Technology Transfer Support on Commercial Heat Pump Water Heaters for Southern California Edison

Transferring Technical Learnings Gained Through Research and Assessment of Emerging Energy Technologies

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ABSTRACT

Southern California Edison's (SCE) Emerging Markets and Technology (EM&T) group:

- Ensures policy oversight and guidance for demand response emerging markets and technologies.
- Develops pilot projects and demonstrations to examine opportunities for technological advances that improve load shape modification and demand-side demand response resources (including storage and electric vehicles) in all customer sectors.

The term “technology transfer” describes activities associated with the EM&T program, where the outputs and key learnings are shared with all of California through detailed public reports and presentations. The activity is also bidirectional: A utility can glean learnings from other regions and organizations conducting research that is similar but perhaps more advanced or comprehensive than a single 'utility's research. The technology transfer ensures that all research supports continued development of the most promising clean energy technologies.

This scope of work includes one such technology transfer activity on commercial electric heat pump water heaters (C-EHPWHs) to better assess these emerging electrical appliances' applicability for demand response opportunities in California. The project also includes stakeholder outreach and communications support to ensure key learnings are shared at a regional level.

Keywords

Commercial heat pump water heaters
Demand response
Technology transfer
Utility Energy Forum

EXECUTIVE SUMMARY

Primary Audience: Electric utility demand-side program implementers

Secondary Audience: Commercial building owners, state and local government leaders

Key Research Questions

- Regional Research Support for Bidirectional Technology Transfer – How can Southern California Edison (SCE) use key learnings from existing commercial electric heat pump water heater (C-EHPWH) pilot projects across multiple regions in the country to accelerate assessment of emerging technology research and future demand response (DR) program design in California?
- Communications Support and Conference Outreach – How can knowledge sharing and real-time technology transfer with active stakeholder engagement provide additional learnings and collaboration across multiple regions?

Regional Research Support for Bidirectional Technology Transfer

SCE recognizes the proven energy and cost savings of' heat pump water heater (HPWH) technology for commercial customers. However, 'the demand response and storage capabilities of today's HPWHs can support many of California's utility distributed energy resource goals. EPRI engaged market research sub-contractor Milepost Consulting SPC to conducted a landscape assessment that included the following:

- Extensive secondary research to identify C-EHPWH studies implemented in the last five years.
- A review of manufacturers currently offering C-EHPWHs.
- Interviews with utility program managers who have pilot demonstrated or are demonstrating C-EHPWHs in buildings with nonresidential meters.

Key Findings

- Bonneville Power Administration in Seattle, WA, and GoodCents on behalf of Hydro One in Toronto, Ontario, Canada, implemented successful pilot projects that provide useful market transformation models for SCE.
- More testing is needed and most existing C-EHPWH products require further development before they will be market ready for demand response. However, the research shows that C-EHPWHs operate well in the field and that business customers in Seattle, WA; Portland, OR; and Toronto, Ontario, Canada, are interested in more-efficient water heating technology that reduces operational costs, especially if upfront costs are offset or deferred. The most successful commercial pilot projects were executed with multi-family and small business customers.
- The project team presented research findings to SCE's Emerging Markets and Technologies (EM&T) group, who expressed interest in using the findings to develop future plans for local demonstration and pilot efforts in Southern California.

Communications Support and Conference Outreach

EPRI with Milepost developed abstracts for the Utility Energy Forum, and the conference committee selected the C-EHPWHs research for poster presentation. (The Utility Energy Forum is a non-profit consortium that produce an annual meeting on current and emerging industry issues.) The conference provided an excellent opportunity to engage fellow C-EHPWH utility technology experts, and the project team summarized the research findings into copy and an infographic for the conference (see Appendix A).

Impact

The successful technology transfer of learnings in the C-EHPWH research was highly relevant to SCE's current research efforts. During a technology transfer session, SCE's EM&T team expressed a keen interest in the results of the C-HPWH research and how California's decarbonization goals requires innovative solutions for electrification and electric HPWHs in both a residential and commercial application. The BPA research showed the EM&T team that there were two potential paths to expansion of this technology across SCE's service territory: 1) The Sanden CO2 refrigerant model not only met BPA's performance criteria, it utilizes a carbon free refrigerant that further reduces GHG emissions and, 2) existing residential units can be affectively applied to multifamily dwellings, most notably in the BPA study, to senior, low-income multifamily housing (another area of interest for SCE.) Presentation from SCE stakeholder meeting is presented in Appendix B.

The outreach provided an immediate opportunity for bidirectional technology transfer with conference attendees, most notably smaller utilities, which typically do not have the available resources to fund this type of research.

Why This Matters

The term "technology transfer" describes the activities associated with SCE's EM&T program, where the outputs and key learnings are shared with all of California through detailed public reports and presentations. The activity is also bidirectional: A utility can glean learnings from other regions and organizations conducting research that is similar but perhaps more advanced or comprehensive than a single 'utility's research. The technology transfer ensures that all research supports continued development of the most promising technologies related to clean energy, grid stabilization, and customer satisfaction.

How to Apply Results

This research accelerates ongoing research, testing, and ultimately deployment, with the goal of implementing commercial end-use technologies for demand response program opportunities.

Learning and Engagement Opportunities

Appendix B contains the compendium presentation to SCE stakeholders on commercial electric heat pump water heaters.

The 2019 Utility Energy Forum poster presentation is online at:
http://2019.utilityforum.org/Data/Sites/5/media/posters/sce-commercial-hpwhs.pdf

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Background

Launched in 2017, EPRI's efficient electrification initiative explores electrification in the context of the global energy system, which includes a wide variety of distributed energy resources, cutting-edge technologies, many audiences, and complex networks. As a result, EPRI is committed to:

- Analyzing current conditions in-depth
- Identifying opportunities for electrification
- Building an electrification technology pipeline
- Collaborating with research and development partners in the United States and abroad

EPRI's initiative supported developing the Integrated Energy Policy Report and continues the mission to identify electrification opportunities and develop the innovative technologies that support California's goals.

This market study continues EPRI's research into new technologies currently testing in the field, as well as customer engagement strategies that result in greater adoption of efficient electric technologies. In partnership with Southern California Edison (SCE), EPRI identified recent commercial electric heat pump water heater (C-EHPWH) studies, manufacturers advertising new C-EHPWH products, and pilot projects that utilities are conducting outside California. SCE wanted to know which products performed best in currently occupied commercial buildings and what strategies utilities used to engage participants in field testing.

Project Overview

SCE recognizes the proven energy and costs savings of' HPWH technology for commercial customers. However, the demand response (DR) and storage capabilities of today's HPWH units can support many of the utility's distributed energy resource (DER) goals. Residential HPWHs have been widely researched, tested, and implemented across the country, but they have been difficult to implement in Southern California[1] because of the customer barrier of high up-front costs and the regulatory barrier of deep penetration of gas water heaters across much of the customer base.

SCE wanted to know if C-EHPWHs might be a demand-response-enabling technology for business customers that currently use electric-resistance water heaters in multi-family and small commercial buildings. These business customers may be more willing to absorb

[1] https://rael.berkeley.edu/wp-content/uploads/2017/07/Raghavan-Wei-Kammen-WaterHeating-_-ENergyPolicy-2017.pdf

planned, up-front costs associated with the technology as a business expense, especially if accompanied by rebates, technical support, and an end goal of consistently lower energy costs. Customers then adopting C-EHPWH systems could provide an opportunity to include DR controls and communications. However, benchmarking external market transformation activities in other regions was a key first step to developing the DR emerging technology research hypothesis.

EPRI conducted a landscape assessment that included the following:

- Secondary research to identify studies implemented in the last five years
- A review of manufacturers currently offering C-EHPWHs
- Interviews with utility program managers who have pilot demonstrated or are demonstrating C-EHPWHs in buildings with nonresidential meters

This research's desired outcome was to transfer technical learnings from the field into recommendations that would support the development of a C-EHPWH DR research plan for SCE business customers.

Secondary Research

To better understand the current landscape of C-EHPWHs, SCE sought to answer the following questions:

- How much research has been conducted?
- Which manufacturers are creating and marketing C-EHPWHs?
- Where are these products being field tested with commercial customers?
- What other information is generally available in the market?

