridge	$80	NA	Limited	Primarily a lighting controller	Best Buy
Belkin	WeMo Maker	$80	$40	Yes	Virtual rather than physical hub. Unique product list: includes small appliances such a crock pots, coffee makers, etc.	Multiple retailers (Home Depot, Best Buy, etc.)

* Reported costs are "street" prices from mass market retailers (Amazon, Home Depot, Best Buy, etc.). Manufacturers' suggested retail prices are typically higher in most cases.

- **Samsung SmartThings Hub & Devices** (product website)–This comprehensive product line offers a variety of monitoring and control devices. The main features include compatibility with Samsung's Smart Things line of products including lighting, motion sensors, controllable outlets, and security products. The system supports Z-Wave, ZigBee, and Wi-Fi wireless communications along with If This Then That (IFTTT) programming protocols promoting open compatibility with other manufacturers' devices. These manufacturers include but are not limited to Osram/Sylvania, CREE, Honeywell, Ecobee, and Belkin. The Smart Things hub works with application software to control devices based on certain events including sunrise, motion triggers, time of day, etc.
- **Wink Connected Home Hub** (product website) – Rather than offering a comprehensive list of products, Wink produces and markets a hub that is compatible with many manufacturers' controllable product lines. They partner with these manufacturers of the controllable products in offering starter kits and packages. The Wink Hubs are compatible with a large variety of controllable devices, including:
  - G.E., Cree, Osram/ Sylvania, Phillips, and TCP controllable LED lamps
  - Leviton and Lutron controllable dimming and on/off light switches
  - Leviton and iHome controllable 120 V plug outlets for lamps and light appliances
  - Rheem Econet water heaters
  - Nest, Honeywell, Emerson, Carrier, and Ecobee thermostats

  The system supports Bluetooth, Wi-Fi, Z-Wave, ZigBee, and Lutron Clear Connect communication platforms and can be controlled via a smartphone application or a home control panel. In September 2015, Wink was sold by its parent company, Quirky, to Flextronics International. The product is not available through the Wink website at the time of this report's publication, although there are multiple third-party retailers that offer the product, and it can be assumed that Flextronics will offer hubs similar to the Wink products.
- **Staples Connect D-Link Hub D-Link** (product website***)* –** This product line, offered through office supply retailer Staples, is associated with the D-Link networking protocol. It features a hub that connects to controllable devices through Wi-Fi networks and Bluetooth. It is compatible with fewer total devices than either the Samsung or Wink hubs, but offers similar energy saving

capabilities. Aside from working with Z-Wave, ZigBee, and Lutron's Clear Connect protocols, D-Link uses Wi-Fi or power-line carriers for networking devices through existing electrical circuits. Bluetooth compatibility allows for communication through Staples' smartphone application and offers control over a variety of products.

- **Lutron Smart Bridge** (product website) –At the time of this report's publication, this is a lighting-and-window-shades-only hub that allows control of Lutron products through a dedicated, hand-held controller and/or a smartphone. The hub works with multiple Lutron devices that provide on/off and dimming control. There is limited compatibility with non-Lutron product lines, although Lutron controllable devices are compatible with Samsung hubs. Lutron Clear Connect is a proprietary communication platform that works with Lutron Smart Bridge and a limited number of Lutron products.
- **Belkin WeMo** (product website) – Rather than utilize a central physical hub, WeMo is a collection of networkable devices controllable with a smartphone application termed IFTTT, which uses Wi-Fi for connectivity. In effect, the smartphone application serves as the hub. Many WeMo products are presently in pre-production and not yet available. Promoted features include:
    - WeMo Lighting Link, which can control up to fifty WeMo-compatible lamps
    - Controllable outlet plugs
    - Motion sensors capable of controlling WeMo plug controls
    - Controllable small home appliances, such as crock pots and coffee makers
    - Portable space heaters with WeMo controllability
    - WeMo is a proprietary brand of Belkin that utilizes Wi-Fi and smartphone applications called IFTTT that are available for iPhone and Android phones.
- **Control4 Home Automation System** – At the request of NEEP staff, ERS also researched the Control4 home automation system that was featured in a New York Times article. Although it may offer some limited energy savings opportunities, it does not fit within this category, as it is marketed as a luxury convenience product offering the combined controllability of entertainment and security systems. Hub prices start at $500, with integrated packages priced over $1,000.

Residential Smart LED Lighting Products

Although some smart lamps can be controlled directly from software applications, many require the use of a hub or gateway to be controlled via a smartphone application. Both individual lamps and kits including hubs and lamps are available. Lamps and lighting systems researched allow for both dimming and on/off controllability. Table 3-12 summarizes information on eight products from six currently available product lines. It should be noted that available products and pricing are changing continuously. It is also observed that pricing for baseline LED lamps at Amazon is consistently lower than the pricing at Massachusetts Home Depot and Lowes stores despite the products' receiving upstream incentives at those retailers.

Table 3-12. Residential Smart Lighting Products[1]

Manufacturer	Product Name	Product Description	Average Unit Cost	Baseline[2] Cost	Incremental Cost	Notes
Philips	A19 LED	Dimmable LED	$23	$6	$15	10 W LED
Philips	BR30 LED	Dimmable LED	$58	$7	$51	7 W LED
Belkin	WeMo LED	Dimmable LED	$25	$6	$19	10 W LED
GE	Link LED	Dimmable LED	$15	$6	$9	10 W LED
CREE	Cree Connected	Dimmable LED	$15	$6	$9	11 W LED
Osram	Lightify	Dimmable LED	$25	$6	$19	10 W LED
LIFX	LIFX Smart LED	Dimmable LED	$48	$6	$42	No hub/bridge required
Philips	Philips Hue kit	Kit – 2 dimmable LEDs & hub	$80	$14	$66	2 10 W LEDs and hub
Belkin	WeMo LED kit	Kit – 2 dimmable LEDs	$49	$14	$35	2 10 W LEDs and multi-lamp link
GE	Link LED kit	Kit – 2 dimmable LEDs & hub	$45	$14	$31	2 10 W LEDs & hub

[1] See study worksheet for prices of all researched A19 and BR30 style lamps researched.

[2] Baseline assumption is non-controllable, dimmable LED for similar application.

Product Lines

With a few exceptions, most of the above lighting products are designed to work with a lighting hub. Although lamp features vary, in that some offer color shifting, all listed offer remote-controlled dimming as well as on/off controllability. The established baseline for this study is a dimmable LED bulb that does not have the connective functionality that a smart light would have. This means that the additional cost a consumer sees would be strictly for the capability to control the lamp through a wireless device or application. Each product is discussed briefly below.

- **Philips Lighting** – Philips offers a comprehensive line of residential smart lighting products. A principal marketing focus is the promotion of expandable lighting kits. Both A-19 type bulbs and reflector-style lamps are available. The lighting system is now promoted as compatible with Nest using the Thread protocol.
- **Belkin WeMo** – Belkin's WeMo LED lamp line currently consists of Osram lamps and private label lamps that are manufactured by Osram. Functionally the line is similar to the Philips line, with starter sets and individual lamps offered.
- **GE Link** – GE offers a line of residential smart lighting products that can be controlled via a mobile device application. Products have the capability to be synced with other smart devices.
- **CREE Connected –** Cree markets controllable lamps marketed as compatible with Wink hubs and Zigbee wireless communication protocols.
- **Osram/Sylvania Lightify** – Osram/Sylvania's controllable lamps are marketed as compatible with Wink and Samsung hubs, and Nest.
- **LIFX** – Unlike the above product lines, LIFX lamps are standalone products that are controlled directly from an included smartphone Wi-Fi application.

Market and Cost Trends for Lighting Hubs and Controllable LED Lamps

The market is expanding in several directions for these products. Trends include systems that are integral with security systems and hybrid systems that offer voice recognition and "infotainment," such as the recently introduced $189 Amazon Echo system, which can control lighting and plug loads as well as stream music and information from the Internet.

The products in this category are all electronic devices. The market experience with both electronic devices and "standard" LED lamps suggests that prices will be reduced over time. However, during the course of this study, we have observed some price volatility but not a consistent price reduction pattern. These products are still emerging, and have not yet reached widespread market acceptance. Some argue that homeowners will never adopt widespread usage of these products, while others predict a significant market shift toward "smart homes" and everything associated with the Internet of Things (IoT). If the market for such products expands, production will shift toward a commodity product, which would absorb much of the R&D costs and allow pricing to be reduced.

"Smart" Adaptive and/or Application Controllable Thermostats

Smart thermostats are readily available on the market and offer energy savings potential compared with typical programmable[23] and manual thermostats through adaptive memory that learns users' habits over time, and/or through controllability on-site or remotely via smartphones, tablets, or personal computers. Many efficiency programs currently offer incentives for these products. For example, many programs in the Northeast offer a $100 incentive for the Nest learning thermostat. Some but not all smart thermostats also offer the capability to be used for utility demand response (DR) programs.

Market Status as of April 2016

Three manufacturers of smart thermostats dominate the consumer market and are available through multiple online and brick-and-mortar retailers: Nest, which is now produced by a Google subsidiary; Ecobee; and Honeywell. Additional smart thermostats are available and have less presence in the marketplace. Models that fit the definition of smart thermostats and were found to be available are included in the following sections, although the top three products are so dominant that their pricing is being used to establish the incremental cost data.

Smart thermostats are readily available and are still evolving. Nest and Ecobee are currently on their third generations of the product line, while Honeywell has recently introduced its second-generation product. The HVAC features of the available units are similar, although Nest has recently announced "Works with Nest" as a feature of their third-generation thermostat, incorporating many of the connectivity features of smart hubs. Table 3-13 illustrates product costs and associated baseline costs for the three market-leading thermostats. Pricing from multiple sources was recorded and the links in the table connect with sample typical pricing.

[23] According to several studies, programmable thermostats are not producing significant savings, and as a result, the ENERGY STAR program no longer lists them as qualified products. https://www.energystar.gov/index.cfm?c=archives.thermostats_spec

Table 3-13. Thermostat Product Costs

Manufacturer	Product Name	Unit[1] Cost	Baseline Product	Baseline Cost[2]	Incremental Cost[3]	Sample Cost Source
Nest	Nest	$249	Programmable thermostat	$54	$195	Amazon
Ecobee	Ecobee3	$249	Programmable thermostat	$54	$195	Multiple retailers
Honeywell	Lyric	$134	Programmable thermostat	$54	$80	Amazon
Allure	EverSense	$210	Programmable thermostat	$54	$156	Amazon
Schneider Electric	WiserAir	$230	Programmable thermostat	$54	$176	Amazon

[1]Nest thermostats are rarely discounted, except through efficiency programs; the MSRP is listed. Ecobee and Honeywell thermostats are listed with average selling prices.

[2]Baseline product is a full-featured, electronic, high quality, programmable thermostat. Less expensive programmable thermostats are available.

[3]Installation costs will vary as the thermostats are capable of being installed by the homeowner while a less handy person may require an hour's worth of time from a contractor (valued at ≈$200).

Product Lines

- **Nest** – The Nest third-generation thermostat (product page) has an adaptive memory feature that learns users' habits over time. The device is controllable via a smartphone, tablet, or computer and is currently the market leader in the smart thermostat industry. Recently, the "Works with Nest" Thread protocol and the Weave software platform have been introduced, both of which promote interoperability among compatible products produced by multiple manufacturers.

- **Ecobee** – The Ecobee3 second-generation thermostat (product page) includes the temperature control features of the Nest thermostat, including adaptive learning capabilities, and also includes a weather forecast data module for user convenience. The product also includes a single remote sensor (users can buy additional sensors individually) that is stated to improve motion recognition throughout the home, giving the thermostat the ability to track separate "zones."

- **Honeywell** – Honeywell's Lyric (product page) is available at various discounted prices and is similar to the Nest and Ecobee in terms of connectivity features. Instead of boasting a "learning" feature, the highlight of the Lyric is occupancy adaptation (known as geofencing), which can detect when a user is within a certain distance of the home and set the temperature accordingly. The product also features voice activated controls.

- **Allure** – Allure EverSense (product page) is another thermostat that uses geofencing to adapt to a daily occupancy schedule. This device is not seen primarily as an energy saver as it boasts infotainment features, including music streaming and weather forecasts. User reviews up to this point have indicated erratic operation that allows the system to run at full load regardless of conditioning demands.

- **Schneider** – Schneider Electric's Wiser Air thermostat (product page) includes adaptive learning features similar to the Nest and Ecobee3. What sets this unit apart is its ability to connect directly with utility advanced metering infrastructure (AMI) for DR capability.
- **Venstar** – Venstar's Voyager (product page) is only available through wholesale distributors and the price is dependent upon the wireless protocol and system configuration for which it is designed. While it does not offer adaptive learning features it does offer programmability with override controls through an application.
- **RCS Technology** – The RCS thermostat (product page) is offered at a discounted price of $145 on Amazon and has models available for Z-Wave, ZigBee, and Wi-Fi compatibility. The product has no automated/learning functionality, although it does offer remote control of the basic thermostat functions.

Smart Thermostat Demand Response Capability

Some smart thermostats are capable of being used for participation in electric utility DR programs. This category includes consumer marketed thermostats, as well as products that are marketed exclusively through utility programs. An organization called the Open ADR Alliance has developed and maintained a product specification and communication protocol termed ADR 2.0. Products compliant with ADR 2.0b are capable of communicating directly with utilities for control associated with DR.

Consumer market thermostats discussed in the previous section that are listed as ADR 2.0b compatible include Ecobee, Honeywell, and Schneider. Although Nest is not listed as ADR compatible, it offers DR capability through its "Rush Hour Rewards" program. An interview with Consolidated Edison confirmed that they use the Nest thermostat in their DR program. Other thermostats are marketed through utility programs primarily for DR programs, including products from Carrier (in collaboration with EnergyHub) Cooper, Pelican Controls, American Standard, and Lux Geo.

For consumer products, the total and incremental costs are the same whether or not they are capable of DR communication. For exclusively utility distributed thermostats, the total costs are not available as it is a function of the program model, and the program administrators we interviewed maintain non-disclosure agreements with thermostat providers.

Cost Trends for Smart Thermostats

Since the introduction of smart thermostats, the retail pricing has remained remarkably stable. Our discussions with market actors reveal that firms such as Nest performed extensive market research before introducing products. As such, the thermostats are being retailed as "what the market will bear." With Nest as the market leader, it is clear that similar producers are matching their prices as a competitive stance. Lower-priced communication-capable thermostats lack some, or all, or the adaptive operation featured with Nest and its direct competitors. With the strong brand recognition involved, it is anticipated that pricing will remain relatively stable for the foreseeable future.

Controllable Major Household Appliances

Controllable appliances are often discussed in association with the Internet of Things (IoT). Appliance manufacturers are now beginning to incorporate communication chips into appliances that allow communication and in some cases, controllability using smartphone, tablets, and PCs. Refrigerators, washing machines, clothes dryers, oven ranges, and hot water heaters are among the major appliance categories to date that manufacturers are focusing on for wireless controllability. However, this is still very much an emerging market and our research has found that many controllable appliances introduced during the last few years have been quickly discontinued. Interviews with market actors have revealed low consumer demand for such products due mostly to a lack of confidence that the communication capabilities offer any real savings or convenience advantages.

Although controllable appliances may offer energy and peak demand savings, to date, controllable features integral to appliances are marketed primarily as convenience features. These features may include weather forecast displays on refrigerators, display of electronic photographs, electronic shopping lists, etc. It is clear from marketing materials and product specifications that the focus has been on these convenience and infotainment features rather than energy savings or load shifting/DR. Limited energy savings and load shifting could be obtained by remotely turning off ice makers and defrost cycles in Wi-Fi Connect refrigerators. Olav Hegland, VP of Analytics at OutSmart (a firm specializing in advanced monitoring), explained in an interview that the ice-making cycle is by far the largest electrical demand related to refrigerators.

An additional market barrier is that manufacturers have tended to add communication features to only the high ends of their product lines. For example, communication-capable refrigerators that have been marketed typically retail in the range of $3,000 to $4,500, and to date, manufacturers are not offering communication capability as an option for moderately priced refrigerators.

Product Lines

Manufacturers in the US market that are currently or were recently offering at least one type of controllable appliance include General Electric (GE), Whirlpool, LG, Samsung, Viking, and Wolf. As of March 2016, GE is the only manufacturer offering a complete line of controllable appliances. These appliances are available with Wi-Fi Connect, which allows communication with a smartphone. The focus is on convenience, such as communicating a scheduled time to replace filters, or notifying if clothes have been left in the dryer. Samsung currently offers a diagnostic service that allows users to troubleshoot their appliances via a smartphone, but does not offer additional control features. LG and Whirlpool have both discontinued their product lines with demand shifting capabilities. Although LG's communication-capable appliances have been reintroduced multiple times, multiple discussions with LG marketing staff did not disclose future marketing plans.

Premium brands Sub-Zero/Wolf and Viking offer smartphone connectivity through an application, but the features focus on monitoring cooking and refrigeration temperatures. These appliances are very expensive. As an example, one of the Sub-Zero refrigerators we researched retails for over $16,000. This makes it difficult to compare when investigating incremental cost.