Although comparatively less research has been performed with C-EHPWHs than residential HPWHs, existing studies have consistently proven C-EHPWHs' energy- and money-saving potential. Some of these studies were completed in laboratory settings using simulated conditions, whereas others assessed C-EHPWHs in field pilot demonstrations. Many of the pilot projects and studies were conducted in multi-family environments, but some studies involved commercial kitchens, laundry facilities, hotels, and other businesses. Sheet 2 of Appendix A contains a list of and links to the studies reviewed.

C-EHPWH Manufacturers

Many manufacturers offer residential HPWHs, but relatively fewer manufacturers publicly offer products specific to the commercial market. Many of these manufacturers advertise primarily to multi-family buildings, but a few manufacturers also advertise to commercial kitchens, hotels, and laundry facilities.

The larger number of HPWH manufacturers in Japan reflects the country' s more mature HPWH market.

- A.O. Smith
- Colmac Waterheat
- Nyle
- Daikin
- Bosch
- Rheem
- Mayekawa
- Ruud
- Vaughn
- Sanden
- GT Heat Pump
- Itomic
- SunTech
- Mitsubishi
- EcoCute

Figure 1: Some of the major manufacturers currently advertising commercial heat pump water heaters online

Primary Research

In addition to secondary research, SCE requested that EPRI conduct interviews with utility program managers who had implemented C-EHPWHs in commercial buildings to gain a firsthand account of key takeaways, lessons learned, and recommendations. EPRI conducted interviews with project managers of pilot projects at Hydro One in Toronto, Ontario, and at Bonneville Power Administration (BPA) in Washington and Oregon. The project team intended to include interviews on a third pilot project that the Northwest Energy Efficiency Alliance (NEEA) implemented, but pilot launch delays precluded its inclusion in this study.

Hydro One Pilot

The project team interviewed a former senior personnel of GoodCents (acquired by Franklin Energy), which had managed the pilot project for Hydro One in Toronto, Canada. The Heat Pump Advantage[2] pilot project operated for one year (October 2015 through October 2016) and was promoted as a new technology designed to help customers with existing electric-resistance water heaters reduce their energy costs. This pilot project was part of a broader government initiative aimed at lowering electricity use across Ontario through conservation. Hydro One tested the following:

- GeoSpring, 50-gallon (189-liter) hybrid from General Electric (this model is no longer available).
- Voltex 50-, 60-, and 80-gallon (189-, 227-, and 303-liter) water heaters from A.O. Smith.

Units were installed in residential and small commercial buildings, such as bakeries, small retail, multiunit residential, strip malls, coffee shops, restaurants, small manufacturing, fast

[2] http://www.ieso.ca/-/media/Files/IESO/Document-Library/conservation/EMV/2016/2016-HONI-Heat-Pump-AdvantageWater-Heater-Rebate-Pilot-Evaluation-Report.pdf?la=en

food, and schools. Direct install incentives incentivized the project, and funding covered a limited number of participants.

Results

Customer response to the incentive for new equipment was so successful that the pilot project was oversubscribed on the first marketing outreach. Units were installed through an approved contractor network, with C-EHPWHs replacing only existing electric-resistance water heaters. Both units performed well in the pilot, with minor differences between the two manufacturers:

- The first difference was price; General Electric's HPWHs were higher in cost.
- The second difference was a product limitation; some compressors in the A.O. Smith HPWHs were impossible to replace without replacing the entire unit.

Heat Pump Advantage participants realized a year-over-year reduction in energy consumption. The pilot project did not collect technical measurement and verification (M&V) data on the installed HPWHs. However, outside influences minimally impacted consumption (in Ontario, consumption varies significantly as a function of weather). Customers experienced overall energy savings between $250 and $400 year-over-year. The immediate oversubscription to the pilot project showed that customers were highly interested in C-EHPWHs. The incentive levels were such that the return on investment (ROI) minimized the purchase payback, while also providing long-term energy savings. In a follow-up survey, participants expressed satisfaction with:

- Their energy savings
- The financial incentives they received to help pay for expensive equipment and save on overhead costs

The pilot's overall purpose was to collect data, gauge customer motivation to invest in energy-saving equipment and compare energy-savings performance with existing electric-resistance water heaters. With proof-of-concept completed, pilot managers suspended the direct install incentive and incorporated the pilot project into the province's existing Save on Energy program portfolio.

Bonneville Power Administration Pilot Project

The project team also interviewed a Bonneville Power Administration representative who leads the utility's C-EHPWH pilot demonstrations. Over the last 10 years, BPA has installed HPWHs through both retrofit and new construction projects for residential and commercial customers. Most of their commercial projects have been in low-, mid-, and high-rise multi-family buildings because of the following considerations:

- Research funding availability for energy upgrades
- Developer interest in high-performance buildings
- Multi-family building customers' willingness to take advantage of energy-upgrade assistance

- Greater flexibility in the trial stage (whereas an unsuccessful application for a small business could have an immediate, negative impact on that business)

To date, BPA's C-EHPWH pilot demonstrations have delivered valuable learnings about the following:

- Specific products' technical capabilities
- Preferred applications for the Northwest (NW)
- Contractor needs
- Customer satisfaction

BPA is currently testing two C-EHPWH brands in multi-family buildings in Washington state:

- Colmac (standard refrigerant):
  - Air-to-Water: HPA Series (various sizes depending on building)
  - Water-to-Water: HPW Series (various sizes depending on building)
- Sanden CO_2:
  - Outdoor Unit Model Number: GS3-45HPA-USTank Models: SAN-43SSAQA, GAUS-315EQTD, SAN-83SSAQA, SAN-119GLBK

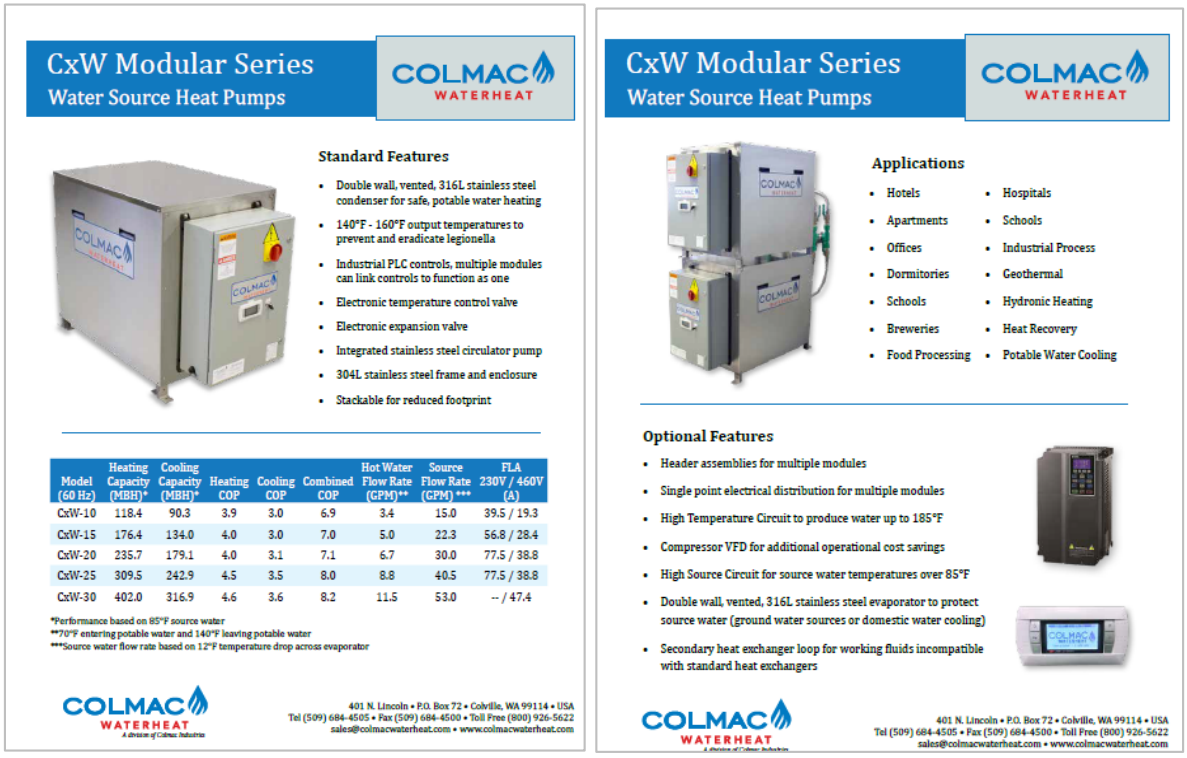


Figure 2: Colmac heat pump water heater product sheet[3]

[3] https://colmacwaterheat.com/cxw-modular-water-source/

Figure 3: Sanden heat pump water heater product sheet[4]

[4] https://www.sandenwaterheater.com/sanden/assets/File/SANDEN-CO2WaterHeater_11_15_19.pdf

Results

The Colmac has proven effective in multi-family buildings but also exhibits the following challenges that could be a barrier to scale:

- The unit requires garage space or a mechanical room where the air is warmer to generate enough heat from the environment to heat water.
- As identified during prior testing in Oregon, all installed units switched to electric-resistance mode when the temperature dropped below freezing, resulting in a demand spike on the system.
- Optimal indoor installation locations have been difficult to find in part because of Seattle's high square footage costs.
- Integrating controls is difficult when multiple units are installed to meet a larger building's water heating volume requirements.

The Sanden CO_2 model also presented challenges but met more of BPA's desired criteria. The current Sanden unit is available in a single 1.25-ton (1.13 metric tons) size and is primarily a residential product. The pilot project aimed to demonstrate this product's range and capability to meet a multi-family water heating load by placing several units together. The controls proved to be simple and exhibited a plug-and-play approach when appropriately configured. Another benefit of the CO_2 refrigerant is the model's capacity to continue working in environments as cold as -20°F (-6.6°C). This capacity facilitates installation on roofs, parking decks, or other outside areas that do not compete for expensive, internal square footage. The pilot project shows Sanden to have the following characteristics:

- Requires comparatively low maintenance
- Facilitates demand response (although manually at this time)
- Reduces greenhouse gas (GHG) emissions through use of natural CO_2 refrigerant

Another critical area for BPA was customer satisfaction, where the Sanden model scored consistently higher. A specific project involved a low-income, senior community housing mid-rise built in the late 1980s. The building owners replaced a failed electric-resistance water heater with a new electric-resistance unit. They then agreed to participate in BPA's pilot project by adding a Sanden CO_2 and using the new electric-resistance unit as a backup. To date, the Sanden has consistently provided hot water, and the electric-resistance unit has not had to activate. The building's owners have expressed high satisfaction with the Sanden CO_2's performance and energy savings.

The Sanden model presents the following challenges:

- The model performs better when input water is colder (for example, a pilot project involved heating a pool, and the system struggled to increase the heat in water that was already warm)
- Very few CO_2 models are on the market, and no 3- to 4-ton (2.7- to 3.6-metric ton) or 6- to 8-ton (5.4- to 7.3-metric ton) sizes are available at this time

Despite these drawbacks, BPA finds that CO_2 HPWHs may provide greater market opportunities than standard refrigerant models for the reasons listed previously.

BPA stressed the importance of ease-of-use and low maintenance if C-EHPWHs will be able to scale. Identified barriers include the following:

- Custom nature of installation and maintenance
- Lack of trained contractors
- Lack of training resources for contractors
- A limited number of available products

Further, low awareness at both the utility and customer levels creates a barrier to greater customer adoption. Overcoming this barrier is hampered because the Northwest Regional Technical Forum has yet to determine an energy savings/rebate value.

BPA is working with research partner Ecotope to develop a more specific set of criteria to guide manufacturers in developing the next round of products. BPA sees excellent potential for C-EHPWHs and has additional pilot projects planned, including large commercial buildings. BPA seeks more utilities to invest in piloting C-EHPWHs, creating the market pull needed to incentivize manufacturers to create more product options and help the market scale more rapidly.

Conclusion

More testing is needed, and most existing products require further development before they can be market ready for use in demand response programs. However, research shows that business customers in the NW and Ontario, Canada, are interested in more-efficient water heating technology (C-HWPHs) that reduces operational costs, especially if up-front costs are offset or deferred. Following year-over-year savings and high customer-satisfaction ratings among pilot participants in both studies, the challenge now is to support manufacturers in developing C-EHPWHs that meet specific market needs identified in these pilot demonstrations. Additionally, scaling from pilot project to program requires product manuals and training for trade allies.

As the next generation of products becomes available, C-EHPWHs could soon provide SCE and other utilities with a viable channel for energy savings, demand response, electrification, and carbon reduction, particularly in multi-family and small business buildings. SCE has an opportunity to accelerate C-EHPWH development and implementation in California through continued collaboration with leaders such as BPA, Hydro One, and research partner EPRI. This cross-pollination effort could help support the utility's business goals, while meeting the needs of real business owners in California and across North America.

2: Communications Support and Conference Outreach

Real-Time Technology Transfer at the Utility Energy Forum

The Utility Energy Forum held its 39th annual session in Cambria, CA, on April 24, 25, and 26, 2019. The conference's core audience is energy services professionals who represent energy utilities and allies serving Western states. This audience included the following:

- Electric utilities from California
- Market transformation organizations such as NEEA
- Technology vendors for energy efficiency markets
- Consultants serving these markets

The conference facilitates a wide range of bidirectional technology transfers of key learnings on developing and implementing customer programs related to the following:

- Energy efficiency
- Demand response
- Renewable energy
- Key account management
- Other customer services
- How customer programs respond to the ever-changing policy landscape

The theme for 2019 energy forum was "Utility Recipes for Meeting Customer Needs" and focused on challenging traditional thinking to better meet customer needs in the rapidly changing utility industry. Utility Energy Forum, Inc. is a nonprofit consortium that produces an annual meeting for attendees, presenters, sponsors, and exhibitors to have a high-quality, noncommercial opportunity to exchange information about current and emerging industry issues[5].

EPRI submitted an abstract on SCE's behalf that highlighted the C-EHPWH research and benchmarking process.

Utility Energy Forum Abstract

Smart Start—Advancing Commercial HPWHs through Industry Cross-Pollination

The high energy-efficiency and carbon-reduction benefits attributed to electric HPWHs are well established, but consumer market adoption at scale continues to be a challenge. In California, carbon-reduction goals are driving electric utilities to look to HPWH studies for future program commercialization. This poster session illustrated how SCE is using a cross-pollination strategy to leverage work conducted by other utilities that have piloted commercial electric HPWHs with real customers. Research and interviews conducted with

[5] Event website: http://www.utilityforum.org/

program implementers such as Bonneville Power Administration, NEEA, Hydro One, and EPRI are providing SCE with some best practices for program design and customer engagement. Attendees were able to learn more about the outcomes of this technology transfer strategy and how SCE hopes to be "fast followers" and use these findings to support their carbon reduction goals using HPWHs.

The project team created the graphic design and content for the poster (see Figure 4) and presented the poster on April 25, 2019. The successful technology transfer of key learnings in the C-EHPWH research was highly relevant to conference attendees, most notably smaller utilities, which typically do not have the available resources to fund this type of research.