There is some activity in Europe supporting communication capable appliances. Bosch markets the "Home Connect" application currently in Germany and Austria. It was launched with the goal of being an open platform facilitating the control of appliances from different manufacturers. To date, it is only offered within its own European appliance lines.

Appliance Load Shift Studies

Numerous studies have been done in the past to test the energy saving capabilities of DR appliances in energy markets where time-of-use pricing is implemented. Pilot studies conducted by GE[24] found that energy savings varied widely from customer to customer, as many found the need to override automatic features to avoid major lifestyle interruptions. The National Renewable Energy Laboratory (NREL) concluded from its own research[25] that many appliances are not suited for DR controls, as their operation is difficult to shift to non-peak hours. NREL also concluded that in order for manufacturers to invest in DR capable appliances, utility time-of-use rates would need to be widely available.

Because the variety of features offered by controllable and non-controllable appliances varies greatly, our research is focused on the additional cost for the inclusion of the communication device within a similar non-communicating product.

Table 3-14 presents a summary of collected product and price ranges.

Table 3-14. Controllable Major Appliances

Manufacturer	Product Name	Average Unit Cost[1]	Average Baseline Cost[2]	Incremental Cost	Notes
GE	Gas range oven	$2,070	$1,899	$171	Equipped w/ Wi-Fi Connect
GE	Refrigerator	$2,970	$2,159	$811	Equipped w/ Wi-Fi Connect
GE	Washer	$1,080	$809	$271	Equipped w/ Wi-Fi Connect
GE	Dryer	$1,170	$899	$271	Equipped w/ Wi-Fi Connect
GE	Dishwasher	$1,350	$1,079	$271	Equipped w/ Wi-Fi Connect
Whirlpool[3]	Smart washer	$1,600	$1,400	$200	Front load washer
Whirlpool[3]	Smart dryer	$1,500	$1,350	$150	Front load dryer
LG[3]	Smart ThinQ	$1,400	$1,200	$200	Top load washer
LG[3]	Smart ThinQ	$1,400	$1,200	$200	Front load dryer

[1]Average costs are the average selling price at mass market retailers and national appliance dealers: Home Depot; Lowes; Best Buy; A.J. Madison; Spencer's; etc.

[2] Reported baseline costs are for appliances produced by the same manufacturer that are identical in capacity and incorporate similar features, without the communication capabilities.

[3]Whirlpool and LG models were discontinued while we were preparing this report. Prices are the latest available and links (which may have expired) can be found in the data worksheet that accompanies this report.

Product Lines

- GE Wi-Fi Connect (product page) – GE offers two different lines of products capable of wireless communication. One line offers products with already built-in

[24] http://www.reuters.com/article/idUS159492+26-May-2010+BW20100526

[25] http://www.nrel.gov/docs/fy14osti/60383.pdf

wireless connectivity while the other line features products that can be equipped with the ConnectPlus module (sold separately), which enables select appliances for wireless monitoring, control, and notifications. The ConnectPlus module currently retails on GE's appliance parts website for $51, and is compatible with some GE refrigerators, ovens, water heaters, and laundry appliances. The module is available; however, according to GE's product website, users are reporting failures and compatibility issues. The main functionality of ConnectPlus is user remote control of water heater temperature, cooking times and temperature, and remote laundry controls. No utility DR functionality is currently offered.

- ❑ Whirlpool Smart Appliances (discontinued – currently unavailable) – The Smart Front Load Washer with 6th Sense Live technology (product page) is capable of DR control through a smart delay feature that shifts the run cycle to off-peak hours. Other features include an energy advisor and rate revealer. This product has since been discontinued.

  The Smart Front Load Electric Dryer with 6th Sense Live technology (product page) uses a similar smart delay feature that can shifts run cycles to off-peak hours. It has also been discontinued.

- ❑ LG Smart ThinQ (currently unavailable) – The Smart ThinQ Top Load Smart Washer (product page) offers the ability to communicate with the utility and operate when electric rates are lowest. This product has been discontinued and reintroduced multiple times.

  The Smart ThinQ Front Load Dryer (product page) offers the same features as its washer counterpart and has also been discontinued and reintroduced multiple times.

Cost Trends for Smart Major Appliances

It is clear that this market is very volatile, with manufacturers introducing and discontinuing product lines frequently. Current incremental costs are now quite high, but this is related to the communication capability only being offered on high-end product lines, rather than more standard models that experience larger production runs. It is also difficult to segregate the costs associated with convenience features from energy related features. If and when communication chips become commonplace in household appliances, it is expected that the incremental cost will be reduced to the $50–$100 price range from the typically $200 plus costs now in place.

3.3.2 3b: Tier 2 Advanced Power Strips

Embertec Tier 2 APS

Advanced power strips (APS) reduce energy consumption by turning electronics fully off, eliminating standby energy consumption. Tier 1 strips control outlets based on the current draw status of a master outlet. Tier 2 strips have added more advanced features, including infrared and/or radio frequency sensors to detect when controlled products have not been manually adjusted by occupants (channel changed, volume adjusted, etc.) and/or when the space is unoccupied. These products are primarily used for the control of entertainment centers with multiple plug loads, including television, cable box, DVD player, gaming console, etc. They can also be used for the control of home office equipment, but several studies have concluded that the most significant energy savings potential is associated with the standby energy of gaming consoles.

Market Status as of April 2016

Tricklestar and Embertec are the two manufacturers with Tier 2 products currently available on the market. Tricklestar also offers Tier 1 strips, while Embertec exclusively produces Tier 2 products. Many efficiency programs offer incentives, or include Tier 1 strips in home direct-install programs, and Tier 2 strips are now entering the efficiency program market, following multiple pilot studies.

Table 3-15 lists the key market actors and product lines.

Table 3-15. Key Market Actors and Tier 2 Product Lines

Manufacturer	Product	Unit Cost[1]	Baseline[2] Product	Baseline Cost	Incremental Cost	Notes
TrickleStar	7-outlet APS+	$40	Power strip	$10	$30	Online retailers and direct discounted efficiency program purchase available in some service territories
Embertec	4-outlet EmberPlug	$48	Power strip	$10	$38	As above
Embertec	8-outlet EmberPlug	$80	Power strip	$10	$70	As above

[1]The listed cost is an average from online retailers. However, the selling prices vary widely, and the vast majority of these products are sold directly through efficiency programs with an upstream incentive.

[2]Although technically no baseline product is necessary in some cases, in most cases a simple power strip would be needed to power multiple devices.

Product Lines

- **TrickleStar's APS+** products are offered by many efficiency programs at discounted rates, although our research has found that they are available on Amazon for prices competitive with these discounted rates. The power strips boast current, infrared, and occupant motion sensing. IR multi-sensors detect both device remote control signals and movement and include a delayed shutoff of devices after no activity is detected after a specified period of time.
- **Embertec's EmberPlug** is also offered via efficiency programs at discounted rates; however, the four-outlet version is available at a comparable price through Amazon. Current and infrared sensors detect when the master control outlet enters standby and when no television or other remote control activity has been detected for an adjustable time period.

Cost Trends for Tier 2 APS

The cost of Tier 2 APS is closely associated with the scale of production. Neither Tier 1 nor Tier 2 products have received wide market acceptance within the standard retail environment. However, within the last year, the manufacturers have made significant progress introducing the products through ratepayer funded efficiency programs, including residential audit and direct install programs. This has allowed production to increase and prices to decrease to well below their original suggested retail list prices. Interviews with the manufacturers informed ERS that prices are not likely to drop below current levels, as the focus is now on introducing further product enhancement rather than price reductions. Further, if efficiency programs do not experience success with the products, it can be anticipated that production numbers will be reduced with pricing likely to increase with production and marketing costs.

3.4 Technology Category 4 – Advanced Rooftop Air Conditioning Units with SEER Ratings of 18 and Above

Note: Following initial research, a decision was made to limit further investigation of this technology, as sponsor efficiency program administrators have been unable to provide incentives for high efficiency RTUs due to cost-effectiveness constraints.

Rooftop A/C units (RTUs) are the most common systems for the conditioning of commercial buildings. Improved compressor, fan motor, evaporative coils, and control strategies have allowed the efficiency of these units to improve significantly over the last several years. Major manufacturers are now developing and introducing RTUs that represent the next step up in efficiency.

The project goal for this measure is to develop an incremental cost for ultra-high efficiency rooftop units (RTUs) in commercial applications. This research initially targeted units with a SEER of 20, but after reviewing the AHRI-rated efficiencies of currently available RTUs and packaged heat pumps, we expanded the scope of this research to include units with a SEER of 18 and higher.[26]

As of March 2016, only one manufacturer (Trane/American Standard) offered a packaged unit with an AHRI rated SEER > 20. However, we identified six manufacturers who sell units with SEERs between 18 and 19 (Lennox, Daikin, Trane/American Standard, Unitary Products Group, Aaon). The sections below summarize the outcome of the market status and cost research on this technology.

The scope of this study is restricted to RTUs and packaged heat pumps with capacities ≤ 135,000 Btu/hr, as the efficiency levels of larger units currently available are significantly lower than those of smaller sizes. As of March 2016, all of the commercial RTUs with AHRI-rated SEER ≥ 18 are 64,000 Btu/hr or smaller.

3.4.1 Baseline Description

The baseline for this measure is a standard efficiency packaged unit that meets the minimum EER and SEER/IEER values required by the applicable state energy code. Only new construction/end-of-life installations are considered in this research. Retrofits

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[26] This revision in scope was approved by the project sponsors on December 2, 2015.

are not included because working HVAC systems are rarely replaced prior to end-of life for energy savings alone.

Tables 3-16 and 3-17 summarize the 2012 IECC code-compliant efficiency ratings as well as the 2016 CEE efficiency ratings.[27] The 2012 code minimum requirements represent the baseline for this incremental cost study while the CEE Tier 1 and 2 efficiencies are similar to those of the existing "high efficiency" products that are the basis for most of the existing incremental cost studies for packaged A/C and heat pump units. The Advanced Tier RTU efficiency was introduced by CEE in 2016, and reflects the advanced efficiency RTUs that are the focus of ERS's research.

Table 3-16. IECC 2012 and 2016 CEE Efficiency Requirements for Packaged AC Units[28,29]

Size Range	2012 IECC Baseline Unit Efficiency	2016 CEE Tier 1 Unit Efficiency	2016 CEE Tier 2 Unit Efficiency	2016 CEE Advanced Tier Unit Efficiency
≤65,000 BTU/hr	SEER ≥ 13	15.0 SEER 12.0 EER	16.0 SEER 12.0 EER	17 SEER 12.5 EER
> 65,000 BTU/hr and ≤ 135,000 Btu/hr	11.0 EER* 11.2 IEER*	11.5 EER* 12.7 IEER*	12.0 EER* 13.8 IEER*	12.4 EER* 17.8 IEER*

*Add 0.2 to the EER and IEER for units if they have electric resistance heat options.

Table 3-17. IECC 2012 and 2016 CEE Efficiency Requirements for Packaged HP Units

Size Range	2012 IECC Baseline Unit Efficiency	2016 CEE Tier 1 Unit Efficiency	2016 CEE Tier 2 Unit Efficiency	2016 CEE Advanced Tier Unit Efficiency
≤65,000 BTU/hr	SEER ≥ 13 7.7 HSPF	SEER ≥ 15.0 8.2 HSPF	SEER ≥ 16 8.2 HSPF	No advanced tier for packaged heat pumps
> 65,000 BTU/hr and ≤ 135,000 Btu/hr	11.0 EER 11.2 IEER 3.3/2.5 COP (medium/low temperature rating)	11.1 EER 12 IEER 3.4/2.4 COP (medium/low temperature rating)	11.6 EER 13.4 IEER No data for COP	No advanced tier for packaged heat pump units

*Add 0.2 to the EER and IEER for units if they have electric resistance heat options.

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[27] 2016 CEE Commercial HVAC Specification, released Jan 12, 2016: http://library.cee1.org/sites/default/files/library/5347/CEE_2016_HECAC_Initiative_Description_and_Specification.pdf

[28] 2012 IECC code mandated efficiency levels

[29] CEE Tier Definitions from the 2016 CEE report: http://library.cee1.org/sites/default/files/library/5347/CEE_CommHVAC_HECAC_InitDescip.pdf

3.4.2 Sources of Data

Research included the NEEP Phase I incremental cost study, reviewed DEER 2016 incremental costs, and interviewed manufacturers and distributors to determine incremental costs for this measure.

- **NEEP Phase I Incremental Cost Study**[30] – In this NEEP study, incremental costs were calculated between standard efficiency units and CEE Tier I and Tier II units. In the time since the 2011 NEEP study was published, the baseline unit efficiency has increased. Despite these changing standards, the NEEP Phase I incremental cost study provides a meaningful estimate of the minimum incremental cost between a standard efficiency and advanced RTU, as it is likely that advanced RTUs will cost the same or more than existing high efficiency RTUs. The NEEP study assumed that the incremental labor and installation cost between high efficiency and standard efficiency rooftop units is $0. ERS believes this may not be the case for advanced RTUs. Contractor interviews and advanced RTU cut sheets indicate that advanced RTUs can weigh at least 30% more than a standard efficiency RTU. This can lead to increased costs due to the need to reinforce the structure supporting the RTUs or additional lifting and installation costs associated with these units.
- **DEER 2016 Incremental Costs**[31] **–** The CPUC released revised DEER incremental cost values in August 2015. This release included updated equipment costs for packaged RTUs and heat pumps and was based on the 2010–2012 WO017 Ex Ante Measure Cost Study Final Report[32], which was released in May 2014. This study included incremental costs for RTUs and heat pumps with SEER values up to 18. Within this data, incremental costs were included for packaged units ≤ 65,000 Btu/h and >65,000 Btu/h and ≤135,000 Btu/h.
- **Manufacturer/contractor interviews –** ERS reached out to several manufacturers' representatives and received cost estimates for standard vs. high efficiency RTUs

[30] NEEP Phase I Incremental Cost Study, http://www.neep.org/incremental-cost-study-phase-1
[31] 2016 DEER update, draft revisions, downloaded in November 2015: http://www.deeresources.com/files/DEER2016/download/DEER2016-Costs_PkgHVAC-Boilers_8-31-2015-DRAFT.xls
[32] *2010-2012 WO017 Ex Ante Measure Cost Study Final Report*, published by Itron in May 2014: http://www.calmac.org/publications/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf

from one manufacturer's representatives. Most contractors were familiar with ultra-high efficiency RTUs, but were not able to provide cost estimates for these units.

- Comparing the incremental cost data from the above resources indicates similar ranges of incremental costs for RTUs with CEER Tier 1 and 2 efficiencies. This gives some confidence that the incremental costs for higher SEER and EER units from the 2016 DEER data is a reasonable estimate of the incremental cost of advanced efficiency RTUs. Should the market adoption of ultra-high efficiency RTUs and packaged heat pumps increase, this cost should be revisited, as the market is rapidly changing and costs will likely change as installation rates increase.

3.4.3 Market Status as of April 2016

ERS interviewed two HVAC contractors for this study. Neither of them had installed more than a handful of ultra-high efficiency RTUs and they could not provide incremental cost estimates for these units. However, these interviews did reveal the other insightful information about the ultra-high efficiency RTU market and some of the factors impacting their adoption, as follows:

- **Equipment availability and lead time** – Both contractors indicated that many customers elect to go with the equipment that is most readily available, especially in end-of-life installations. Currently, this means that standard efficiency equipment is most often selected for installation.
- **Return on investment** – One of the contractors interviewed indicated that they often struggle to justify the added cost of higher efficiency RTUs against the marginal improvements in energy efficiency and energy cost savings, especially in the Northeastern climate, where there are relatively few cooling hours compared to other regions of the US.
- **Installation costs** – Ultra-high efficiency RTUs often weigh significantly more than standard efficiency units, which may require additional labor hours and materials, particularly for end of life equipment upgrades. In addition, depending upon the specific nature of the site, structural support modifications may be required. A typical example of the difference in weight between a standard efficiency and ultra-high efficiency RTU is shown in Table 3-18.

Table 3-18. Weight Penalty for Lennox Ultra-high Efficiency RTU

	Lennox Raider	Lennox Energence	Weight Difference (lb.)	Percent Increase
Model number	ZGA092S	LGH094U4M		
Type	Code-compliant	Ultra-high efficiency		
Tons	7.5	7.5		
Manufacturer's IEER	11.8	20.7		
Model weight (lb)	902	1260	358	40%

3.4.4 Incremental Cost

Data from the 2016 DEER cost database indicates an incremental cost of $362/ton for ultra-high efficiency (SEER ≥18) RTUs. This data was validated by comparing similar unit sizes and efficiencies between the 2015 DEER update, NEEP's 2011 Phase I Incremental Cost Study, and market actor interviews. Tables 3-19 and 3-20 summarize the incremental cost data collected by ERS for RTUs with direct expansion (DX) cooling/fossil fuel heating and heat pumps.

Table 3-19. Incremental Cost Data for Advanced Packaged Units

		CEE Efficiency Tier			
Capacity	**Reference**	**Tier 1**	**Tier 2**	**Tier 2+**	**Advanced Tier**
≤65,000 Btu/h	2011 NEEP Phase I Study	$123/ton	$174/ton	N.D.	N.D.
	2016 DEER Cost Data	$90	$181	$271	$362
	Manufacturer data	$75–$100	N.D.	N.D.	N.D.
>65,000 Btu/h and ≤135,000 Btu/h	2011 NEEP Phase I Study	$184/ton	$235/ton	N.D.	N.D.
	2016 DEER Cost Data	$139	$277	$416	$555

N.D. = No data

Table 3-20. Incremental Cost Data for Advanced Packaged Heat Pumps

	CEE Efficiency Tier			
Capacity	**Tier 1**	**Tier 2**	**Tier 2+**	**Advanced Tier**
≤65,000 Btu/h	$142	$284	$426	N/A
>65,000 Btu/h and ≤135,000 Btu/h	N.D.	N.D.	N.D.	N.D.

ND = No data

3.4.5 Cost Trends

The CPUC (Itron) 2010–2012 Ex Ante Incremental Cost research on which the 2015/2016 DEER updates are based suggests that, if the incremental cost of typical "high efficiency" RTUs are changing, they are doing so in increments that are within the uncertainty of the available incremental cost data. Additionally, changing efficiency standards (i.e., 2016 CEE standards) are likely to drive the market toward higher efficiency equipment. With this shift and the subsequent increase in market adoption of higher efficiency RTUs, it is likely that the cost for ultra-high efficiency equipment will come down to some degree. However, there is little consensus regarding cost trends as some market actors interviewed do not expect product prices to be reduced in the near future.

3.5 Technology Category 5 – Integrated Residential Multi-System Heat Pump Controls

Air-source heat pump systems are becoming increasingly common in homes in the Northeast and Mid-Atlantic States, driven in part by the improved efficiency and installation flexibility afforded by modulating ductless heat pumps (DHP). Until recently, most of the air source heat pumps on the market have been extremely efficient at mild temperatures, but delivered low efficiency and capacity restrictions when lower outdoor air temperatures were encountered. This historically meant that air-source heat pumps were installed along with back-up fossil fuel or electric resistance heating systems. Recent advances have brought to market air-source heat pumps that perform well at colder temperatures, but many homeowners still have them installed co-existent with another heating system.

Recent studies, including those sponsored by NEEP, have revealed that homeowners do not necessarily understand how best to control two heating systems with differing operating characteristics. In addition, proper control of the two systems requires active homeowner adjustment of thermostats, whereas they have come to expect thermostats to offer "set and forget" operation. Typically, this situation leads to both systems running simultaneously when only one is needed or the heat pump system being underutilized.

Integrating the heating system controls into a single thermostat or controller would allow for optimized system operation via integrated algorithms that respond to input from exterior and interior temperature sensors. The project team is aware of the development of thermostats that are designed to control both an air-source heat pump(s) and an additional heating system. Originally scheduled for market introduction this past spring, the products are still under development, but market pricing projections are available, and predictive extrapolations can be made from related product lines. In addition, we have learned that the approach currently being developed by DHP manufacturers has evolved. Recognizing the market for advanced "smart" thermostats, such as those covered elsewhere in this report, interfaces are being developed that allow DHPs and an additional system to be controlled by one smart thermostat.

3.5.1 Market Chains Identified

ERS interviewed three heat pump manufacturers and one thermostat manufacturer to determine the future of multi-system thermostats. Through these interviews, we found that, in general, heat pump manufacturers are reluctant to provide third-party thermostat producers with access to their proprietary control protocols that typically rely on thermistors (electronic devices that correlate temperature with electrical resistance) installed in air streams rather than utilizing 24 V thermostat connections. This limits the number of options available to control multiple heating systems through a single interface to primarily those being offered by heat pump manufacturers rather than third-party thermostat manufacturers. However, there are some heat pump manufacturers, such as Mitsubishi and Fujitsu, that offer "interfaces" which enable third-party smart thermostats the ability to control their DHP systems.

- **Mitsubishi** – An interview with Mitsubishi research and development staff indicated that the development of an integrated multi-system heat pump thermostat is a possibility, but not a priority. Such a product would only target a small portion of Mitsubishi's global market, as milder climate zones require only a heat pump for space heating. In lieu of an integrated multi-system heat pump thermostat, Mitsubishi offers two solutions for integrating heating system controls through a single interface:

Thermostat interface[33] (current retail price; $235)[34] – This interface enables Mitsubishi heat pumps to be controlled by third-party thermostats. For full functionality, the third-party thermostat must be capable of controlling at least two stages of heating and two stages of cooling, and several smart thermostats include this capability. In order to intelligently select the heating mode, the third-party thermostat must be able to access outdoor air temperature data either via an Internet connection (i.e., access to NOAA's local weather station) or an outdoor temperature sensor external to the thermostat. To date, Mitsubishi has successfully tested their interface with thermostats from Nest, Energy Hub, Ecobee, Lutron, Wi-Fi 9000, Honeywell Lyric, Pro1, and Converge, although a single packaged interface and thermostat solution has not yet been brought to market.

Kumo Cloud[35] heat pump interface (current retail price; $195)[36] is capable of controlling select Mitsubishi heat pumps[37] and other heating systems via a Wi-Fi-connected web interface. This interface enables the heat pump user to wirelessly control their heat pump via their smartphone, but does not automate the control of the heat pump with other heating systems in the home. With the heat pump and an additional heating source addressable through the user's smartphone, remote decisions could be made regarding which heating system to operate. Software applications could help to automate this approach.

The Mitsubishi representatives interviewed believe that, rather than introducing their own thermostats, Mitsubishi will likely invest in developing additional software-based solutions that will allow homeowners to control multiple heating systems remotely via a smartphone or computer interface in conjunction with third-party smart thermostats.

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[33] http://www.mitsubishicomfort.com/sites/default/files/thermostat_interface_pr.pdf

[34] https://www.goductless.com/Mitsubishi-Air-Conditioners/PAC-US444CN-1-Mitsubishi-Thermostat-Interface/54596.ac?gclid=CNrYv42U8MkCFc6RHwodXvoEhw

[35] Mitsubishi Kumo Cloud product description: http://www.mitsubishicomfort.com/kumocloud

[36] Estimated cost for Mitsubishi Kumo Cloud: https://www.goductless.com/Mitsubishi-Air-Conditioners/PAC-WHS01WF-E-Ductless-Wi-Fi-Interface-Adapter-for-Kumo-Cloud/61592.ac?gclid=CLCUtO6T8MkCFQokHwodKwgIYA

[37] Mitsubishi Kumo Cloud compatibility chart: http://www.mitsubishicomfort.com/kumocloud/compatibility

- **Fujitsu** – Fujitsu also offers a Wi-Fi-enabled interface[38] that retails for approximately $195[39] and is similar to Mitsubishi's Kumo Cloud. This interface operates within the Intensis[40] home communication network and allows limited control of Fujitsu's heat pumps via third-party smart thermostats such as those offered by Nest and Honeywell. In addition, Fujitsu is currently developing embedded Wi-Fi controls for their heat pumps that will integrate with Intensis and are expected to be rolled out later in 2016. These controls will integrate Fujitsu heat pump control with other Wi-Fi-enabled controls and equipment, and will enable control via a smartphone or other web-connected device.
- **Daikin** – Daikin offers a thermostat solution, the "Envi", that is capable of integrating heat pump control with a single back-up heating source. The Envi thermostat is manufactured for Daikin by Ecobee and can control up to two stages of heating: one heat pump heating stage and one auxiliary heating stage. The operation of the auxiliary heating control is enabled by the thermostat user based on outdoor air temperature. The Envi must be wired into each heat pump head that it controls and must also be wired to the auxiliary heating system. In addition, the Envi can be programmed by the user, although it is anticipated that initial programming will be completed by the installer. Our research indicates a cost of approximately $350 for an Envi thermostat.[41] Representatives from Daikin also indicated that they will be releasing a Wi-Fi-interface that enables heat pump control directly from smartphones, tablets, etc., without the need for a traditional thermostat interface. However, this Wi-Fi-interface will not be capable of controlling multiple heating systems.

3.5.2 Summary of Integrated Thermostat Interface Offerings

Table 3-21 summarizes the currently available and forthcoming heat pump thermostat offerings from the three manufacturers that are most active in the NEEP market.

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[38] Fujitsu wireless technology information: http://www.fujitsugeneral.com/Wi-Fi.htm

[39] Fujitsu wireless interface cost: https://www.younits.com/fj-ir-Wi-Fi-1na-Wi-Fi-mdl.html?gclid=CN3h5uCY8MkCFYQXHwodTIINWg

[40] Information on Intesis, which is the system that enables Fujitsu heat pumps to integrate with smart home thermostats: https://www.intesishome.com/ifttt/

[41] Product number *DACA-TS1-1* at www.ecomfort.com

Table 3-21. Summary of Integrated Thermostat Offerings

Manufacturer	Method of HVAC System Control	Temperature Sensor Locations	Able to Control More Than One System?	Equipment Cost
Mitsubishi HP interface	Thermostat	*Interior* – third-party thermostat *Exterior* – third-party thermostat (web connection)	Yes (with third-party thermostat)	$235 + cost of third part thermostat
Mitsubishi Kumo Cloud	Smartphone	*Interior* – heat pump head *Exterior* – web connection weather data	No	$195
Fujitsu FJ-IR-WI-FI-1NA & FJ-RC-WI-FI-1NA	Smartphone	*Interior* – third-party thermostat *Exterior* – third-party thermostat (web connection)	Yes (with third-party thermostat)	$195 to $250 + cost of third-party thermostat
Daikin Envi	Thermostat & Smartphone	*Interior* – thermostat *Exterior* – outdoor heat pump unit	Yes	$350
Daikin web-based control (soon to be available in US)	Smartphone	*Interior* – heat pump head *Exterior* – TBD	No	Data not yet available

3.5.3 Compatible Smart Thermostats

Both Mitsubishi and Daikin currently offer heat pump interfaces that enable control by third-party thermostats, such as the Nest 2.0 and 3.0 smart thermostats. According to Nest, their thermostats are capable of controlling up to three stages of heating and two stages of cooling[42]. Nest thermostats rely on integrated indoor temperature sensors and pull data from the Internet for outdoor temperatures. The primary heating source, which is often a heat pump, operates until the outdoor air temperature drops below a user-defined outdoor air temperature[43]. Below this temperature, the auxiliary heating source (electric resistance heat, furnace, boiler, etc.) takes over to meet the heating demands of the home. As with Daikin's Envi system, the Nest thermostat can be programmed to adjust the outdoor air temperature at which the auxiliary heating system is enabled.

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42 https://nest.com/support/article/How-does-Nest-manage-different-stages-of-heating-and-cooling

43 By default, the outdoor air temperature at which the auxiliary heating system turns on is 35°F, as per: https://nest.com/support/article/Is-Nest-compatible-with-dual-fuel-hybrid-heating-and-cooling-systems

In order for Nest thermostats to interface with multiple heating systems, wired control connections must be available from all heating sources or Wi-Fi-based control systems, such as the Intensis system utilized by Fujitsu, must be in place. For ductless heat pumps, this typically means that some kind of interface (such as the one offered by Mitsubishi) must be available to enable the Nest thermostat to control the heat pump. For more conventional heating systems, such as furnaces, boilers, and electric resistance heat, the Nest thermostat is able to connect to and control the systems directly.

ERS interviewed one of Nest's Product Managers, who indicated that, nationwide and globally, the majority of multi-system configurations controlled by Nest thermostats are heat pumps with electric resistance heat, with a much smaller portion of their heat pump customer base relying on fossil-fuel fired heat sources for backup. This interview also revealed that Nest is in the process of integrating their thermostats into the OpenTherm[44] communication system in Europe. This system enables integration of HVAC equipment and thermostats. According to Nest, it is also quickly gaining traction in Europe as a means of more efficiently integrating home HVAC systems, as OpenTherm allows for modulating control of home HVAC equipment.

3.5.4 Third-Party Wi-Fi Interfaces

In addition, we investigated third-party controllers, such as the Pebble Wi-Fi controller, which is capable of wirelessly controlling a heat pump via a smartphone or tablet. The controller retails for $220[45] and is able to control multiple systems of differing configurations if they are made by the same manufacturer.[46] These units are similar to the Wi-Fi controllers manufactured by Intensis for Fujitsu.

3.5.5 Incremental Costs

The baseline for this measure is separate control of DHPs and secondary heating systems. We estimate the baseline equipment cost for new construction projects to be $90[47] for a standard programmable thermostat to control the secondary heating system

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[44] Open Therm protocol information: http://www.opentherm.eu/

[45] Estimated cost of the Pebble Wi-Fi controller: http://www.mcssl.com/store/davidkentagentofpebbleairusa

[46] Information on the Pebble Wi-Fi controller: http://pebbleair.com/faqs.html#faqs

[47] See "Smart Thermostat" section of Technology Category 3A and 3B write-ups, above, for the source of this baseline thermostat cost estimate.

and zero for retrofit projects as DHPs are delivered standard with a remote control and fan unit integral thermistor, which together act as a thermostat.

Our research indicated two options for controlling both a heat pump and auxiliary heating system:

- **Wired or wireless heat pump interface with a third-party thermostat, equipment cost – $450–$500.** ERS's research indicated that at least one heat pump manufacturer, Mitsubishi, offers an interface that enables their heat pump to be directly controlled by third-party thermostats via a wired 24 volt connection. Controlling a heat pump and a second heating system would require both an interface ($235) and a smart thermostat ($250), with a combined cost for a wired integrated heating system controller in the range of $450–$500. Wireless interfaces, like the one offered by Fujitsu ($195), enable lower equipment costs compared to their wired counterparts, and may also reduce installation costs due to the need for less wiring.
- **Integrated heat pump and auxiliary heating thermostat, equipment cost – $350.** ERS's research indicated that Daikin offers an integrated heat pump and auxiliary heating thermostat at a cost of $350.

These costs are for single-zone new construction applications and do not include labor costs or additional sensor costs. According to the manufacturers that were interviewed, only one zone can be controlled by the existing multi-system controls setups; additional thermostats with related interfaces would be required to control multiple heating zones within a home.

Additional costs may also be incurred should it be necessary to install an outdoor air temperature sensor and/or an interior temperature sensor to optimize the control of the two heating systems. Either of these options is approximately $100.

For new construction installations, we estimate the labor cost to be approximately $70 for a baseline thermostat and $175 for an integrated heat pump thermostat. ERS estimates the labor cost for a retrofit to be $0 for existing equipment and $175 for an integrated heat pump thermostat. However, the retrofit cost could escalate quickly if additional wiring must be run to integrate the heat pump and secondary system control. In general, professional installation is recommended for the integrated heat pump controls. Although the third-party and manufacturer-specific heat pump thermostats can be programmed by homeowners, most manufacturers recommended having installers perform the initial setup to ensure proper control and sequencing of the heat pump and auxiliary heating systems. Table 3-22 presents a summary of estimated incremental costs.

Table 3-22. Multi-System Thermostat/Control Incremental Cost

Multi-System Control Solution	Baseline	Material Cost			Labor Cost		Total Incremental Cost
		Base Case	Measure		Base Case	Measure	
			Thermo-stat	Heat Pump Interface			
Heat pump interface + third-party thermostat	New construction	$90	$250	$195–$235	$70	$175	$460-$500
	Retrofit	$0	$250	$195–$235	$0	$175	$620-$660
Integrated thermostat	New construction	$90	$350	N/A	$70	$175	$365
	Retrofit	$0	$350	N/A	$0	$175	$525

3.5.6 Cost Trends

Our interviews indicate that the total incremental costs shown in Table 6-2 represent the upper end of what the market will bear for integrated heating system control, especially given the rapidly developing capabilities of smart thermostat and Wi-Fi-based heating system control solutions. Market actors interviewed anticipate that the incremental cost of integrating heating system control will decrease as software solutions are developed that enable control of multiple heating systems via smart thermostat interfaces. These market actors also expect that the number of homes requiring multi-system control will decrease as consumer confidence in DHP technology increases, heating performance at colder temperatures further improves, and new homes become more energy efficient.