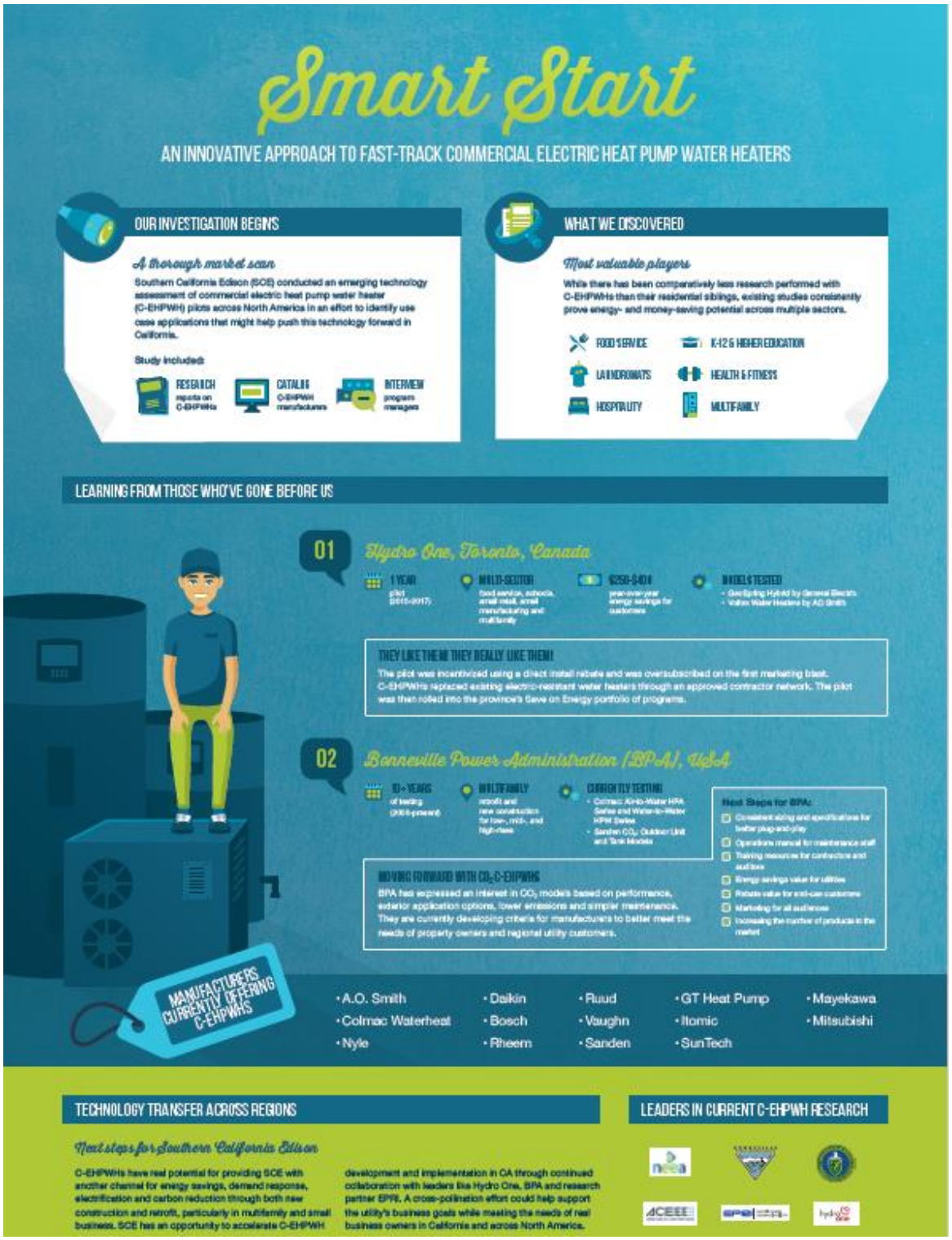


Figure 4: C-EHPWH poster created for the Utility Energy Forum

Figure 5: Photos from Utility Energy Forum Poster Challenge

Response to the Poster Presentation

The successful technology transfer of key learnings in the C-EHPWH research was highly relevant to conference attendees, most notably smaller utilities, which typically do not have the available resources to fund this type of research.

Appendix A: Commercial Heat Pump Water Heater Research

Secondary Research – Literature Review

To access, double click on the links. We categorized our research into separate tabs that are listed below.

Table A-1: Manufacturers

Company	Location	Link
A.O. Smith	Ashland City, TN	https://www.hotwater.com/lit/spec/com_elec/aosze15000.pdf https://www.hotwater.com/news/a-o-smith-introduces-new-commercial-electric-heat-pump-water-heaters/ https://aceee.org/files/pdf/conferences/hwf/2010/6D_Greg_Wilson.pdf https://www.businesswire.com/news/home/20160705005188/en/New-Heat-Pump-Water-Heater-Game
Bosch	Farmington Hills, MI	https://www.prowaterheatersupply.com/PDFS/Bosch_Therm_Commercial_Catalog.pdf
Colmac Waterheat	Colville, WA	http://colmacwaterheat.com/ http://heatpumpindonesia.com/products/colmac/
Daikin	Plymouth, MN	http://www.daikin.com/products/ac/lineup/heat_pump/index.html https://www.daikin.com/csr/environment/climatechange/heat_pump.html
GT Heat Pump	China	http://www.gtheatpump.com/commercial-heat-pump-gt-skr40kp-10.html
Itomic	Japan	https://www.itomic.co.jp/english/ http://www.r744.com/files/atmoasia_itomic.pdf
Mayekawa	Japan	http://www.mayekawa.com/products/features/eco_cute/
Mitsubishi	Japan	http://www.atmo.org/presentations/files/553_27_shigeru_yoshida_mitsubishi.pdf http://www.mitsubishi-electric.co.nz/hotwater/c/9575/commercial-hot-water-and-heating https://www.mhi.com/products/industry/heat_pump.html https://www.mhi-mth.co.jp/en/products/detail/air_to_water_commercial.html http://www.msaircon.co.za/atw-heat-pump.html

Table A-1: Manufacturers, continued

Company	Location	Link
Nyle	Brewer, ME	https://www.nyle.com/water-heating-systems/air-source/ https://www.nyle.com/wp-content/uploads/2017/04/Reduced-Nyle-Presentation-for-website.pdf
Panasonic	Japan	https://www.aircon.panasonic.eu/GB_en/happening/aquarea-commercial-solutions/
Rheem	Montgomery, AL	https://www.rheem.com/group/rheem-commercial-electric-water-heaters-hybrid/
Ruud	Montgomery, AL	https://www.ruud.com/product/ruud-commercial-electric-water-heaters-hybrid/
Sanden	Plymouth, MI	https://www.sandenwaterheater.com/sanden/assets/File/Sanden_sanc02_technical-info_10-2017_4.pdf http://www.smallplanetsupply.com/sanden/ http://www.smallplanetsupply.us/sanden-sanco2-heat-pump-water-heater-3rd-gen-83-gal-system/ https://foursevenfive.com/sanden-sanco2/ https://foursevenfive.com/blog/sanden-sanco2-the-water-heater-to-end-all-water-heaters/
SunTech	Japan / Taiwan	https://suntek.en.taiwantrade.com/product/co2-heat-pump-water-heaters-566754.html# https://suntek.en.taiwantrade.com/product/commercial-heat-pump-water-heaters-1617993.html https://suntek.en.taiwantrade.com/product/commercial-heat-pump-water-heaters-1617991.html https://suntek.en.taiwantrade.com/product/commercial-heat-pump-water-heaters-1617984.html https://suntek.en.taiwantrade.com/product/commercial-heat-pump-water-heaters-1617989.html
Vaughn	Salisbury, MA	http://www.vaughncorp.com/commercial/ http://www.vaughncorp.com/products/hybrid-heat-pump/#.XABDeJNKjVo