3.6 Technology Category 6 – Advanced Compressors for Commercial Refrigeration

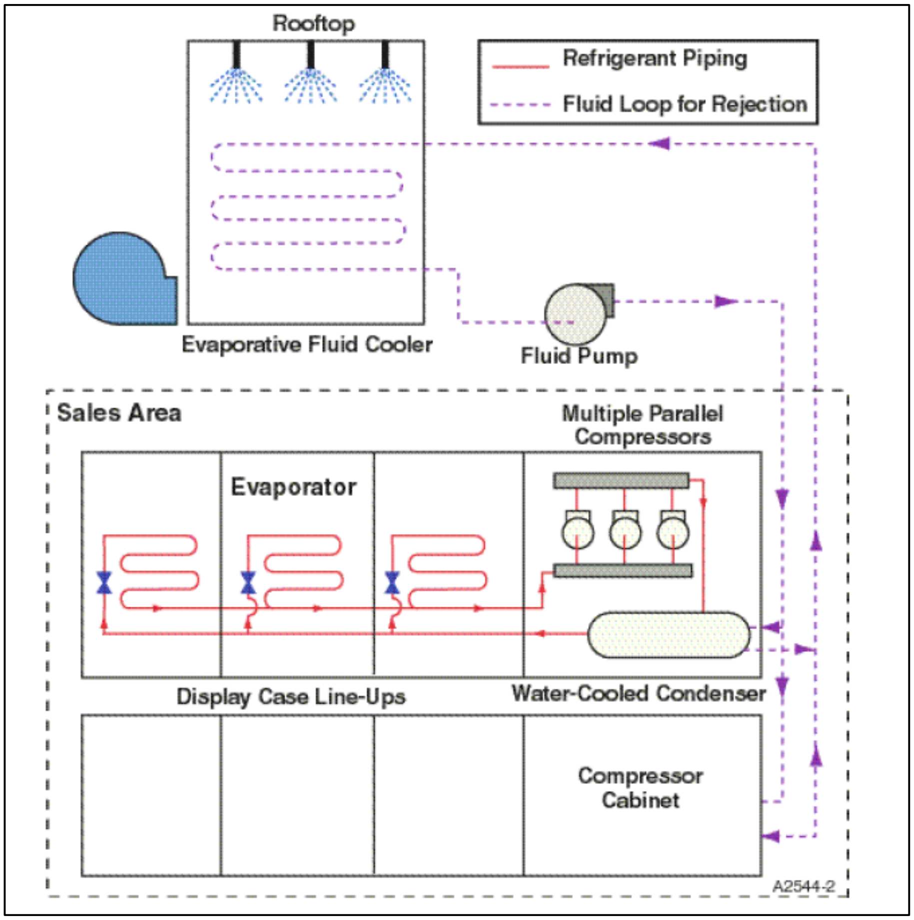
This category addresses improvements and alternatives to the centralized direct expansion (DX) systems that are used to provide cooling for nearly all food stores and other commercial refrigeration applications in the United States. DX systems use a refrigerant vapor expansion/compression (RVEC) cycle to directly cool the supply air to the space. It is the same basic technology as that used for standard air conditioning systems. Advanced refrigeration compressor solutions are now available that offer efficiency improvements, reduced refrigerant leakage, and alternative refrigerants with lower greenhouse gas (GHG) impacts compared with standard-practice equipment. This is typically a new construction measure covering a variety of possible solutions. Research identifies that COPs of approximately 10% higher than standard-practice equipment are possible. Many energy efficiency refrigeration solutions that involve incremental enhancements to standard systems are available on the market; however, ERS focused on emerging solutions that include compressor reconfiguration. The four technologies that ERS focused on for this report include:

- Distributed DX systems
- Secondary loop systems
- CO_2 cascade systems
- CO_2 transcritical booster systems

Each of these technologies is described below, with a description of the system and the source of energy savings compared to the baseline of centralized direct expansion systems. All of these systems are appropriate alternatives for supermarket applications that involve multiple refrigerated units throughout the facility. However, CO_2 transcritical booster systems generally perform better in colder climates, and there will be facility-specific situations that may favor one system type over another.

- **Distributed DX systems** – Compared to central DX systems, the refrigerant charge (amount of refrigerant) is reduced. Multiple parallel compressors installed in cabinets with small compressors are located in closer proximity to the refrigerated loads than the compressors would be in a centralized DX system. Each cabinet is dedicated to a single load. Heat rejection is performed with an air-cooled condenser located on the roof or with a glycol loop and fluid cooler. Scroll compressors are typically used for this system type. Distributed DX systems save energy because they are dedicated to a single load and are located near it, which reduces thermal distribution losses and those due to friction. Because of these minimized losses, the pressure drop is reduced. This allows the suction temperatures to closely match the evaporator temperature. High efficiency scroll compressors typically installed with these systems allow for low condensing pressures. Figure 3-3 presents a graphic of a distributed direct expansion system.

Figure 3-3. Example of a Distributed Direct Expansion System[48]

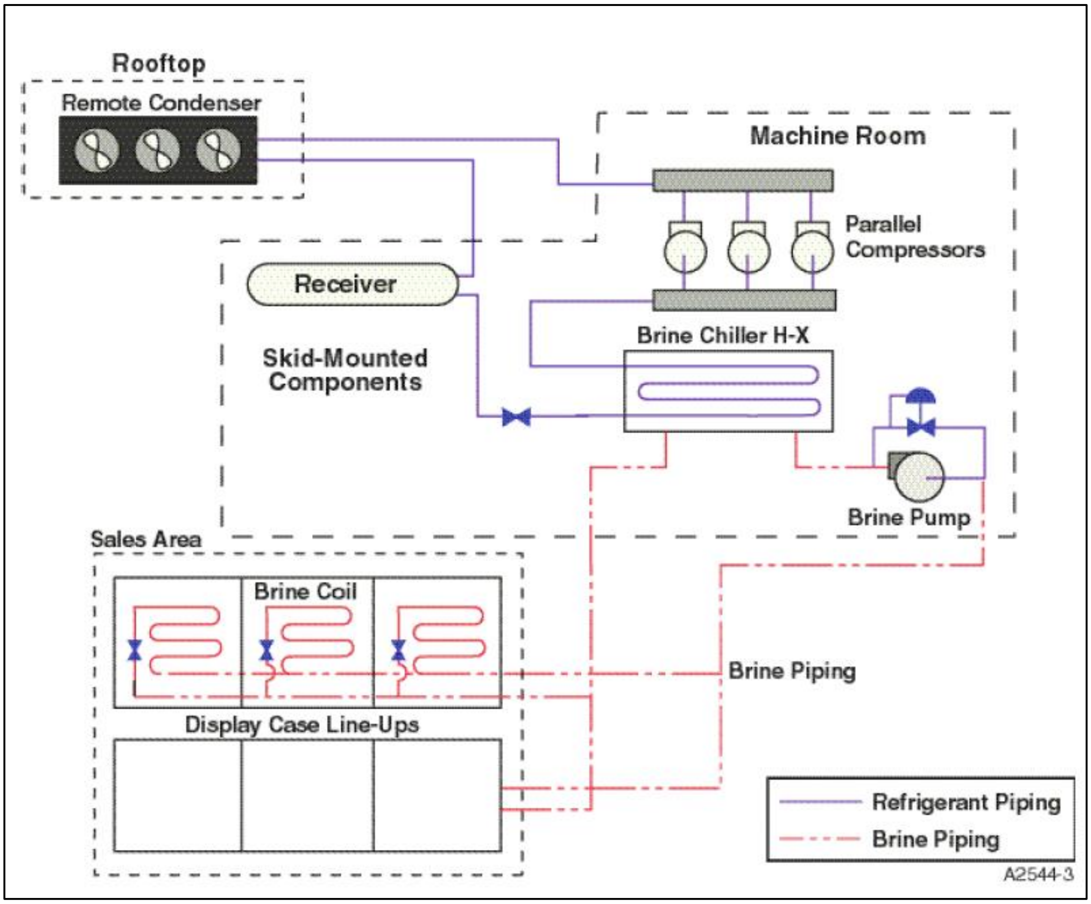


- **Secondary loop systems –** Two fluids are used in a secondary loop system; the primary fluid, typically a traditional HFC refrigerant, is used to cool the secondary fluid (via a heat exchanger) that is pumped to the loads to remove heat. Figure 3-4 depicts a secondary loop system. The use of multiple fluids allows for more appropriate matching of refrigerant with the temperature range at which it will be operating and can lead to energy savings. An ideal match would be a fluid that will remain a liquid at the target temperature and which has low viscosity at that temperature. However, the fluids often need to be pumped at high flow rates in these systems, which can minimize energy savings or generate an energy penalty.

[48] International Energy Agency (IEA). 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1-Executive Summary."

CO_2 secondary fluid loops offer significantly lower pumping demand compared to glycol and water mixtures.

Figure 3-4. Example of a Secondary Loop System[49]



- **CO_2 cascade systems –** A CO_2 cascade system consists of two refrigeration systems with a heat exchanger serving as an evaporator for the top system and condenser for the lower system. R-744 (CO_2) is used in the lower system as a DX refrigerant serving low temperature loads. This means that the CO_2 in the heat exchanger that rejects heat to the upper cycle will always operate below its critical temperature and pressure, which leads to several energy savings advantages. CO_2 is also more effective as a heat transfer fluid than some more commonly used refrigerants.

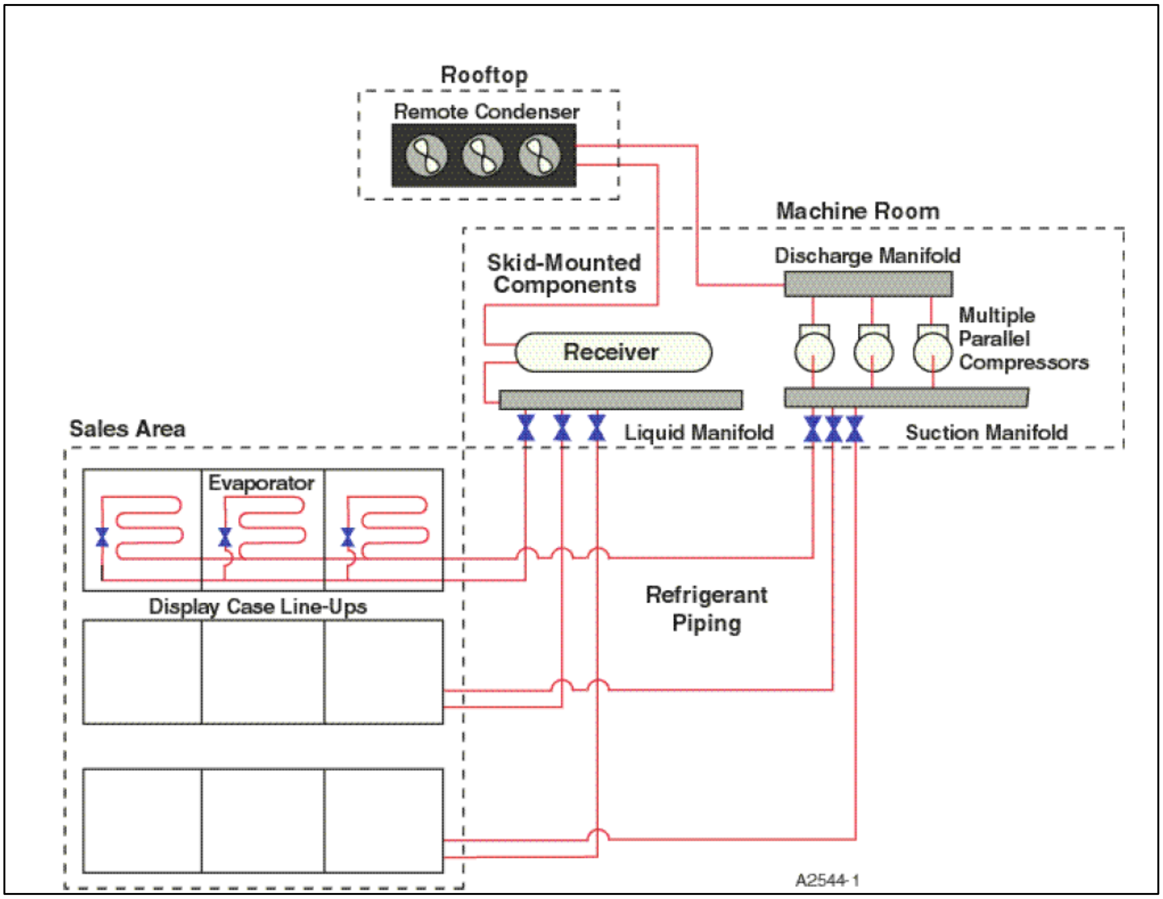
[49]International Energy Agency (IEA). 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1-Executive Summary."

- **CO_2 transcritical booster systems –** These systems use R-744 (CO_2) directly as a refrigerant, often have multiple stages, and operate at high pressures. These systems require specialized equipment and high-grade materials rated for the high pressures involved. This reduces the operations and maintenance costs involved with decreased component failures due to high quality components. Heat rejection occurs above the CO_2 critical pressure with a gas cooler instead of a condenser. Cooling occurs below the critical pressure of CO_2. The naturally high discharge pressures allow for greater heat recovery options for space heat than standard centralized DX systems. As mentioned with CO_2 cascade systems, CO_2 has high heat transfer capabilities due to the high pressure and density involved. This can lead to lower temperature differences in evaporators, which is one source of energy savings. The discharge pressures are high in these systems, but allow for great heat recovery for space heating off of the discharge temperature, which can be another source of energy savings. Low ambient temperatures allow the system discharge to operate below the critical temperature and pressure of CO2, also called subcritical operation. During subcritical operation, the CO_2 compression ratio is less than other refrigerants, which leads to higher compressor isentropic efficiency.

3.6.1 Baseline Description

Our research identified two possible baseline refrigeration systems: stand-alone systems and centralized DX systems. Stand-alone systems include a single compressor with an attached air-cooled condenser mounted on a skid. These are found in small stores or stores that are over 20 years old. Centralized DX systems include groups of compressors piped in parallel to a common discharge and suction mounted on a skid or rack. The condenser is remotely located, typically on the roof. Several compressor racks are installed to serve most or all refrigeration loads at a supermarket. Figure 3-5 illustrates a typical centralized DX system.

Figure 3-5. Typical Direct Expansion System[50]



A centralized DX system is identified as the appropriate baseline for these advanced systems. Our research confirmed that centralized DX is the predominant system in supermarkets within the United States and is considered the baseline scenario for the advanced systems reviewed. A review of commercial refrigeration projects, summarized in Table 3-23, reveals that centralized DX system cost ranges from $3,877 to $8,944 per ton. The full cost and cost per ton in Table 3-23 include the installation labor costs. Research did not show a pattern in labor costs being higher or lower for the emerging technologies compared to the baseline technologies. Interviewees indicated that installation costs varied widely from project to project.

[50] International Energy Agency (IEA). 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1-Executive Summary."

The average baseline cost per ton of was $5,103. This was not used as the cost of the baseline system when calculating incremental cost for each of the four emerging technologies studied, as each emerging technology project document reviewed included its own estimated baseline cost; however, the baseline costs in these documents matched well with this calculated value.

Table 3-23. Centralized DX System Costs

System Size (Tons)[1]	Full Cost ($)	Cost per Size ($/Ton)	Source
47	$183,195	$3,877	Efficiency Maine grocery store project report, Fort Kent, ME, 2012
16	$93,578	$5,971	Efficiency Maine grocery store project report, Oakland, ME, 2011
27	$156,000	$5,688	Efficiency Maine grocery store project report, Guilford, ME, 2010
25	$107,957	$4,379	Efficiency Maine grocery store project report, Cornish, ME, 2010
40	$157,600	$3,955	Efficiency Maine grocery store project report, Columbia, ME, 2010
36	$160,000	$4,388	Efficiency Maine grocery store project report, Patten, ME, 2009
10	$92,722	$8,944	Efficiency Maine Ice manufacturing project report, Brewer, ME, 2009
94	$420,000[2]	$4,468	Estimated from Dev. And Demo. Of an Advanced Supermarket Refrigeration HVAC System Report
94	$400,000[2]	$4,255	Estimated from Dev. And Demo. Of an Advanced Supermarket Refrigeration HVAC System Report

[1] Tons = Tons of refrigeration

[2] Estimated based on incremental cost percentage provided in study review

3.6.2 Sources of Data

ERS identified published resources, key market actors, and manufacturers in our research effort for this measure. A review of two grocery store energy programs from National Grid and PG&E appears to show that upgraded controls such as floating head pressure, floating suction pressure, and variable speed fan controls are already well established. Such controls are typically retrofitted to standard refrigeration systems, but may also be included in advanced compressor systems depending on the type of configuration.

Research did not identify program incentives that were specific to the advanced refrigeration technologies mentioned above. However, a custom projects could qualify under existing rebate programs with proven energy savings through a technical assistance study.

The industry papers, case studies, and presentations regarding advanced refrigeration systems we researched provided the majority of the incremental cost data. The incremental costs collected are highly variable, ranging from 0% to 55% more than the baseline scenario for all of the advanced technologies identified. Even when isolating the specific advanced technologies, the cost range is still variable. Estimated incremental costs per system expressed as a percentage are as follows:

- Distributed direct expansion (DX)

  Incremental cost: 15%

- Secondary loop

  Incremental cost: 0%–35%

- CO_2 cascade

  Incremental cost: 10%–30%

- CO_2 transcritical booster informative

  Incremental cost: 20%–55%

Interviews conducted did not lead to direct incremental cost data, but provided other insightful, relevant information. For example, the mentioned variability in implementation costs is partially due to the fragmentation of the refrigeration industry. Multiple manufacturers are often involved with the components of a whole system. Site-specific conditions and system requirements also affect the uniformity of implementation cost.

- **Key market actors** – ERS identified eighteen key market actors, including several manufacturing and installation providers. We reached out to many of the market actors and interviewed Richard Travers of Freeaire, Jim Boyko of Boyko Engineering, and Kevin Cote, Brian Owens , and Christopher Rogers of ClearResult. The interviews and outreach with market actors, such as Jodi Beebe of ClearResult, resulted in the identification of case studies and additional resources with incremental cost data.

ERS identified several papers, studies, and presentations that detail advanced refrigeration compressor technologies. The sources of this information include Oak Ridge National Laboratory, PG&E, ASHRAE, Ingersoll-Rand, EPA, Accelerate America, and kW Engineering. We reviewed several supermarket projects performed by ERS for applicable baseline cost data. The studies are shown in Table 3-24, and the presentations are shown in Table 3-25.