Table A-2: EPRI Studies

Study	Year	Type of Building	Overview	Results	Link
Performance Assessment of an Eco-Cute Heat Pump Water Heater	2008	Lab Research	A Daikin Eco-cute HPWH was installed in the lab in EPRI's Knoxville campus. The goals of the installation were to verify performance and learn through first-hand experience installation challenges associated with a HPWH that uses carbon dioxide as a refrigerant Unlike some of the integral (or drop-in) designs in the US, the Daikin Eco-cute HPWH system has two separate components. The heat pump and heat exchanger are one unit and the water storage tank is the second unit. For the EPRI test, the heat pump is place outdoors, and the storage tank and associated control system is placed indoors.	Lab testing indicated an average COP of 2.76 even under condition of a cool outdoor temperature (35F) and a high-temperature supply water (65F). The initial COP reached 5.1	https://www.epri.com/#/pages/product/000000000001016074/?lang=en-US
Assessment and Demonstration of Advanced Heat Pumps for Commercial Building Water Heating Applications	2010	Hotel & Lab Research	A comprehensive review of commercial HPWHs, including technological and historical overviews, recommended applications, and existing obstacles is presented in this report. A commercial field test performed by EPRI in a hotel in Birmingham, AL, where a 5-ton heat pump with a 350-gallon storage tank is installed and operates	The system provided hot water from May 12 - Aug 24, 2010, when it was taken off-line for a water leak The system had an apparent COP of 2.33	https://www.epri.com/#/pages/product/000000000001020137/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
HPWHs for Commercial Buildings	2011	Lab Research	Tested two HPWH systems in the EPRI lab in steady-state and simulated usage testing across a broad range of conditions They were tested with a storage tank using a simulated restaurant load profile to quantify the energy savings and load profile of a "real world" application	High efficiency across a variety of conditions, with energy savings as high as 72% in simulated use applications Combined COPs including air cooling in addition to water heating of over 10.0 are feasible Testing indicates that HPWH is viable in all climates provided that an adequate air heat source is available on site Estimated energy savings in a laboratory simulation of a restaurant application was as high as 65%, with payback periods of 1.8-4 years Best conditions for higher COP: warmer ambient air and colder entering water	https://www.epri.com/#/pages/product/1021970/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Laboratory & Field Evaluation of Four Heat Pump Water Heater Systems	2012	Hotel & Lab Research	A.O. Smith commercial HPWH was installed and monitored in a hotel in Birmingham Two systems manufactured by Sanden, which use CO_2 as a refrigerant, were also tested in the laboratory in Knoxville	Results were as expected: The commercial HPWH installation showed energy savings in the range of 35-50% monthly. The efficiency seen with the CO_2-based Sanden systems was higher than the ATI66, or other typical US HPWH systems. The external gas cooler of the Sanden units steadily drew water in near the mains water temperature and uses a counterflow heat exchanger, maximizing the efficiency of the gas cooler.	https://www.epri.com/#/pages/product/1024336/?lang=en-US
Advanced HPWH Technology: Testing Commercial and Residential Systems in the Lab and Field	2013	Lab Research & Restaurant	A commercial water-to-water HPWH using CO_2 as the refrigerant was tested in the laboratory. This system, unlike many conventional-refrigerant systems, can provide hot water at temperatures approaching 200°F (93°C), overcoming a key obstacle for some commercial applications. Another commercial system, using R134a, was installed and monitored in a restaurant application. That system provides all of the restaurant's hot water using a single-pass heating approach, which enables near-immediate hot water recovery during reheats.	Results are not accessible.	https://www.epri.com/#/pages/product/000000003002001369/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Technology Insights Brief: Heat Pump Water Heaters	2013	Overall Info	White paper talking about the overall pros and cons and market of HPWHs Not residential- or commercial-specific	None	https://www.epri.com/#/pages/product/000000000001025728/?lang=en-US
Advanced Heat Pump Water Heaters	2014	Residential & Commercial	Two field-installed, air-to-water commercial HPWHs continue to be monitored	One HPWH has operated with continuing success, while the other provides important learnings on practices to avoid in the field	https://www.epri.com/#/pages/product/000000003002003477/?lang=en-US
Next Generation Heat Pump Water Heater: BPA Preliminary Testing Report	2014	Lab Research	Unclear from the abstract if this is residential or commercial Through modeling, EPRI and subcontractor Optimized Thermal Systems identified potential efficiency improvements through reconfiguration of heat pump components and the potential utilization of variable speed compressors	Results are not accessible.	https://www.epri.com/#/pages/product/000000003002003943/?lang=en-US
Evaluation of Field Performance for San Diego Gas & Electric	2015	Condomi-nium	Evaluate performance of a HPWH in a condo building at a time-share resort outside of San Diego HPWH was installed and monitored for 12 months at the site, and its performance, energy efficiency, and cost-effectiveness were compared to a baseline electric resistance water heater installed previously at the facility	52% energy savings over baseline ERWH technology Payback of 3.2 to 4.4 years under SDG&E existing commercial rate structure	https://www.epri.com/#/pages/product/3002005496/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
HPWHs for Small Commercial Applications	2016	Lab Research	This report summarizes lab testing of a packed, commercial HPWH intended for small commercial applications such as kitchens and cafeterias, fast food restaurants, and full-service restaurants with low hot water usage. The system was tested in the EPRI Knoxville, TN Thermal Laboratory	Testing resulted in coefficients of performance (COPs) of approximately 2.5 to 4.0 for water draws not requiring backup resistance heat, and 1.5 to 3.0 for draws with backup heat, depending on the ambient air conditions. In the right installations, and depending on local prices, the system could be competitive in terms of operating cost with natural gas water heating. Significant energy and operating cost savings would be expected compared with electric resistance heat, with the savings increasing for applications with greater hot water usage.	https://www.epri.com/#/pages/product/000000003002008233/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Demonstration of HPWH at Mississippi State University	2017	University Cafeteria	A single-pass, water-to-water HPWH was installed at the Perry Cafeteria at MSU to work in parallel with an existing gas water heater The HPWH was installed in a mechanical room in the basement of the cafeteria facility, which is unconditioned but contains several small condensing units and the gas water heater. The configuration for this field study was designed so that the water flow through the HPWH and gas water heater could be adjusted via valves and the HPWH system could be shut off by a temperature sensor if it ran out of hot water. This approach increased the storage and heating capacity while simultaneously reducing the flow rate through the gas water heater tank.	The HPWH was able to provide adequate hot water capacity in all normal usage conditions except for a few very cold days. The operating cost of the HPWH and the gas water heater was highly sensitive to the cost of gas and electricity In this field study the HPWH was similar or slightly less expensive per-gallon to operate than the gas water heater The study shows that depending on local prices, HPWHs in this configuration can be competitive in terms of operating cost with high efficiency gas water heating	https://www.epri.com/#/pages/product/000000003002010321/?lang=en-US&lang=en-US
Energy Efficiency Demonstration 2.0: Results of Four Demonstrations of Three Commercial Technologies	2017	Laundry Facility & University Cafeteria	EPRI and TVA demonstrated three commercial technologies at four sites in Energy Efficiency Demonstration 2.0 HPWH field studies were conducted at a laundry facility at Tennessee Technological University and at a cafeteria at Mississippi State University.	Results are not accessible.	https://www.epri.com/#/pages/product/000000003002009947/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Heat Pump Water Heater Demonstration at Tennessee Technological University	2017	University Laundry	HPWH storage tank was installed in series with the existing gas water heater in a pre-heating configuration in which water from the cold-water supply enters the HPWH pre-heat tank prior to going to the gas water heater. The HPWH provides heating but does not have to provide the full heating lift because water first travels to the gas water heater.	In addition to water heating benefits, the HPWH was installed to provide space cooling. The HPWH ductwork was louvered so it could alternately provide cooling to the laundry space or an adjacent mechanical room. The HPWH ran from Oct 2014 to May 2015 when a hardware failure ended the demonstration During the demonstration, the HPWH effectively pre-heated water going to an existing gas water heating system The HPWH generated small savings on water heating costs, but the high installation cost would result in a prohibitively long payback period.	https://www.epri.com/#/pages/product/000000003002010320/?lang=en-US&lang=en-US
CO_2 Heat Pump Water Heater Field Evaluation in a School Cafeteria Application	2018	School Cafeteria	Field test of a CO_2 HPWH at a school cafeteria in Mobile, AL The system was instrumented to capture performance and hot water delivery and monitored for over one year	The results show good efficiency, with a COP of 2.9 The water heater delivered supply water with a setpoint of 149F and provided the full hot water demand on all monitored days	https://www.epri.com/#/pages/product/000000003002011060/?lang=en-US

Table A-2: EPRI Studies, continued

Study	Year	Type of Building	Overview	Results	Link
CO_2 Heat Pump Water Heater Performance Testing: A Laboratory Assessment to Evaluate the Performance of a CO_2 Heat Pump Water Heater	2018	Light Commercial Kitchen	EPRI is evaluating the HPWH for functionality, energy performance, and potential for light commercial kitchen applications To verify the HPWH's reported capability, one 4.5-kW unit was installed and tested at Optimized Thermal Systems, Inc. A dedicated environmental chamber housed the unit and controlled temperature and humidity level.	In full heating tests, the unit's performance depended on the ambient temperature and performed more efficiently at warmer ambient condition (average COP of 8.53 at 100F) vs. average COP of 2.41 at 16.2F. Simulated drawdown tests incorporated an actual water usage profile. Under these tests, the unit had better performance at warmer ambient condition (COP 4.26 at 100F against COP of 2.18 at 15.7F) with warmer drawdown water, leading to a shorter recovery time (as much as 324 minutes shorter)	https://www.epri.com/#/pages/product/000000003002011061/?lang=en-US
Heat Pump and Heat Pump Water Heater Economic Assessment: Applicability for Residential and Small Commercial Markets	2018	Not Available	This report focuses on the market viability of air-source heat pumps and HPWHs in different regions of the country by evaluating the benefits of adopting heat pump technology, while simultaneously assessing the potential market barriers	HPWHs were found to be cost effective in most of the southern states, however the primary factor impacting the economics of HPWH were favorable electric to natural gas price rations, more so than climate. This assessment also suggests the level of first cost incentives or tipping points of electricity pricing where heat pumps will become viable.	https://www.epri.com/#/pages/product/3002013328/?lang=en-US