Table 3-24. Identified Studies on Advanced Compressors for Refrigeration

Description	Source	Cost Info	Technology Info
IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems	Oak Ridge National Laboratory	Yes	
Supermarket 2013 NR15 CASE Report draft 17Mar11	PG&E	Yes	
Refrigeration Energy Savings with Floating Head Pressure "floating head paper"	Greg Wheeler (OSU), Gayland Smith (ODE)		Yes
Dev. and Demo. of an Advanced Supermarket Refrigeration HVAC System	Oak Ridge National Laboratory	Yes	
Dedicated Mechanical Subcooling Design Strategies_Thornton	UWM (University of Wisconsin – Madison)		Yes
Advanced Supermarket Refrigeration System	Oak Ridge National Laboratory		Yes
Supermarket refrigeration system with completely secondary loops	ASHRAE		Yes
Energy Analysis of Various Supermarket Refrigeration Systems	Ingersoll-Rand Climate Control		Yes
Analysis of advanced_low-charge refrigeration systems for supermarkets	Oak Ridge National Laboratory		Yes
Case Study: Transcritical CO_2 Supermarket Refrigeration Systems, DOE Better Buildings	U.S. DOE	Yes	
"In Love with CO_2" Angelo Caputo's Fresh Market article	Magazine: Accelerate America June 2015	Yes	
"Food Retail Panel Discussion" Ahold USA article	Magazine: Accelerate America July-August 2015	Yes	

Table 3-25. Identified Presentations on Advanced Compressors for Refrigeration

Description	Source	Cost Info	Technology Info
High efficiency low emission refrigeration system	Oak Ridge National Laboratory		Yes
kW Engineering 2011_WEEC-commercial refrigeration	kW Engineering		Yes
PG&E-ESG-refrigeration-controlcard-web-final	PG&E		Yes
Advanced Refrigeration Systems_Emerson	Emerson	Yes	Yes

3.6.3 Market Status as of April 2016

Many advanced compressor technologies are available in the marketplace at the time of this report. For example, Zero-Zone, Hill Phoenix, and Hussmann all offer distributed DX units. Although limited market trend information was obtained during the research, Christopher Rogers from ClearResult discussed his experiences and mentioned that distributed systems appear to have a higher prevalence with store expansion projects than with retrofits or new stores. Additionally, Chris has seen a decline in secondary loop systems in grocery stores. A full list of identified, available advanced compressor products is presented in Tables 3-26 through 3-29.

Table 3-26. Distributed Systems Available on the Market

Manufacturer	Product Name	Description
Hussmann	Protocol	Indoor distributed cabinets with 2–8 scroll compressors enclosed; horizontal or vertical configurations available
Hussmann	Protochill	Protocol distributed cabinets with integrated secondary loop for medium temperature applications
Zero-Zone	Edge	Exterior and interior units, with scroll or reciprocating compressors
Hillphoenix	ParaTemp	Exterior units for roof or behind store, includes a self-contained parallel condenser
Hillphoenix	AdaptaPac	Modular system for small footprint retail refrigeration and convenience stores. Each unit contains up to 3 bays with up to 4 scroll or hermetic reciprocating compressors per bay.
Hillphoenix	InviroPac	Indoor distributed cabinets. Up to 8 reciprocating or scroll compressors for horizontal configurations. Up to 4 reciprocating or scroll compressors for vertical configurations.
Hillphoenix	WeatherPac	Larger external distributed system for larger stores, installed on roof above loads; variety of compressor options

Table 3-27. Secondary Loop Systems Available on the Market

Manufacturer	Product Name	Notes
Hussmann	TerraChill	Liquid CO_2 secondary fluid, both medium and low temperature loads
Hussmann	Pump Station	Propylene glycol 30%–35% mixture secondary fluid, medium temperature loads
Zero-Zone	Coldloop	Glycol or CO_2 secondary fluid
Hillphoenix	SNLT2	Liquid CO_2 secondary fluid, low temperature loads
Hillphoenix	SNMT2	Liquid CO_2 secondary fluid, medium temperature loads

Table 3-28. CO_2 Cascade Systems Available on the Market

Manufacturer	Product Name	Notes
Hillphoenix	SNLTX2	Upper system is a traditional medium temperature DX; lower system is a low temperature CO_2 subcritical DX system.
Zero-zone	Coldloop	Low temperature loads served by CO_2 DX system; medium temperatures served by a CO_2 secondary fluid loop; CO_2 is cooled with an R-407A upper refrigeration system.

Table 3-29. CO_2 Transcritical Booster Systems Available on the Market

Manufacturer	Product Name	Notes
Hussmann	Purity	Multiple CO_2 compressor racks, with various options including heat recovery, mechanical sub-cooling, and adiabatic gas coolers
Hillphoenix	Advansor	Parallel CO_2 reciprocating compressor racks that can serve both medium and low temperature loads. System comes standard with electronic expansion valves standard. Heat recovery option available.
Hill phoenix	Advansor Flux	Packaged multiple compressor CO_2 transcritical booster system. This system is compact enough to use as a distributed system for large stores, or as a central system in smaller stores.

3.6.4 Incremental Cost

A review of identified resources resulted in at least one incremental cost data point for each advanced system considered in this study. Table 3-30 summarizes the incremental cost for the advanced refrigeration systems selected for this report versus a centralized DX baseline. All of the data collected is based on a new construction measure basis.

Table 3-30. Incremental Cost Information for Advanced Refrigeration Systems

Adv. System	Incremental Cost	Description	Notes	Source
Distributed DX	$60,000 (15%)	A 94-ton water cooled distributed system	Incremental cost: equipment: $53,000; installation: $7,000	Dev. and Demo. of an Advanced Supermarket Refrigeration HVAC System, (2001)
Secondary loop	$147,000 (35%)	A 94-ton R-507 primary system with propylene glycol secondary loop	Baseline system uses R22 or R404A with air-cooled condensers. Extra costs associated due to condenser type difference. Incremental cost: equipment: $70,000; installation: $77,000	Dev. and Demo. of an Advanced Supermarket Refrigeration HVAC System, (2001)
Secondary loop	15%	R404A or R507 primary and propylene glycol or potassium formate secondary loop	Study states that maintenance cost for secondary system should be less	IEA Annex 26 Report, (2003)
Secondary loop	0%	A 23-ton system with R717 (ammonia) primary and HFE-7100 secondary loop	Study considers total cost of system (cases, piping, refrigerant, brine, labor, compressor rack or chiller)	IEA Annex 26 Report, (2003)
Secondary loop	$150,000	A 105-ton system using R404A primary and CO2 secondary loop.		PG&E Supermarket Refrigeration Codes and Standards Enhancement Initiative (2011)
CO_2 cascade	10%	A 26-ton system using propane for the top and CO_2 for the bottom system.		IEA Annex 26 Report, (2003)
CO_2 cascade	10%	A 71-ton system with R404A for the top and CO2 for the bottom system.	Incremental cost takes into account reduced refrigerant charge (R404A) compared to DX system. Includes Denmark's tax on R404A.	IEA Annex 26 Report, (2003)
CO_2 cascade	$50,000	A 33-ton system using R404A for the top, and two CO2 loops serving refrigeration loads.	System includes both CO_2 direct expansion and a secondary recirculated loop of CO_2.	PG&E Supermarket Refrigeration Codes and Standards Enhancement Initiative, (2011)
CO_2 transcritical booster	50-55%	A 62-ton transcritical system at Hannaford supermarket in Turner, Maine. First in the U.S., and began operation in 2013.	40% incremental cost for refrigeration equipment, an additional 10%-15% for the required piping and display cases.	Case Study: Transcritical CO_2 Supermarket Refrigeration Systems, DOE Better Buildings, (2015)
CO_2 transcritical booster	$250,000	A 112-ton transcritical CO_2 system with dry gas cooler.	Incremental cost includes equipment and installation.	"Food Retail Panel Discussion" Ahold USA, Accelerate America July-Aug 2015 article
CO_2 transcritical booster	20%	A 364-ton transcritical CO2 system with 4 CO_2 compressor racks. Each rack includes 3 low temperature compressors and 5 to 6 medium temperature compressors.	Incremental cost includes equipment only.	"In Love with CO_2" Angelo Caputo's Fresh Market, Accelerate America June 2015 article

Table 3-31 summarizes the cost data points from Table 3-30 averaged if more than one data point was available for the technology, and listed as incremental cost per ton of refrigeration.

Table 3-31. System Cost Data

Upgrade Type	Incremental Cost per Ton Refrigeration ($)	Number of Data Points for Cost Calculation	Incremental Cost per Ton Refrigeration (%)	Number of Data Points for Percentage Calculation
Distributed refrigeration system	$638	1	15%	1
Secondary loop system	$1,496	2	17%	3
CO_2 cascade systems	$1,515	1	10%	2
CO_2 transcritical systems	$2,232	1	36%	2
All upgrade technologies considered	$1,470	5	19%	8

Our research did not indicate that the incremental cost of these four technologies correlates to system efficiency. The efficiency improvements seemed to be highly variable and depended on store location, store configuration, temperature requirements, store size, etc. The higher cost for CO_2 transcritical systems is partially due to the requirement for components rated for the higher pressures and the brand new market for transcritical CO_2 systems. However, it's possible that maintenance costs are reduced with transcritical CO_2 systems because of the high quality parts used.

3.6.5 Cost Trends

For CO_2 transcritical systems, there appears to be a downward cost trend as the number of installations of these systems increase. Our research did not reveal generally accepted cost predictions for distributed DX, secondary loop, or CO_2 cascade systems. Tracking projects over the next 1 to 2 years should reveal additional cost trends.

3.6.6 Additional Market Insights

Our interviews for these systems indicated that energy efficiency was sometimes a secondary concern during the decision process of whether to install one of these systems. Eliminating HFC refrigeration was the primary consideration and is likely to be more influential in future market adoption than the cost savings from reducing energy consumption. If HFCs could not be eliminated, then reducing the refrigerant charge to reduce the potential leaks of HFCs is preferable. Additional non-energy benefits that may help increase market adoption include reduced refrigerant costs due to low charge solutions or lower cost of refrigerants (such as CO_2).

3.7 Technology Category 7 – Advanced Compressed Air Diagnostic Monitoring

Advanced compressed air system diagnostic monitoring is an industrial measure with large savings potential. While there are multiple compressed air diagnostic monitoring solutions available, the emerging technology option that this study focused on includes systems that communicate with a dashboard visible by either the company providing the service or the client itself. These systems can automatically determine and adjust the number of compressors and storage tanks in a plant that are operating, detect leaks, and improve pressure control through increasing the accuracy of the system pressure. ERS is aware of two providers of this service in the Northeast. These providers do not manufacture the controllers themselves and are not aware of other competitors in the Northeast. In order to preserve the requested anonymity of the manufacturers who provided pricing information, the specific brands and models of the controllers are not listed. We have identified other companies that provide automatic compressed air monitoring services in other parts of the country, such as Air Technologies Compressed Air Systems and Airleader Master Control.

One interviewee mentioned that in his experience the desire for energy savings as a result of installing these controllers is often secondary to a desire for knowledge that the system is stable and running reliably, as well as the ability to monitor both real time and historical data.

3.7.1 Technology Description

Advanced compressed air diagnostic monitoring systems are identified as having the following features:

- Ability to control and optimize multiple compressors
- Provide a real-time system map to the end user, to the provider of a monitoring service, or both. This is a map of where all of the compressors are, their operating status, and pressure at various points in the system and is sometimes available through a web-based or a remote graphical user interface.
- Ability to rotate operating hours of machines to ensure even wear on each machine, to prioritize the most efficient compressors, to bring back-up compressors into operation, to control the machines to prevent frequent cycling, and to assign the most efficient combination of compressors for a specific load
- Automated warnings when parameters fall out of a desired range and caching of historical events to allow for easier problem diagnosis

Conversations with key market actors indicated that these systems are typically installed in compressor plants with roughly four or five air compressors, although it is possible to install them on systems with fewer, and they can be installed on systems with more than ten compressors.

3.7.2 Baseline Description

The baseline case is no action, or $0, which is consistent with the baseline used in the Eversource Energy Rewards Program project we reviewed. There are no codes in the Northeast that would dictate a baseline for this measure, and standard controls are required for the basic operation of compressed air systems.

3.7.3 Sources of Data

We conducted interviews with the two companies in the Northeast who provide these compressor controllers and services to customers. One interview was with a current employee and one was with a former employee. Both were able to give ballpark ranges for the compressor controller itself, along with other valuable information regarding typical characteristics of sites that install these controllers, what factors affect cost, and expected price trends. ERS also reviewed project documentation for one project at a manufacturing facility in the Northeast which involves installation of one of these systems as well as a service contract for 5 years of monitoring the system. Additionally, we interviewed two representatives of companies that manufacture these controllers to cross-check the prices provided by the representatives of the service companies.

3.7.4 Market Status as of April 2016

These controllers are available in today's marketplace, although there are a limited number of companies that offer them as part of a service. As part of this study, we investigated monitoring hardware and software from CDI meters, which appeared to be a third company that provides these types of systems in the Northeast. However, an interview with a representative of CDI clarified that the hardware and software that they offer only monitors points in the compressed air plant and does not have the ability to control the compressors.

3.7.5 Incremental Cost

The cost information for this measure came from two representatives from service providers, two representatives from controller manufacturers, and one set of reviewed project documents. The interviews revealed a number of factors influencing the cost of these systems, and the ranges reflect the variety of different site characteristics.

Factors affecting incremental cost include:

- Number of compressors
- Location of and distance between the compressors
- Working requirements in the plant
- Piping and wiring required
- Number of different brands of compressors
- Presence of variable speed compressors

The factor that affects the cost of the system the most by far, according to the conducted interviews, is the number of compressors in the plant. The other factors listed above are all secondary.

Table 3-32 presents the incremental cost information collected for this measure.

Table 3-32. Pricing Information for Automatic Compressed Air Monitoring

Cost	Amount	Description	Notes	Source	Date collected
Full = Incremental	$15,000-$20,000	Complex controller for many compressors	Automatic compressor sequencing enabled	Interview with compressed air controller service provider #1	12/8/2015
Full = Incremental	$15,000-$20,000	Complex controller for many compressors	Confirmed above pricing with the manufacturer	Interview with compressed air controller manufacturer #1	4/4/2015
Full = Increm	$9,000	Base cost of controller for small number of compressors	This is the base price of a controller for 4 compressors, without other associated difficulties	Interview with manufacturer #2	4/4/2016
Full = Incremental	$8,000-$10,000	Price of power, pressure, and flow remote monitoring to customer	Upfront cost paid for by customer	Interview with compressed air controller service provider #2	11/12/2015
Full = Incremental	$5,000-$6,000	Base cost of controller for small number of compressors	Does not include real time system map	Interview with manufacturer #1	4/4/2016
Full = Incremental	$8,000 - $10,000	Cost of controller for fewer compressors with site specific challenges	Cost if there are multiple brands of compressors, and/or are farther apart, or have other associated difficulties, the cost may be increased to this much	Interview with manufacturer #1	4/4/2016
Partial	$5,000 - $6,000	Addition of a real time system map	Gives a system map of the plant, the pressures etc. This can be added to the customer's choice of controller	Interview with manufacturer #1	4/4/2016
Partial	$8,000 - $10,000	Base cost of controller that controls a small number of compressors	This price reflects compressors that are all of the same brand, are close to each other, and doesn't have other associated difficulties	Interview with manufacturer #1	4/4/2016
Full = incremental + service	$45,000	Controller + installation and end-user leak detection training	This is a project cost that includes the compressor controller, installation, and in house leak detection training	Proposed project document quote	2/23/2016
Additional service	$13,730	5 year monitoring service	Does not include equipment cost	Proposed project document quote	2/23/2016
Additional	$2,500	Cost to control VFD compressor	If at least one of the compressors in the plant has a VFD, this module must be added to the compressor cost	Interview with manufacturer #1	4/4/2015
Partial	$1,500	Data acquisition System	Price of the data acquisition system paid for by service provider	Interview with compressed air service provider #2	11/12/2015

Table 3-33 summarizes the data above by averaging costs when multiple data points are available. This was done for each of four different types of systems, based on the number of compressors and system complexity. A “simple” system refers to one where the compressors are all the same brand, have no VFDs, are close together, and are easily accessible, while a “complex” system has at least a few of those challenges. Note that according to the interviews, the addition of a real-time system map is estimated at $5,500. The prices listed in table 3-33 do not include labor costs.

Table 3-33. Summary of Incremental Cost Data for Advanced Compressed Air Diagnostic Control

Incremental Cost	Number of Data Points	Number of Compressors	Relative complexity of system
$7,833	3	5 or fewer	Simple
$9,000	1	5 or fewer	Complex
$9,000	1	10 or more	Simple
$17,500	2	10 or more	Complex

3.7.6 Cost Trends

An interview with one service provider predicted that costs for these systems must go down over time, as today they are often hard to justify from an economical point of view. A representative from another service provider expects the price to stay the same while new features are added.

3.7.7 Additional Market Insights

Interviews revealed that the main barriers to the installation of these systems are cost and the ability to secure enough plant downtime to install the system. Education and understanding of the entire value proposition and lack of a corporate initiative to save energy were also cited.