Table A-3: Non-EPRI Studies

Study	Year	Researcher	Type of Building	Overview	Results	Link
Commercial HPWH in Dorms	2008	Japanese Smart Energy Products & Technologies	Dormitory	Compared a HPWH with a hot water supply system comprised of the combination of a heavy oil boiler and a city gas firing hot water supply unit	CO_2 emissions were reduced by 60% Running costs were reduced by about 61% At the link, there are graphs showing these two statistics	https://www.jase-w.eccj.or.jp/technologies/pdf/office/O-03.pdf
Commercial Heat Pump Water Heater Research for Schools	2013	Advanced Energy	School	An A.O. Smith HPWH was installed in an elementary school in NC • It was monitored over a 5-month period and had later supplemental testing	Based on the measured results, there is an estimated 12% annual energy reduction associated with use of the HPWH at the school While the heat pump does increase water heating system efficiency, it also increases standby losses due to the additional, less-insulated heat pump water storage tank	https://www.advancedenergy.org/2015/07/22/commercial-heat-pump-water-heater/
HPWHs for Single and Multi-family Residential Buildings	2014	Ecotope	Single & Multi-Family	PowerPoint presentation that reviews: Concepts governing heat pump performance Reviews a range of currently available heat pump water heater technologies Reviews critical code and design issues to ensure good heat pump water heater performance in residential applications Review case studies and lessons learned	None	https://www.ecobuilding.org/summit/previous-years/presentation-files/2014-presentations/EB2014HPWaterHeaters.pdf

Table A-3: Non-EPRI Studies, continued

Study	Year	Researcher	Type of Building	Overview	Results	Link
Feasibility Analysis of a Commercial HPWH with CO_2 Refrigerant	2017	Oak Ridge National Library	Commer-cial Residen-tial	A scoping-level analysis was conducted to establish the feasibility of using CO_2 as refrigerant for a commercial heat pump water heater (HPWH) for U.S. applications using the DOE/ORNL Heat Pump Design Model (HPDM) modeling tool for the assessment with in addition to data from a Japanese heat pump water heater (Sanden) using CO_2 as refrigerant for calibration. A CFD modeling tool was used to refine the HPDM tank model. After calibration, the model was used to simulate the performance of commercial HPWHs using CO_2 and R-134a (baseline).	Compressor discharge pressure and water temperature stratification are critical parameters for the system. The proposed design deploying a gas-cooler configuration exceeds the Energy Star Energy Factor criteria (2.20) and is comparable to some of the most efficient products in the market using conventional refrigerants.	https://info.ornl.gov/sites/publications/Files/Pub73586.pdf
Multi-family HPWH Evaluation	2017	US DOE	Multi-Family	The Alliance for Residential Building Innovation team monitored the performance of a central HPWH installed on student apartments at the University of California, Davis, West Village zero net energy community from October 2011 through February 2013; and then monitored models later installed in Phoenix, Houston, Sacramento, Seattle, Denver, and Chicago	High-level project conclusions: although savings of 50% or more relative to electric resistance water-heating systems are easily achievable. Could get greater savings by optimizing system performance: increasing the average compressor duty cycle through modified controls, use of variable-speed or two-stage compressors, and/or increased storage volumes. More attention to reducing standby parasitic energy would also improving seasonal performance, especially in milder climates	https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/66430.pdf

Table A-3: Non-EPRI Studies, continued

Study	Year	Researcher	Type of Building	Overview	Results	Link
Retrofitting Fossil-based heating systems with air to water heat pumps in multi-family houses	2017	Energy Technology Network	Multi-Family	Studied three pilot projects that are replacing fossil-based heating systems with air to water heat pumps in multi-family housing in Geneva, Switzerland.	Older buildings are not as compatible with the air to water system. These three projects demonstrated technical and economic difficulties and solutions for integrating air to water heat pump solution in existing multi-family houses. "This type of renewable solution is technically and economically feasible in the case of energy contracting, although it demands high quality engineering expertise and cost optimization efforts."	http://hpc2017.org/wp-content/uploads/2017/05/P.1.5.4-Retrofitting-fossil-based-heating-systems-with-air-to-water-heat-pumps-in-multifamily-houses.pdf
Better Buildings Alliance Demonstration Opportunities: Commercial HPWH	2015	Better Buildings Alliance	Not Available	Participating organizations receive a discounted high-efficiency product in exchange for their cooperation with the field study and can see firsthand the performance, energy savings, and economic benefits of commercial HPWHs	Was only able to find this flyer; no results.	https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/BBA%20HPWH%20Demo%20Opportunity%20Fact%20Sheet.pdf

Table A-3: Non-EPRI Studies, continued

Study	Year	Researcher	Type of Building	Overview	Results	Link
Field Test of High-Volume Heat Pump Water Heaters	Future	BPA	Not Available	Call to participate in study: "The ET Field Test could fully fund up to 5 High Volume Heat Pump Water Heaters, replacing retrofitting electric resistance water heaters with total daily domestic hot water consumption of 500 gallons per day or more, with the intent of informing a region-wide offering…Please consider participating in this ET Field Test and help fill the pipeline with a new conservation measure. Your participation and feedback are essential to developing technologies and future BPA program offerings."	None	https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Field-Test-of-High-Volume-Heat-Pump-Water-Heaters-.aspx

Table A-4: Compiled Studies

Study	Year	Type of Building	Overview	Results	Link
Performance Assessment of an Eco-Cute Heat Pump Water Heater	2008	Lab Research	A Daikin Eco-cute HPWH was installed in the lab in EPRI's Knoxville campus. The goals of the installation were to verify performance and learn through first-hand experience installation challenges associated with a HPWH that uses carbon dioxide as a refrigerant Unlike some of the integral (or drop-in) designs in the US, the Daikin Eco-cute HPWH system has two separate components. The heat pump and heat exchanger are one unit and the water storage tank is the second unit. For the EPRI test, the heat pump is place outdoors, and the storage tank and associated control system is placed indoors.	Lab testing indicated an average COP of 2.76 even under condition of a cool outdoor temperature (35F) and a high-temperature supply water (65F). The initial COP reached 5.1	https://www.epri.com/#/pages/product/000000000001016074/?lang=en-US
Assessment and Demonstration of Advanced Heat Pumps for Commercial Building Water Heating Applications	2010	Hotel & Lab Research	A comprehensive review of commercial HPWHs, including technological and historical overviews, recommended applications, and existing obstacles is presented in this report. A commercial field test performed by EPRI in a hotel in Birmingham, AL, where a 5-ton heat pump with a 350-gallon storage tank is installed and operates	The system provided hot water from May 12 - Aug 24, 2010, when it was taken off-line for a water leak The system had an apparent COP of 2.33	https://www.epri.com/#/pages/product/000000000001020137/?lang=en-US

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
HPWHs for Commercial Buildings	2011	Lab Research	Tested two HPWH systems in the EPRI lab in steady-state and simulated usage testing across a broad range of conditions They were tested with a storage tank using a simulated restaurant load profile to quantify the energy savings and load profile of a "real world" application	High efficiency across a variety of conditions, with energy savings as high as 72% in simulated use applications Combined COPs including air cooling in addition to water heating of over 10.0 are feasible Testing indicates that HPWH is viable in all climates provided that an adequate air heat source is available on site Estimated energy savings in a laboratory simulation of a restaurant application was as high as 65%, with payback periods of 1.8-4 years Best conditions for higher COP: warmer ambient air and colder entering water	https://www.epri.com/#/pages/product/1021970/?lang=en-US
Laboratory & Field Evaluation of Four Heat Pump Water Heater Systems	2012	Hotel & Lab Research	A.O. Smith commercial HPWH was installed and monitored in a hotel in Birmingham Two systems manufactured by Sanden, which use CO_2 as a refrigerant, were also tested in the laboratory in Knoxville	Results were as expected: The commercial HPWH installation showed energy savings in the range of 35-50% monthly. The efficiency seen with the CO_2-based Sanden systems was higher than the ATI66, or other typical US HPWH systems. The external gas cooler of the Sanden units steadily drew water in near the mains water temperature and uses a counterflow heat exchanger, maximizing the efficiency of the gas cooler.	https://www.epri.com/#/pages/product/1024336/?lang=en-US

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Commercial Heat Pump Water Heater Research for Schools	2013	School	An A.O. Smith HPWH was installed in an elementary school in N.C. It was monitored over a 5-month period and had later supplemental testing	Based on the measured results, Advanced Energy estimates a 12 percent annual energy reduction associated with use of the heat pump water heater at Rand Road Elementary.	https://www.advancedenergy.org/2015/07/22/commercial-heat-pump-water-heater/
HPWHs for Single and Multi-family Residential Buildings	2014	Single & Multi-Family	PowerPoint presentation that reviews: Concepts governing heat pump performance Reviews a range of currently available heat pump water heater technologies Reviews critical code and design issues to ensure good heat pump water heater performance in residential applications Review case studies and lessons learned	None	https://www.ecobuilding.org/summit/previous-years/presentation-files/2014-presentations/EB2014HPWaterHeaters.pdf
Feasibility Analysis of a Commercial HPWH with CO_2 Refrigerant	2017	Commercial Residential	A scoping-level analysis was conducted to establish the feasibility of using CO_2 as refrigerant for a commercial heat pump water heater (HPWH) for U.S. applications using the DOE/ORNL Heat Pump Design Model (HPDM) modeling tool for the assessment with in addition to data from a Japanese heat pump water heater (Sanden) using CO_2 as refrigerant for calibration. A CFD modeling tool was used to refine the HPDM tank model. After calibration, the model was used to simulate the performance of commercial HPWHs using CO_2 and R-134a (baseline).	Compressor discharge pressure and water temperature stratification are critical parameters for the system. The proposed design deploying a gas-cooler configuration exceeds the Energy Star Energy Factor criteria (2.20) and is comparable to some of the most efficient products in the market using conventional refrigerants.	https://info.ornl.gov/sites/publications/Files/Pub73586.pdf

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Multi-family HPWH Evaluation	2017	Multi-Family	The Alliance for Residential Building Innovation team monitored the performance of a central HPWH installed on student apartments at the University of California, Davis, West Village zero net energy community from October 2011 through February 2013; and then monitored models later installed in Phoenix, Houston, Sacramento, Seattle, Denver, and Chicago	High-level project conclusions: although savings of 50% or more relative to electric resistance water-heating systems are easily achievable. Could get greater savings by optimizing system performance: increasing the average compressor duty cycle through modified controls, use of variable-speed or two-stage compressors, and/or increased storage volumes. • More attention to reducing standby parasitic energy would also improving seasonal performance, especially in milder climates	https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/66430.pdf
Retrofitting Fossil-based heating systems with air to water heat pumps in multi-family houses	2017	Multi-Family	Studied three pilot projects that are replacing fossil-based heating systems with air to water heat pumps in multi-family housing in Geneva, Switzerland.	Older buildings are not as compatible with the air to water system. These three projects demonstrated technical and economic difficulties and solutions for integrating air to water heat pump solution in existing multi-family houses. "This type of renewable solution is technically and economically feasible in the case of energy contracting, although it demands high quality engineering expertise and cost optimization efforts."	http://hpc2017.org/wp-content/uploads/2017/05/P.1.5.4-Retrofitting-fossil-based-heating-systems-with-air-to-water-heat-pumps-in-multifamily-houses.pdf
Commercial HPWH in Dorms	2008	Dormitory	Compared a HPWH with a hot water supply system comprised of the combination of a heavy oil boiler and a city gas firing hot water supply unit	CO_2 emissions were reduced by 60% Running costs were reduced by about 61% At the link, there are graphs showing these two statistics	https://www.jase-w.eccj.or.jp/technologies/pdf/office/O-03.pdf

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Better Buildings Alliance Demonstration Opportunities: Commercial HPWH	2014-2015	Multiple Building Types	Participating organizations receive a discounted high-efficiency product in exchange for their cooperation with the field study and can see firsthand the performance, energy savings, and economic benefits of commercial HPWHs	None	https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/BBA%20HPWH%20Demo%20Opportunity%20Fact%20Sheet.pdf

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Field Test of High-Volume Heat Pump Water Heaters	Pre-sent	Multiple Building Types	Call to participate in study: "The ET Field Test could fully fund up to 5 High Volume Heat Pump Water Heaters, replacing retrofitting electric resistance water heaters with total daily domestic hot water consumption of 500 gallons per day or more, with the intent of informing a region-wide offering…Please consider participating in this ET Field Test and help fill the pipeline with a new conservation measure. Your participation and feedback is essential to developing technologies and future BPA program offerings."	None	https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Field-Test-of-High-Volume-Heat-Pump-Water-Heaters-.aspx

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Demonstration of HPWH at Mississippi State University	2017	University Cafeteria	A single-pass, water-to-water HPWH was installed at the Perry Cafeteria at MSU to work in parallel with an existing gas water heater The HPWH was installed in a mechanical room in the basement of the cafeteria facility, which is unconditioned but contains several small condensing units and the gas water heater. The configuration for this field study was designed so that the water flow through the HPWH and gas water heater could be adjusted via valves and the HPWH system could be shut off by a temperature sensor if it ran out of hot water. This approach increased the storage and heating capacity while simultaneously reducing the flow rate through the gas water heater tank	The HPWH was able to provide adequate hot water capacity in all normal usage conditions except for a few very cold days. The operating cost of the HPWH and the gas water heater was highly sensitive to the cost of gas and electricity In this field study the HPWH was similar or slightly less expensive per-gallon to operate than the gas water heater The study shows that depending on local prices, HPWHs in this configuration can be competitive in terms of operating cost with high efficiency gas water heating	https://www.epri.com/#/pages/product/000000030020103 21/?lang=en-US&lang=en-US

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
Heat Pump and Heat Pump Water Heater Economic Assessment: Applicability for Residential and Small Commercial Markets	2018	Not Available	This report focuses on the market viability of air-source heat pumps and HPWHs in different regions of the country by evaluating the benefits of adopting heat pump technology, while simultaneously assessing the potential market barriers	HPWHs were found to be cost effective in most of the southern states, however the primary factor impacting the economics of HPWH were favorable electric to natural gas price rations, more so than climate. This assessment also suggests the level of first cost incentives or tipping points of electricity pricing where heat pumps will become viable.	https://www.epri.com/#/pages/product/3002013328/?lang=en-US
CO_2 Heat Pump Water Heater Field Evaluation in a School Cafeteria Application	2018	School Cafeteria	Field test of a CO_2 HPWH at a school cafeteria in Mobile, AL The system was instrumented to capture performance and hot water delivery and monitored for over one year	The results show good efficiency, with a COP of 2.9 The water heater delivered supply water with a setpoint of 149F and provided the full hot water demand on all monitored days	https://www.epri.com/#/pages/product/000000003002011060/?lang=en-US

Table A-4: Compiled Studies, continued

Study	Year	Type of Building	Overview	Results	Link
CO_2 Heat Pump Water Heater Performance Testing: A Laboratory Assessment to Evaluate the Performance of a CO_2 Heat Pump Water Heater	2018	Light Commercial Kitchen	EPRI is evaluating the HPWH for functionality, energy performance, and potential for light commercial kitchen applications• To verify the HPWH's reported capability, one 4.5-kW unit was installed and tested at Optimized Thermal Systems, Inc. A dedicated environmental chamber housed the unit and controlled temperature and humidity level.	In full heating tests, the unit's performance depended on the ambient temperature and performed more efficiently at warmer ambient condition (average COP of 8.53 at 100F) vs. average COP of 2.41 at 16.2F.• Simulated drawdown tests incorporated an actual water usage profile. Under these tests, the unit had better performance at warmer ambient condition (COP 4.26 at 100F against COP of 2.18 at 15.7F) with warmer drawdown water, leading to a shorter recovery time (as much as 324 minutes shorter)	https://www.epri.com/#/pages/product/000000003002011061/?lang=en-US

Table A-5: Conferences Information

Conference	Organization	Speakers	Date	Link
ACEEE Hot Water Forum - HPWH in MF Buildings	ACEEE / Ecotope	Jonathan Heller	2017	https://aceee.org/sites/default/files/pdf/conferences/hwf/2017/Heller_Session5C_HWF17_2.28.17.pdf
HPWH Workshop	Association for Energy Affordability Passive Housing California	John Neal Pierre Delforge	2017	http://www.passivehousecal.org/sites/default/files/media/1_PHCA-%20HPWH%20Workshop-%20Part%201.pdf
IEA Heat Pump Conference	Energy Technology Network	Fabrice Rognon Alisa Yushchenko Mattias Rüetschi	2017	http://hpc2017.org/wp-content/uploads/2017/05/P.1.5.4-Retrofitting-fossil-based-heating-systems-with-air-to-water-heat-pumps-in-multifamily-houses.pdf
Heat Pump Water Heaters for Multi-family	Northeast Sustainable Energy Association	Robb Aldrich Robin Neri Ted Hetzel	2018	http://nesea.org/session/heat-pump-water-heaters-multifamily
MF HPWH Workshop	Association for Energy Affordability	Alex Hansen	2018	https://www.eventbrite.com/e/multifamily-heat-pump-water-heating-workshop-tickets-48250481489