3.8 Technology Category 8 – Improved Efficiency Electric Heat Pump Water Heaters

This technology category is focused on residential and small commercial electric heat pump water heaters that offer improved performance in installation environments that experience ambient temperatures below the standard testing/rating ambient temperature.

The manufacturer-published efficiency ratings for heat pump water heaters (HPWHs) are calculated at an industry standard ambient temperature of 68°F. Below that temperature, the performance deteriorates rapidly for most HPWHs. In the northeast, most residential water heaters are installed in un-heated or semi-heated basements with average temperatures below 68°F. Some manufacturers are producing, and others are developing, HPWHs that maintain better performance at lower ambient temperatures.

3.8.1 Baseline Description

HPWHs are installed as both retrofit and new construction measures. For assessing the energy savings potential and incremental costs of HPWHs, the baseline is an electric storage water heater of similar size, meeting federal efficiency standards. HPWHs also replace tankless “side-arm” water heaters that are heated off of fossil fuel space heat boilers; however the suggested baseline remains an electric storage water heater as the most common alternative, and does not involve a fuel switch. With the current and predicted pricing for natural gas, HPWHs are not an economically attractive alternative to a gas water heater.

3.8.2 Northern Climate Specification

In 2013, the Northwest Energy Efficiency Alliance (NEEA) released a standard for rating HPWHs in cold climate installations. This standard divided HPWH performance into three tiers; tier 1 includes HPWHs that meet the minimum Energy Star requirements, while tier 2 and tier 3 HPWHs include features that enable them to perform more efficiently than other units in cold climate installations. Figure 3-6 summarizes the rating tiers of the NEEA Northern Climate Heat Pump Water Heater Specification.[51] In this table, the northern climate energy factor (EF_{nc}) is rated at an ambient temperature of 50°F rather than 68°F.

Figure 3-6. Northern Climate Specification Qualification Summary

Tier 1 Requirements:

$EF_{ncs} \geq 1.8$

- ENERGY STAR compliance
- Installed in semi-conditioned or unconditioned spaces

Tier 2 Requirements are the same as Tier 1, plus:

$EF_{ncs} \geq 2.0$

- Minimal use of electric heating elements
- Freeze protection
- Exhaust ducting option with airflow guidance
- Compressor shutdown/notification
- 10 year Warranty
- Condensate Mgmt.
- Installed in conditioned, semi-conditioned or unconditioned spaces

Tier 3 Requirements are the same as Tier 2, plus:

$EF_{ncs} \geq 2.4$

- Intake ducting option
- Air filter management

[51] This version of the specification was available at http://neea.org/advancedwaterheaterspec. NEEA has since updated the specification. The new version can be found at the above website.

NEEA staff indicated that many of the HPWH manufacturers who are active in the Northeast have come to market with HPWHs that are capable of operating more efficiently at low ambient temperatures. As of March 2016, NEEA listed cold climate energy factors for more than a dozen HPWHs. Key observations regarding currently rated cold climate HPWHs:

- There are two manufacturers (GE and Bradford White)[52] offering HPWHs in the United States that met NEEA's Tier 2 and 3 requirements and thirteen manufacturers (American, A.O. Smith, GE, Kenmore, Lochinvar, Reliance, Rheem, Ruud, State, Stiebel Eltron, U.S. Craftmaster, and Whirlpool) offering HPWHs that met NEEA's Tier 1 requirements.
- Among the Tier 1 HPWHs, most of the units have cold climate EF_{nc}s between 1.8 and 2.2; Stiebel Eltron is the only manufacturer offering a Tier 1 HPWH with a cold climate EF_{nc} greater than 2.2 and this is their Accelera 220 E model, which has a cold climate EF_{nc} of 2.6.
- GE and Bradford White both offer Tier 3 HPWH models with cold climate energy factors of 2.7 and above. ERS was able to determine that the Stiebel Eltron Accelera 220 E, although it has a qualifying energy factor, did not meet the Tier 2 or 3 requirements of the northern climate specification, due to the lack of a manufacturer designed exhaust ducting accessory for the unit.
- Typical HPWHs allow users to operate units in "heat pump", "hybrid", and "electric resistance" mode. What differs between each of these modes is how often the HPWH's electric resistance element is used. Higher efficiency northern climate models (e.g. the Stiebel Eltron Accelera) only enable the electric resistance element as needed to meet periods of extremely high demand or have a "cold climate" mode (e.g. Bradford White and GE) that minimizes the runtime of the electric resistance element.[53] Interviews with Stiebel Eltron indicated that their Accelera 220 achieves an EF_{nc} of 2.6 while in standard operating more. In order for the Bradford White Aerotherm and GE Geospring to achieve $EF_{nc} \geq 2.6$ they must be put into a "cold climate" mode; in standard "hybrid" mode these heat pump

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[52] As of February 2016, the Bradford White Aerotherm (RE2HXXR10B), GE Geospring (GEHXXDFEJXXX & GEHXXDEEJXXX)

[53] https://neea.org/docs/default-source/reports/laboratory-assessment-of-stiebel-eltron-accelera-220-e-heat-pump-water-heater.pdf?sfvrsn=6

operate with EF_{nc}s between 2.0 and 2.2. As of March 2016, the GE, Bradford White, and Stiebel Eltron units tested for the cold climate specifications are the same models as the standard efficiency units offered by those manufacturers.

NEEA plans to issue a revised cold climate specification in 2016. This revised specification will build off NEEA's experience working with installers, manufacturers, and homeowners to better tailor their guidelines to cold climate applications. According to NEEA, their testing has shown very limited improvement in energy efficiency due to the installation of intake and exhaust ducting and they anticipate eliminating the requirement to have ducting in the 2016 update to the specification. In addition, the 2016 specification will include two additional efficiency tiers and will require that the default operating mode be the heat pump mode and that the electric resistance element only be used when low ambient temperatures are present.

3.8.3 Market Status as of April 2016

Market actors – As of February 2016, there were three manufacturers (GE, Bradford White, Stiebel Eltron) offering HPWHs in the United States with $EF_{nc} \geq 2.6$. NEEA expects this number to grow as additional manufacturers enable cold climate operating modes on their HPWHs. In addition, ERS reviewed HPWHs available in Europe and the Stiebel Eltron Accelera stands out as the unit with the highest COP.[54] While several other HPWHs available in Europe have similar efficiencies to the Accelera, they are not currently available in the US market. Within Europe their pricing is comparable to the Stiebel Eltron HPWH.

Market factors – HPWHs, including cold climate models, have seen increased market adoption in the last several years. However, ERS's interviews with manufacturers, plumbers, and market actors indicated that there are still several factors that influence customers' decisions to install HPWHs and the realization of savings from cold climate HPWHs in particular:

- Availability of natural gas and other fossil fuels – HPWH installations are less economical in regions with an established natural gas infrastructure and in buildings with existing natural gas service. Natural gas water heaters are less

[54] http://www.topten.eu/english/building_components/electric_water_heaters.html

expensive than HPWHs, and with current natural gas prices, are a more attractive option for customers with access to natural gas.

- **Siting and heat pump location** – In general, plumbers were familiar with the need to install HPWHs in open spaces with mild ambient temperature. Most of the plumbers indicated that unfinished basements are the most typical location for HPWH installations, while one of the plumbers has utilized ducting kits to enable installation in smaller spaces such as closets.
- **Incentive availability** – HPWH manufacturers indicated that incentive availability has a significant impact on the adoption of their units. Without incentives, many consumers are unable or unwilling to act on the higher cost of the HPWH. They indicated that incentives are a key factor in motivating consumers to invest in the higher cost HPWH technology.
- **Heat pump operating mode programming familiarity** – Our research found that improved efficiency cold climate HPWHs are currently available on the market. However, "cold climate" is not the default operating mode on most heat pump water heaters, nor is it listed as one of the typical operating modes on applicable units (GE Geospring and Bradford White Aerotherm). In addition, interviews with plumbers and distributors indicated that they were not familiar with the programming required to enable this mode on HPWHs. The obscurity of the cold climate programming sequencing on many existing heat pumps prevents them from achieving the higher efficiencies available via this operating mode.

3.8.4 Incremental Costs

Interviews with market actors and review of manufacturer data indicated that the "cold climate" HPWHs rated by NEEA are the same models as the standard efficiency units offered by GE, Bradford White, and Stiebel Eltron, but configured to operate in a mode that limits the hybrid/electric heating element modes in favor of heat pump operation, and includes the capability of outside air ducting. The prospective elimination of the ducting requirement from the 2016 NEEA guidelines would make the cold climate heat pump installation and labor costs equivalent to those of standard HPWHs of the same manufacture. However, the most efficient of these HPWHs—the Stiebel Eltron models—are more expensive than other HPWHs on the market.

The 2014 NEEP Phase 3 Incremental Cost Study[55] provided incremental installed costs between electric resistance water heaters and conventional HPWHs by region and hot water heater storage tank size. This data is summarized in Table 3-34.

Table 3-34. 2014 NEEP Phase 3 Incremental Cost Data for HPHWs

Baseline Storage Water Heater (Gallons)	Market 1 Northern New England Incremental Cost ($/Unit)	Market 2 Central/Southern New England Incremental Cost ($/Unit)	Market 3 New England City Incremental Cost ($/Unit)	Market 4 NY Metro Incremental Cost ($/Unit)	Market 5 NY Upstate Incremental Cost ($/Unit)	Market 6 Mid-Atlantic Incremental Cost ($/Unit)	All Markets – Base Cost Factor Incremental Cost ($/Unit)
50	$818	$1,176	$1,319	$1,621	$1,029	$909	**$1,029**
60	$876	$1,235	$1,383	$1,688	$1,089	$970	**$1,092**
80	$992	$1,354	$1,510	$1,823	$1,208	$1,092	**$1,217**

We reviewed this data and confirmed with our sources that it is still current, but does not accurately reflect the higher incremental cost of the Stiebel Eltron models. Table 3-35 summarizes our review of the incremental costs for the GE, Bradford White, and Stiebel Eltron HPWHs with $EF_{nc} \geq 2.6$.

Table 3-35. Incremental Cost Data for HPWHs with EFnc ≥ 2.6

Baseline Storage Water Heater (Gallons)	Tank Size (Gallons)	Baseline Equipment Cost	HPWH Equipment Cost	Incremental Equipment Cost	Baseline Installation Cost	HPWH Installation Cost	HPWH Total Installed Incremental Cost
GE Geospring	50	$614	$999 to $1,399	$385 to $785	$419	$1,087	$1,053 to $1,453
	80	$982	$1,599 to $1,899	$617 to $1,285	$419	$1,087	$1,285 to $1,953
Bradford White Aerotherm	50	$614	$1,090	$476	$419	$1,087	$1,144
	80	$982	$1,940	$958	$419	$1,087	$1,626
Stiebel Eltron	58+	$736	$2,399	$1,663	$419	$1,087	$2,131

The information in Table 3-35 reflects the following key findings from our research:

- Baseline electric water heater costs – The baseline equipment and labor costs in Table 3-35 are from NEEP's Phase 3 Incremental Cost Study. Review of this cost data, and interviews with installers, confirmed that these baseline costs are consistent with standard efficiency electric resistance water heaters. Higher

[55] http://www.neep.org/incremental-cost-study-phase-3

efficiency/quality electric water heaters with longer warranties, such as the Rheem Marathon line, are priced higher, at around $1,000 for 80-gallon models.

Baseline electric water heater costs have been steady over the last several years, but may increase in the near future with the release of more stringent electric resistance water heater efficiency requirements from the DOE.[56]

- **HPWH equipment costs** – The incremental costs for the GE and Bradford White water heaters are consistent with units of similar size from NEEP's Phase 3 Incremental Cost study while the incremental equipment cost for a Stiebel Eltron HPWH is significantly higher. The GE and Bradford White HPWHs are generally considered to be similar in cost to standard efficiency HPWHs, while the Stiebel Eltron products are generally higher priced and are advertised as premium units.
- **HPWH installation costs** – ERS interviewed several heat pump water heater installers and NEEP sponsors regarding the installation cost to install a heat pump water heater. These installers indicated that, on average, it costs between $760 and $800 to install a HPWH. In addition, condensate pumps are typically required for basement installs when no floor drain is available. This results in an additional labor and miscellaneous materials cost of approximately $300. This incremental cost is exclusive of any electrical wiring costs to meet current codes or to connect condensate pumps.

  Some interviewees reported that a portion of the incremental labor cost was associated with "unknown" factors regarding placement of the HPWH in the space and general unfamiliarity with new product lines. However, this appears to be less of a factor than it was during NEEP's 2014 Phase 3 Incremental Cost study, when the installers interviewed quoted between 8 and 12 hours of time to install HPWHs as compared to the 8 hours estimated by the installers interviewed in 2016.
- **Optional HPWH outside air ducting costs** – As discussed, NEEA's current (2013) standard, includes a requirement for outside air ducting to reach the highest tiers of the northern climate specification. ERS's discussions with NEEA confirm that they intend to delete this requirement from the 2016 northern climate specification

[56] DOE residential water heater energy efficiency requirements: http://energy.gov/eere/femp/covered-product-category-residential-electric-resistance-water-heaters

as ducting was not found to have a significant impact on the efficiency of the HPWHs. However, we investigated the cost of ducting with installers who estimated the cost at approximately $750 ($200 for a ducting kit, $100 for miscellaneous materials, and $450 in labor) to install a ducting kit with a GE Geospring HPWH. In discussing the ducting kits, we found that they are not being recommended for standard installations in the Northeast due to our extreme winter temperatures, but may be needed to duct to larger interior spaces when HPWHs are installed in restricted areas.

3.8.5 Cost Trends

Pricing has remained stable for the last two years for HPWHs. As long as efficiency programs continue to support this technology with incentives, it can be anticipated that costs will remain stable. If that support is terminated, it is clear from our research that HPWH costs will need to be reduced to remain viable in an open market. Another factor is that the DOE is working to revise the energy standards for baseline electric resistance water heaters. As energy efficiency requirements are elevated, baseline prices will also increase, reducing incremental costs.

3.8.6 Additional Market Insights

The pending updates to the NEEA cold climate specification require that the default operating mode for HPWHs in the northern US be optimized for heat pump operation, limiting electric resistance operation. It is likely that HPWH manufacturers will respond to this requirement by offering cold-climate heat pump models with default operating modes specific for northern markets. Early market analysis suggests that the costs for these “cold climate” units will be only nominally more expensive due mostly to setup and stocking costs. However, as HPWHs gain more market acceptance, more European manufacturers may enter the U.S. market, and inexpensive less efficient models may also be introduced. NEEP sponsors should watch this market carefully.

3.9 Technology Category 9 – Commercial Natural Gas Engine Powered Heat Pump Water Heaters

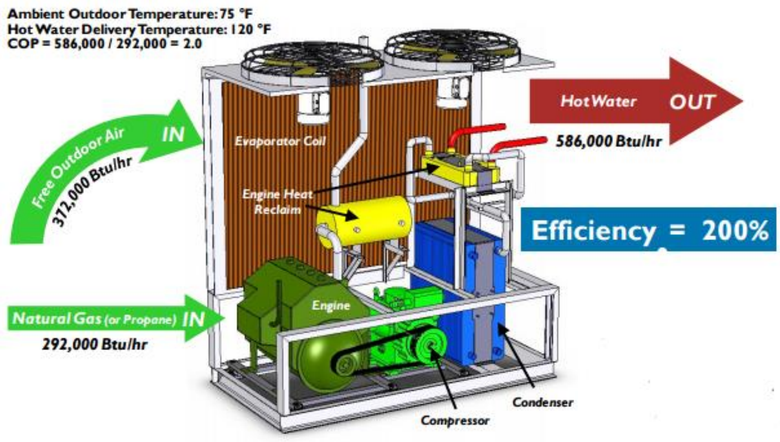
Gas engine heat pump water heaters (GHPWHs) are an emerging technology that combines two very mature technologies: engine generators and heat pumps. To date, very few systems have been installed in the US. Because of this, costs and pricing are not fully mature and projects are customized to the particular situation and end uses. According to our research, Ilios Dynamics, a subsidiary of Tecogen is the only firm currently marketing GHPWHs in the US. As such, general technology guidance is being provided, along with several case study examples. With stable and low natural gas prices, manufacturers are now beginning to reintroduce this technology to the US market and we anticipate that future research will solidify costs through additional case studies.

GHPWHs are similar to combined heat and power systems in that the best economic outcomes are achieved with positive spark spreads[57], and continuous hot water demands. They are advantageous, because they use a cheap fuel (natural gas), and an efficient technology (heat pumps). There are a number of different types of GHPWH systems including, air-to-water, water-to-water, air-to-air with WH modules, and variable refrigerant flow (VRF) type air-to-air systems with WH modules. Just as there are many different types of electric heat pumps, there are multiple approaches to GHP WH technology:

- **Air-source GHPWHs** – The primary function of these units is to generate hot water. They typically have heat recovery units on the exhaust streams of the engines that provide increased efficiency and capability to produce higher water temperatures. These systems are appropriate for continuous low to medium temperature (<150°F) hot water demands, and are often seen as an alternative to combined heat and power since ideal sites have year round water heating loads. A schematic of a GHPWH is shown in Figure 3-7.

[57] "The spark spread is the difference between the price received by a generator for electricity produced and the cost of the natural gas needed to produce that electricity," http://www.eia.gov/todayinenergy/detail.cfm?id=9911

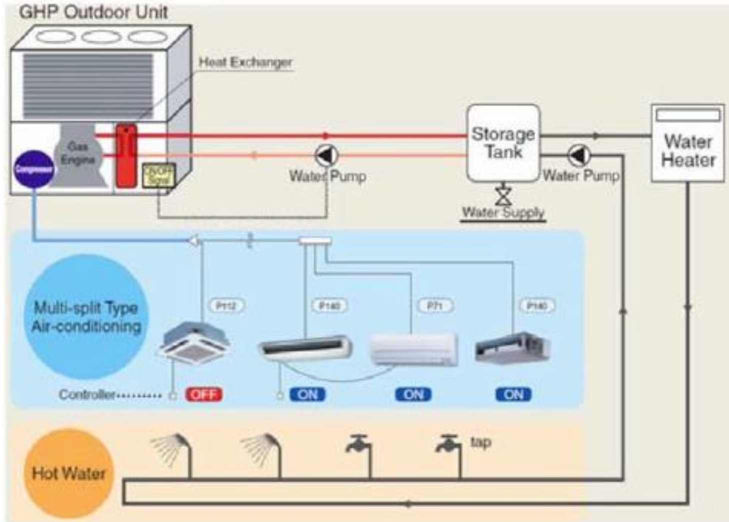
Figure 3-7. Schematic of a GHP System[58]



- ❑ **Water-source GHPWHs** – Similar to air-source GHPWHs, these types of units provide water heating by transferring heat from a water-source heat sink, and capturing exhaust heat through a heat exchanger to boost temperatures. These units are applicable for scenarios where a regenerative temperature water reservoir is available to pull heat from. These systems are also most appropriate for continuous low to medium temperature (<150°F) water demands.
- ❑ **Air-to-air GHPs with WH modules** – These units are simply traditional heat pumps powered by natural gas engines, and equipped with exhaust heat exchangers to provide hot water. In contrast to air-to water type systems, air-to-air type systems with WH modules are not typically equipped for engine exhaust heat recovery, which substantially reduces their efficiency. These systems are most suitable for cooling dominated locales that have continuous low temperature hot water demands (<120°F). A schematic of an air-to-air GHP HP system with a WH add-on unit is shown in Figure 3-8.

58 http://www.iliosdynamics.com/product-air-source.htm

Figure 3-8. Schematic of a GHP HP with WH Add-On Unit[59]



This study is focused on systems that make hot water as a primary product in comparison to GHP air-to-air type units with WH heater add-ons and no exhaust heat recovery. Note that gas-fired, absorption-driven air-source heat pump water heaters are also available from Robur[60]. The Robur units are different from mechanically driven heat pump products in that the compression is provided by absorption, and the expansion by heat from burning natural gas. The absorption cycle has inherent inefficiencies compared to mechanical heat pumps, but with recent advancements in heat recovery within the cycle, performance is improved. Absorption style units are not included in the scope of this study.

3.9.1 Market Status as of April 2016

Despite the fact that GHP WHs have been actively used in Japan since the 1980s, U.S. market acceptance has been poor with very few systems installed. During the 1990s, York offered a GHP WH unit, but it was discontinued due to lack of sales and reliability issues. Manufacturers report that they have struggled to gain traction in the US market. As a result, there are very few GHP WHs available in the US and very limited experience upon which to document costs. Interviews with manufacturers informed that the technology has been slow to take hold in the US due to a number of factors including:

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59 http://www.iges.or.jp/files/research/business/PDF/20140304/4_PD_Mr.Kaneko.pdf

60 http://www.roburcorp.com/heat_pumps/air_to_water_gas_absorption_heat_pump_gahp_a

- Gas utilities are resistant to promote the technology because it reduces gas consumption significantly compared to traditional boilers.
- Most equipment manufacturers are located overseas.
- The technology has not been well promoted in the US.
- The technology is best suited to large volume applications with continuous low temperature (<150°F) hot water demands.
- The systems are inherently custom installations requiring significant engineering expertise.

Key market actors – Manufacturers with current GHP product offerings include Tecogen – Ilios, Intellichoice Energy (ICE) who represents Aisin in the US, Yanmar, and Panasonic. Of these manufacturers, only the Tecogen – Ilios is designed as a dedicated GHP WH, while the others make chillers or ASHPs with heat recovery capabilities for water heating. The GHP WH solution that Ilios provides is a unit with thermal output ranging between 400,000 Btu/hr and 600,000 Btu/hr depending on the current outdoor air temperatures. Current manufacturer offerings are shown in Table 3-36.

Table 3-36. Summary of GHP Manufacturer Product Offerings

Manufacturer	GHP Type
Tecogen-Ilios	Dedicated WH
Robur	Gas absorption air-to-water
ICE (Aisin)	Chiller with heat recovery for WH
Yanmar	Air-to-air heat pump with heat recovery add-on for WH
Panasonic (Sanyo)	Air-to-air heat pump with heat recovery add-on for WH

3.9.2 Baseline Description

Our research indicated that the baseline for GHP WHs is boilers of similar capacity with storage water heaters. GHP WH equipment packages can be configured to work with existing storage water heaters when a boiler is replaced, or they can be installed with a new storage tank. The average installed cost for a cast-iron hot water boiler with output ranging from 100 MBtu/h to 1,000 MBtu/h is $23.50 per MBtu/h[61].

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[61] https://rsmeansonline.com

3.9.3 Incremental Costs

While these costs are highly variable, several case studies on the Ilios units indicate the installed costs of these systems are on the order of $200/MBtu/h to $300/MBtu/h of average thermal output capacity. These costs should continue to be developed through further case studies, and as additional manufacturers enter this market. At this point, project costs should still be considered highly custom and subject to specific location needs, and installation requirements.

The Hotchkiss School in Connecticut purchased an Ilios GHPWH unit primarily to provide efficient water heating during warmer months, which allows them to avoid using an oversized boiler during those periods. In addition, the unit produces chilled water as a byproduct, further increasing its benefit.

The Harbour House in Florida installed an Ilios GHPWH unit in order to reduce the year-round water heating costs of their domestic hot water, pool, and spa needs.

A summary of both projects is shown in Table 3-37.

Table 3-37. Summary of Two GHP WH Case Studies

Case Studies	Hotchkiss School	Harbour House
Type of unit	HEWH-500-AS	HEWH-500-AS
Thermal output	400 MBtu/h to 600 MBtu/h	400 MBtu/h to 600 MBtu/h
Installed cost	$100,000	$150,000
Estimated annual savings	$25,000	$35,000
Estimated annual maintenance	$7,500	$5,000
Net cost savings	$17,500	$30,000
Annual natural gas savings (therms)	30,000	17,000
Estimated carbon reduction (tons CO_2)	175	130
Annual run hours (hours	7500	3500
Simple ROI (years)	5.7	5.0
Installed cost ($/MBtu)	**$200**	**$300**

Incremental cost for GHPWHs is estimated to be between $177/MBtu/h, and $277/MBtu/h depending on the specific location and installation characteristics.

3.9.4 Cost Trends

There is no reliable indication that costs will vary for this technology in the near future. If competitive systems enter the US market, it is possible that costs would come down some, but the current US market needs to be further developed to attract such competition. The systems' main competition is fossil fuel fired boilers, and with the current costs of natural gas and fuel oil, the demand for GHPWHs is not strong. Our interviews further indicate that the industry does not currently recognize opportunities to either lower or increase the costs of these systems.

3.10 Technology Category 10 – Q-Sync Motors

Q-Sync refrigeration fan motor

Q-Sync motors are a proprietary synchronous motor from QM Power with operating efficiencies in excess of 70%, which is more than 10% greater than the energy efficient electrically commutated motors (ECMs or EC motors) currently available on the market.[62]

Q-Sync motors are permanent magnet synchronous motors that directly utilize utility-supplied AC current.[62] By contrast, EC motors require that the AC current be rectified to DC before it is applied to the motor windings, and rectifying electrical current produces some parasitic losses. Therefore, Q-sync motor savings over EC motors is due to the lack of AC to DC conversion losses, and this improved efficiency is additive to the efficiency advantage offered by EC motors compared with shaded pole motors.

Previously developed synchronous motors were prohibitively expensive due to elaborate electronic controls, while the Q-Sync motors rely on a proprietary and patent-pending control system that is simpler and less expensive to manufacture. QM Power's motor design is currently protected by pending patents; ERS was unable to identify any

[62](ORNL 2015) Efficiencies as per a study performed by Oak Ridge National Laboratory, "Q-Sync Motors in Commercial Refrigeration: Preliminary Test Results and Projected Benefits," Fricke and Becker, 2015, http://info.ornl.gov/sites/publications/Files/Pub58600.pdf

other manufacturers that are currently offering anything comparable to QM Power's Q-Sync motors.

Currently available Q-Sync motor models are fractional horsepower (9 to 12 watts of output power) to be used in refrigeration applications such as reach-in, coffin, and closed-door cases. A larger 38-50 watt size is being developed for walk-in coolers and QM Power anticipates developing additional motor sizes in the coming years for household appliances and HVAC systems.[63] Currently, Q-Sync motors are constant speed, which makes them well-suited to refrigerated cases, but incompatible with existing EC motor controls and other variable speed control technologies. According to QM Power, research is underway to develop controls for variable speed operation of Q-Sync motors.

Because QM Power currently offers motors in sizes between 9 watts and 12 watts that are designed as a one-for-one upgrade for replace-on-burnout and new commercial refrigerated case evaporator fan motors, these are the applications that were targeted in ERS's incremental cost research. This research includes review of existing studies on evaporator fan motor incremental costs, an interview with the energy manager of a large New England-based grocery chain, and an interview with representatives from QM Power.

3.10.1 Baseline Description

According to research completed by NEEP in 2014, 1/15th hp (approximately 50 watts of input power and 12 watts of output power) shaded pole motors are the least cost and most widely installed motors for commercial refrigeration evaporator fans.[64] Shaded pole motors dominate the evaporator fan market, although EC motors (ECMs), and to a lesser degree, permanent split capacitor (PSC) motors, also maintain a share of the market.[65]

Table 3-38 summarizes the typical efficiencies, power factors, and power usages of shaded-pole motors, old and new ECMs, and Q-Sync motors, as provided in research performed by ORNL.

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63 http://www.arpae-summit.com/paperclip/exhibitor_docs/14AE/QM_Power_192.pdf

64 (NEEP Refrig 2015) http://www.neep.org/commercial-refrigeration-loadshape-report-10-2015-0

65 See reference above for ORNL 2015.

Table 3-38. Characteristics of Evaporator Fan Motors[66]

Motor Type	Motor Efficiency (%)	Power Factor	Output Power (W)	Input Power (W)
Shaded pole	20	0.601	12	60
EC motor, old	53.1	0.601	12	22.6
EC motor, new	66	0.601	12	18.2
Q-Sync	73.1	0.936	12	16.4

ERS reviewed existing motor efficiency standards to establish the baseline motor efficiency requirements. Efficiencies for small motors in the US are regulated by the EISA Small Motor Rule, which applies to open construction motors from ½ to 3 horsepower that have size 42 frames and larger.[67] At this time, most evaporator fan motors relevant to this incremental cost study, including Q-Sync motors, are 1/15th hp (approximately 50 watts) or less, which excludes them from the EISA requirements.

Shaded pole motors are currently considered the baseline for more efficient motor technologies. Shaded pole motors are still the standard motor for most applications and are less expensive than either EC or Q-Sync motors. As market trends and energy codes and standards begin to make EC motors more common, baselines will likely shift for some applications. Research indicated that motors of 9 to 12 watts of output power are the most applicable size for Q-Sync motors, and therefore baseline motors that offer equivalent output of this size were the focus of the research.[68] Larger Q-Sync motors are planned for later development, including motors for non-refrigeration applications, but the near term focus of Q-Sync motor development is on small refrigeration fan motors for refrigerated cases.

3.10.2 Sources of Data

As QM Power is the only manufacturer making this type of product, all pricing information came from an interview with a QM Power representative. ERS also interviewed a manager of a northeastern grocery store chain who is considering installing Q-sync motors in his stores to cross check some of the information provided by QM power, although he was unable to verify pricing information.

[66] See reference above for ORNL 2015.

[67] http://machinedesign.com/motorsdrives/ramifications-december-19-2010-motor-efficiency

[68] According to the NEEP 2015 refrigeration study cited above, the majority of the motors used in the cooler evaporator fan application were 1/15th hp (50 W). No incremental costs were provided with that study.

3.10.3 Market Status as of April 2016

Q-sync motors are available on the market and have not been widely installed. ERS was unable to find a QM Power customer who had already installed Q-sync motors at the time of this writing, although one contact was aware of the technology and is considering installing them in his commercial refrigerators.

3.10.4 Incremental Cost

According to QM Power, all Q-Sync motors are currently being offered at similar prices as EC motors. QM Power expects this to be the case for the foreseeable future, with economies of scale for increased production of Q-Syncs contributing to higher profit margins on motor sales. In addition, according to QM Power, Q-Sync motors have universal mountings that make them a drop-in replacement for existing shaded pole motors and are fixed speed so there are no control issues to resolve.

QM power is currently offering refrigerated case motor and fan upgrades via a packaged Q-Sync motor and fan installation. By offering this packaged solution, QM Power claims that they can significantly reduce installation time. QM Power markets these motors directly to consumers and via vendors and refrigeration contractors. Price points for Q-Sync motors differ depending on where in the supply chain the motors are purchased. According to QM Power, the cost of Q-Sync motors that are sold directly to the end user is approximately 50% higher than motors that are sold to refrigeration contractors.

ERS performed background research on the cost of ECMs as these motors represent the closest technology to Q-Sync motors currently available in the market and because QM Power indicates that the company is selling Q-Sync motors at cost points similar to ECMs in an effort to gain market traction.[69] Secondary research suggests an incremental cost of between $122 and $231 for the installation of an ECM motor rather than a shaded pole motor. This finding is based on several existing studies, the most relevant information from which is summarized in Table 3-39.

[69] See the answer to the question, "If Q-sync has superior performance and greater reliability, why is it the same cost as a comparable ECM?" in the FAQs section of QM power's website: http://qmpower.com/faqs/.

Table 3-39. Incremental Costs for Refrigerated Case Motor Upgrade

Reference	Baseline Technology	Efficient Technology	Motor Size[1]	Incremental Equip. Cost
2012 CA Municipal Utility Association [70]	Shaded pole	ECM	16 W to 0.75 hp	$169–$230
2010–2012 Ex Ante Cost Study (released in May 2014)[71]	Shaded pole	ECM	12 W	$122
DEER 2008[72]	Shaded pole	ECM	0.20 hp	$231
2016 QM Power Equipment Cost Estimate	N/A	Q-Sync	9–12 W	$110[2]

[1]The smaller motors are sized for refrigerated display cases and are typically rated in watts. The larger motors are sized for walk-in coolers and are typically rated in units of horsepower.

[2]The QM Power cost estimate is for selling direct to the OEM market or customer. With average market actor markups this cost is estimated to be $125 – $175 depending upon the final distributer and contractor arrangements.

ERS interviewed QM Power and northeastern grocery store chains regarding the estimated cost of Q-Sync motors. These interviews revealed estimated costs direct to the OEM market or end user of $110 for 9- to 12-watt Q-Sync motor and fan assemblies. They also estimate an end-use cost of $189 for 38-50 watt Q-Sync motors that are planned for future market introduction. In total, QM Power estimates a typical Q-Sync motor installation to cost between $100 and $125 per motor, including both equipment and labor. However, Q-Sync motors are not marketed through normal distribution chains at this time, but are sold directly to the OEM market and installers for the retrofit market. With normal market actor markups QM Power's motors can be predicted to sell at prices similar to EC motors, which is the stated marketing policy of QM Power.

Cost data from 2016 web research indicated costs between $110 and $125 for a 1/15th horsepower shaded pole motor and between $174 and $210 for an equivalent output EC motor.[73] The shaded pole and ECM costs shown in ERS's research suggest an incremental equipment cost of between $50 and $100 for EC motors in refrigerated cases.

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[70] California Municipal Utilities Association TRM, generated by ERS in 2012. http://cmua.org/energy-efficiency-technical-reference-manual

[71] See Table 3-21 on page 3-83 of 2010–2012 CPUC Ex Ante Measure Cost Study, Itron, 2014: http://www.calmac.org/publications/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf.

[72] See Table 3-21 of the 2010–2012 CPUC Ex Ante Measure Cost Study, Itron, 2014.

[73] Data taken from Grainger and cross referenced across other websites: http://www.grainger.com/category/hvac-motors/motors/ecatalog/N-9xz?ssf=3#nav=%2Fcategory%2Fhvac-motors%2Fmotors%2Fecatalog%2FN-9xzZ1z0nw7rZ1yzon7x%3Fssf%3D3

This is a decrease from the $122 incremental cost stated in the 2010-2012 Ex Ante Cost Study that was released in 2014. In addition, the $110 to $125 cost for a refrigerated case shaded pole motor is competitive with the cost estimates provided by QM Power for Q-Sync motors, which suggests that Q-Sync motor incremental costs are similar to, and perhaps even lower than, the incremental costs for EC motors.

Another approach for estimating costs is to calculate what price point is needed for cost competitiveness, which is a stated pricing policy of QM Power. The U.S. Energy Information Administration states the average price per kilowatt-hour for commercial utility customers in the Northeast as $0.15/kWh.[74] For a 100% duty cycle evaporator fan motor, energy savings between a 1/15th horsepower shaded pole and Q-Sync motor would amount to 382 kWh per year, or $57 per year.[75] A payback of 3 to 4 years would require that the Q-Sync incremental cost (price difference) compared to a shaded pole motor be between $170 and $230, as illustrated in Figure 3-9, which shows the equivalent incremental cost required for Q-Sync or EC motor installations to meet a range of simple payback criteria. These estimates are based on the motor wattages shown in Table 3-39, and assume that the motors run 8,760 hrs/yr; all estimates are exclusive of any secondary effects such as reduced refrigeration loads and exclude utility incentives.

[74] http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a; this is the same reference for the 2005 year.

[75] For Q-sync motors: (12 watts/20% efficiency – 12 watts/73% efficiency) ÷ 1000 watt/kW × 8760 hrs/yr = 382 kWh/yr × 0.15 $/kWh = $57
For new EC motors: (12 watts/20% efficiency – 12 watts/66% efficiency) ÷ 1000 watt/kW × 8760 hrs/yr = 366 kWh/yr × 0.15 $/kWh = $55

Figure 3-9. Incremental Cost vs. Simple Payback for Q-Sync and EC Motors

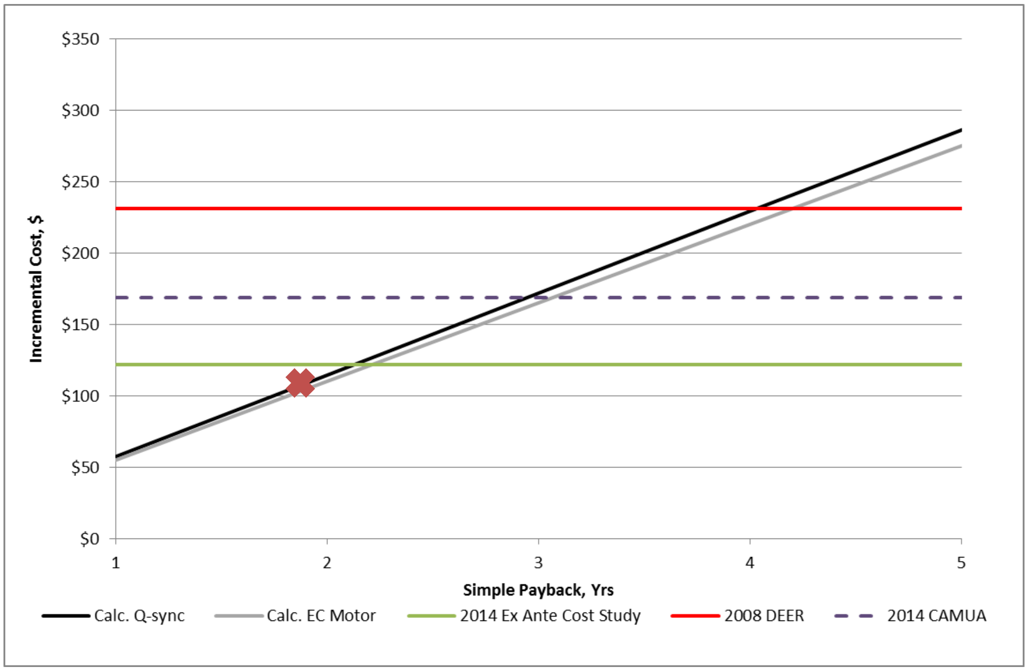
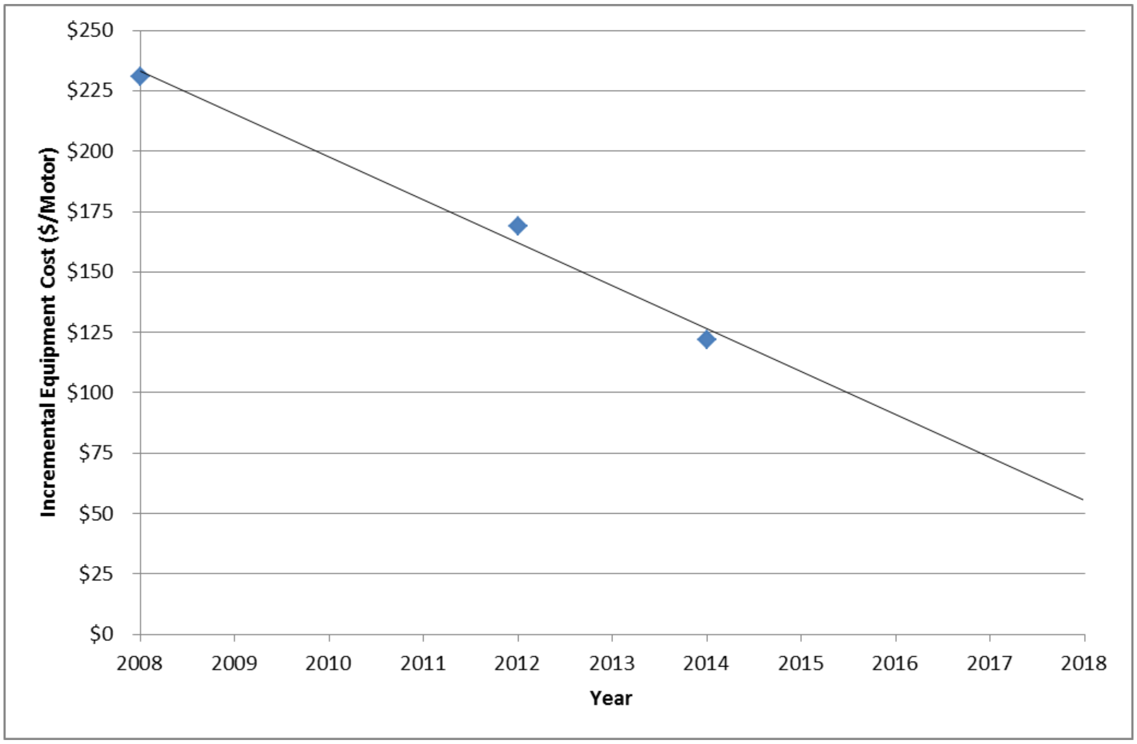


Figure 3-9 illustrates the relatively similar energy savings, and thus incremental costs required to meet a range of simple payback criteria for Q-Sync and EC motors. Based on this information, it is reasonable that the average consumer would require that Q-Sync motor costs be similar to EC motor costs in order to make them a cost-effective solution from an energy efficiency perspective. In addition, this graph illustrates that the full equipment cost of $110 for a Q-Sync motor and fan assembly (indicated by red "X" in Figure 3-9) would put the payback for such a measure under 2 years.

3.10.5 Cost Trends

ERS reviewed the historic cost of EC motors as a means of projecting how the incremental cost of refrigerated case motors may change in the future. Figure 3-10 shows the trajectory of refrigerated case motor incremental costs in California from 2008 through 2014. Considering that Q-Sync motor costs are competitive or perhaps even lower than EC motor costs, it is reasonable to assume that the incremental costs and simple payback for Q-Sync motors may follow a similar trajectory. Should the market continue to follow this trajectory, incremental costs for EC motors will approach $50 by the year 2018, which, according to Figure 3-9, above, will put the simple payback for such measures at or under 1 year.

Figure 3-10. Incremental Cost of EC Motors for Refrigerated Cases 2008 to 2018 (projected)



All of the cost data above is exclusive of installation costs. For ECM or Q-Sync motors in end-of-life or new construction circumstances, there is no incremental labor cost – they are a direct swap. However, in retrofit applications, there is some cost associated with removing existing motors and installing higher efficiency units. QM Power estimates that the labor required for removal and replacement is up to 50% lower for Q-Sync motor and fan assemblies than ECMs. Interviews with a grocery store energy manager indicated that the Q-Sync motor assembly could save installation costs, but he did not have hard data to support this as his company was about to undertake their first Q-Sync motor installation. However, this manager did indicate that the motor and fan installation time is small relative to the time required to remove and restock products on the refrigerated case shelves during the motor and fan upgrade.

3.10.6 Additional Market Insights

ERS conducted an interview with a representative from a major grocery chain to gain his perspective of Q-Sync motors, as he is currently considering them for a pilot-project installation. His current default installation is ECMs for all new and retrofit installations in refrigerated cases. Through both this interview and our additional research, we identified the following factors that are likely to influence the future market adoption of Q-Sync motors are as follows:

- Refrigerated case evaporator fan motor installations typically need to have a payback of 3 to 4 years or less. This is currently achieved with ECMs, and therefore can likely also be achieved with Q-Sync motors given their similar equipment cost.
- The yearly energy savings from either a Q-Sync or EC motor is small compared to the labor costs involved with emptying and restoring food in the cooler in preparation for the trial. This makes reliability a priority for evaporator fan motors as the labor cost can be amortized over a longer period with less frequent evaporator fan motor upgrades. If Q-Sync motors are proven to be more reliable, it will be a significant factor in upgrade decisions.
- QM Power is currently marketing their Q-Sync products as a fan and motor assembly. This approach is intended to optimize the airflow, allowing a smaller motor to be utilized. Installing this assembly could reduce installation costs, particularly for retrofits and end of life motor replacements, as a one for one change out of the entire fan system may require less time than mounting an existing evaporator fan on a new motor.
- Q-Sync motors are still largely an unknown product. The grocery representative interviewed by ERS considers this a trial installation of an emerging technology.
- Although shaded pole motors are currently the baseline for refrigerated cases in Northeastern states, this market may undergo a significant transformation in the future as the incremental cost between EC and shaded pole motors continues to decrease.

More comprehensive independent validation of the motor market and performance will be available when the US DOE concludes a study of Q-Sync motor installations at 50 pilot locations throughout the US, which is underway and expected to be complete in 2016 or 2017.[76]

[76] Data from QM Power regarding their pending trial with the DOE: http://qmpower.com/2015/09/qm-power-introduces-the-q-sync-smart-synchronous-motor/

4 Summary Conclusions and Recommendations for Additional Research

Efficiency programs need to progressively adopt emerging technologies in order to keep step with evolving market activities, and to harvest new savings as many of the efficiency measures supported for years are becoming standard practice due to advancing codes, standards, and technology progress. Although some program rules allow emerging technologies to be piloted outside the barriers of cost-effectiveness tests, for new technologies to be supported for full program delivery, incremental costs must be known and cost-effectiveness demonstrated.

This research study report presents estimated incremental cost information for residential and commercial emerging technologies that are likely candidates for inclusion in energy efficiency programs. Our research found that all technologies covered are progressing toward general market acceptance. A possible exception is "smart" home appliances such as refrigerators, washing machines, and dryers. Although there is much media attention regarding these products, we found that many product lines introduced over the last few years have since been discontinued and reoffered multiple times, and that the recent focus has been on convenience features rather than energy savings or demand response (DR). However, development is continuing in this area, and future market success is likely given the attention the Internet of Things is receiving.

The summary table including estimated incremental costs presented in the Executive Summary is repeated in Table 4-1 for convenience.

Table 4-1. Researched Technology Categories with Summary Incremental Cost Information

		Sector			Application*				
	Technology	RES	C&I	Category Range	NC	R	Approximate Incremental Cost	Report Section	Notes
1a	VRF heat pump – A/C	x	x	Multi-split and VRF systems – Single-family residential, multifamily, and small commercial units ≤ 16 ton	x		Variable from approximately $1,500 to $6,000 per ton - plus an additional 17% for cold climate performance	3.1	Single zone mini-split systems are covered in earlier NEEP incremental cost studies
1b	Multiple-zone variable capacity HP – modulating compressors	x	x		x			3.1	
2	Advanced LED lighting controls		x	Fixtures with integral controls and control systems designed for LED	x	x	Highly variable	3.2	Typically priced on a building area basis
3a	Home energy management products	x		"Smart" hubs and dedicated energy-impacting devices; appliances with communication capability for energy savings; power strips with logic beyond master/controlled operation	x	x	Highly variable cost, from $9 for "smart" lamps to $200+ for major appliances	3.3	Often referred to as "smart" products, the home energy management products category focuses on products with energy saving or load-shifting capabilities.
3b	Tier 2 power strips	x			x	x	$30-$70 depending on # of outlets and control features	3.3	
4	Advanced/ultra-high efficiency rooftop packaged A/C (SEER >18)		x	CEE size categories ≤ 65,000 Btu/hr and 65,000 to 135,000 Btu/hr include current packaged high efficiency units (15–18 SEER)	x		$360–$560/ton capacity	3.4	Limited reseach as deemed not cost-effective in the study region
5	Integrated heat pump multi-system thermostatic controls	x	x	Controls that are capable of controlling hp and additional heating system(s) typically via an interface with "smart" thermostats	x	x	$365–$660 per control	3.5	Ductless mini-splits are now controlled seperately from other heating systems, preventing automatic sequencing.
6	Advanced compressors for commercial refrigeration		x	Supermarket refrigeration systems for new construction of reconfiguration of existing systems	x		Highly variable from 0-55%	3.6	Current retrofit market dominated by compressor rebuilding and the retrofit of controls
7	Automatic compressed air system diagnostic monitoring		x	Focus on systems communicating with dashboard	x	x	Fullly installed cost; typical systems average $7,500–$17,500	3.7	Industrial measure – large savings potential
8	Improved HP water heaters	x		Residential systems offering higher-than-typical COPs at ambient temperatures below 68°F	x	x	$1,000–$2,100 compared with electric storage water heaters	3.8	Many heat pump water heaters as currently configured do not perform well in cool basements
9	Natural gas heat pump water heaters		x	Large-capacity commercial industrial systems	x	x	$176.50/MBtu/hr and $276.50/MBtu/hr	3.9	Limited market activity; commercial, municipal, and multifamily, large DHW loads
10	Q-Sync motors for evaporator fans (proprietary QM Power product)	x	x	Limited sizes and applications, further products under development; current market focus is small refrigeration fan motors	x		Estimated at $120–$230 for typical installed project cost	3.10	Proprietary - one supplier to date; currently available on a pilot basis - UL approved for some sizes

*Application: NC = New construction and end-of-life replacement; R = Retrofit applications

4.1.1 Cost Stability

The technology categories are evolving rapidly. In the last several months, new thermostats have be introduced, new communication protocols have entered the market, appliances have been discontinued and reintroduced, and improved heat pumps have been introduced by both US and Asian manufacturers. This expanding market offers exciting opportunities, but makes cost tracking difficult. However, using the same approaches used for this study, program administrators and efficiency organizations such as NEEP can readily stay current with cost changes and apply them to cost-effectiveness tests and use the changes to adjust incentives.

4.1.2 Additional Technology Considerations

The project team learned a great deal regarding these technologies while researching the cost data. Although the project scope does not allow for a comprehensive study of technology characteristics, there are many factors that are of interest to efficiency program administrators.

Some of the categories are moving extremely fast in terms of technical development and market expansion. Inverter driven multi-split heat pumps and VRF systems are a prime example. Manufacturers reported that they were "constantly" introducing new models, increasing efficiency levels, and improving cold weather performance. In addition they reported that competitive expansion involving both Asian and US firms was driving installed costs down. Advanced LED lighting control systems are another good example of a fast moving market. Our research identified many firms entering this market. Operational configurations and pricing vary greatly, and it's logical to assume that a smaller set of product lines will become market leaders and costs will reach a higher level of consistency. Although the savings for these advanced lighting controls promise to be impressive compared with simple manual controls, advancing energy code requirements are making it difficult for attributing savings to programmatic efforts.

Commercial refrigeration opportunities are very promising as they address what is typically the largest energy using system in supermarkets. But these systems are complicated and require the engagement of specialized vendors and engineering firms to assure appropriate installations and sustainable savings. Similar challenges are involved in supporting compressed air monitoring systems and gas fired heat pump water heaters.

Home energy products represent an ever expanding collection of products. Some, such as adaptive thermostats are straight forward in terms of the energy savings and/or DR potential. Others such as communication capable large appliances are experiencing difficulty establishing a foothold in the marketplace due to a combination of technical difficulties, luxury product pricing, and the lack of identifiable useful functions. Appliance manufacturers are now focusing on convenience features rather than energy savings in promoting these products. “Smart” lighting hub systems offer energy saving dimming and remote on/off control, but the hub itself uses a small amount of energy 24/7 in standby mode waiting for a command. For residential lighting that is used sporadically, the net savings may be significantly limited.

Overall, emerging technologies are an exciting area to explore both for their energy savings potential and for the other benefits they may provide. It is a fast moving field as the technologies that efficiency programs considered to be emerging only a few years ago (LED lighting, self-commissioning lighting controls, condensing boilers, and many others) are now commonplace.

4.1.3 Additional Research Recommendations

As these technologies evolve, these research results will become outdated. In addition, many of these technologies will become the next efficiency program offerings with program administrators looking anew for the next generation of emerging technologies. Ideally, efficiency programs should provide ongoing funding for the annual maintenance of emerging technology pricing allowing the programs to offer appropriate value and continue to promote the most efficient technologies available.