Table A-6: Rebates

Organization	Contact Person	Links
Austin Energy	Not Available	https://savings.austinenergy.com/rebates/multifamily/offerings/appliances-and-equipment/hp-water-heate https://austinenergy.com/wcm/connect/psp/ri-demo/multifamily/offerings/appliances-and-equipment/heat-pump-water-heatersr
BPA	Erik Boyer	https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Field-Test-of-High-Volume-Heat-Pump-Water-Heaters-.aspx
City of Lodi California	Not Available	http://www.lodielectric.com/pdf/residential/newresrebates.pdf
Dawson Public Power	Not Available	https://dawsonpower.com/customer-service/rebates/ https://dawsonpower.com/wp-content/uploads/2016/01/Heat-Pump-Water-Heater-Program_2016.pdf https://dawsonpower.com/wp-content/uploads/2017/05/Heat-Pump-Water-Heater-Program-Guidelines.pdf
Duke Energy	Not Available	http://programs.dsireusa.org/system/program/detail/1549
Energy Trust of Oregon	Nate Collins	https://insider.energytrust.org/tier-3-heat-pump-water-heater-incentive-available-existing-multifamily-properties/
Madison Gas & Electric	Not a rebate program, but lots of great info	https://www.mge.com/saving-energy/business/bea/article_detail.htm?nid=1777
Pacific Gas & Electric	Not Available	https://www.pge.com/includes/docs/pdfs/myhome/saveenergymoney/rebates/property/multifamily_catalog.pdf
Port Angeles, WA	Not Available	http://wa-portangeles.civicplus.com/199/Rebates
Rush Shelby Energy	Not Available	http://programs.dsireusa.org/system/program/detail/2664
Tampa Electric	Not Available	https://www.tampaelectric.com/business/saveenergy/waterheating/

Table A-7: HPWH Improvements

Study	Year	Overview	Results	Link
Performance Improvements in Commercial HPWHs Using Carbon Dioxide	2011	The use of carbon dioxide (R744) as the refrigerant in HPWHs can improve performance for relatively small increase in initial cost and make HPWHs more appealing What makes R744 an excellent candidate for use in heat pump water heaters is not only the wide range of ambient temperatures within which it can operate, but also the excellent ability to match water to refrigerant temperatures on the high side, resulting in very high exit water temperatures of up to 180F, as required by sanitary codes in the US in a single pass, temperatures that are much more difficult to reach with other refrigerants This can be especially attractive in applications where this water is used for the purpose of sanitation	Both R744 systems investigated can achieve water temperatures between 74-82F without the use of any source of auxiliary heat Both R744 systems showed areas of lower energy consumption at these higher water temperatures The baseline R744 system would likely provide 2% savings in energy consumption, while the R744 system with internal heat exchange has the potential to save up to 10% in energy consumption at the higher water temperatures needed for sanitary applications	https://www.osti.gov/servlets/purl/1063974
Development of High Efficiency Carbon Dioxide Commercial Heat Pump Water Heater	2012	Performance results from the development of four R744 commercial HPWH packages of approximately 35 kW and comparison to a commercially available baseline R134a unit of the same capacity and footprint	The combined COP of the system increased for each development step compared to the R744 baseline system At low (12C) and medium (26.7C) water inlet temperatures the system with enhanced evaporator showed the highest relative performance increase with approximately 15% and 11% respectively At a water inlet temperature of 50C the system with enhanced evaporator and internal heat exchange showed the best performance with a relative improvement of 35% compared to the R744 baseline system	https://pdfs.semanticscholar.org/ff59/b6548315cc66189c39036dee5b5a044cfcc1.pdf

Table A-7: HPWH Improvements, continued

Study	Year	Overview	Results	Link
Development of R744 Two Stage Compressor for Commercial Heat Pump Water Heater	2012	A novel CO_2 two stage compressor has been developed. The developed compressor equips one rotary and one scroll compression chambers as first and second stage respectively. For efficiency improvement, authors measured the cylinder pressure in each stage and conducted loss classification in the compressor	By adopting appropriate compression type in each stage, and by decreasing critical loss found by measuring the pressure, it resulted in 6% and 10% improvement of heating capacity and COP respectively on rated condition, and 25% and over 50% improvement on deep-frozen condition compared with conventional single stage compressor. The developed compressor is installed on our newly developed commercial HPWH	https://docs.lib.purdue.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=3055&context=icec

C-EHPWH
Research Overview

Appendix B: Commercial Heat Pump Water Heater Compendium Presentation 061819

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

EPRI / SCE Technology Transfer

Commercial Electric Heat Pump Water Heaters (C-EHPWH)

Julie Hayes
Utility Program Strategist
Milepost Consulting
June 18, 2019

www.epri.com

What are we going to do today?

our agenda

1. WHY C-EHPWHs?
2. RESEARCH METHODOLOGY
3. MARKET RESEARCH FINDINGS
4. RECOMMENDATIONS
5. UPDATE ON BPA PILOTS IN NW

tech transfer overview

Regional Research on C-EHPWHs

Why C-EHPWHs?

1. Integrated Energy Policy Report
   - Approved by CEC – 100% zero carbon by 2045
2. EPRI's Efficient Electrification Initiative
   - Building the path towards electrification
3. Deep Penetration of Gas Water Heaters in CA
   - Residential barriers are steep
   - Commercial customers may be more willing to participate

tech transfer overview

tasks & deliverables

REGIONAL RESEARCH SUPPORT

1. CONDUCT RESEARCH ON COMMERCIAL HPWHs
   - Research Report
2. Provide Updates On Process, Key Learnings, And Results
3. Facilitate Stakeholder Engagement
   - Agenda, Notes, And Materials For Facilitated Meetings

How we did it

research methodology

1 — 2 — 3 — 4 — 5

RESEARCH METHODOLOGY

research methodology

our approach

PRIMARY RESEARCH

- Contacted field reps with experience testing C-EHPWs
- Created Interview Guide and conducted outreach
- Documented key findings on best practices and lessons learned

SECONDARY RESEARCH

- CHPWH Manufacturers
- Sector and building applications
- Literature review of existing studies
- Market characteristics

What we learned

market research findings

1 — 2 — 3 — 4 — 5

MARKET RESEARCH FINDINGS

market research findings

primary research

GoodCents
A FRANKLIN ENERGY COMPANY

hydro one

MANUFACTURERS

AO Smith

General Electric

ENVIRONMENTS

Bakeries, small retail, multi-unit residential, strip malls, coffee shops, restaurants, small manufacturing, schools

PILOT DELIVERY

Direct installation through approved contractor network

Rebates for equipment and installation

SUCCESS

Oversubscribed

Customer energy savings

market research findings

primary research

Bonneville
POWER ADMINISTRATION

Robert Weber
Engineering Technical Lead

MANUFACTURERS

Sanden

Colmac

ENVIRONMENTS

Mostly multifamily (low-, mid-, & high-rise), laundry for a hospital, city commercial building, hoping to continue expanding

PILOT DELIVERY

Both new construction and retrofit

Usually recruit through utilities and low-income groups

SUCCESS

Large energy & money saving for successful pilot projects

Learned the pros and cons of using different manufacturers in different environments

market research findings

C-HPWH manufacturers

market research findings

C-HPWH technical considerations*

CHPWH COP performs better in environments with:

- ☑ Warmer ambient air temperature
- ☑ Colder entering water temperature
- ☑ Increased humidity

market research findings

C-HPWH sector applications

- MULTI-FAMILY*
- FOOD SERVICE*
- HIGHER EDUCATION*
- LAUNDROMATS
- K-12 EDUCATION*
- HOSPITALITY*
- HEALTH & FITNESS

*Denotes sector in which CHPWH testing or field study has been conducted and/or documented

market research findings

C-HPWH field testing organizations

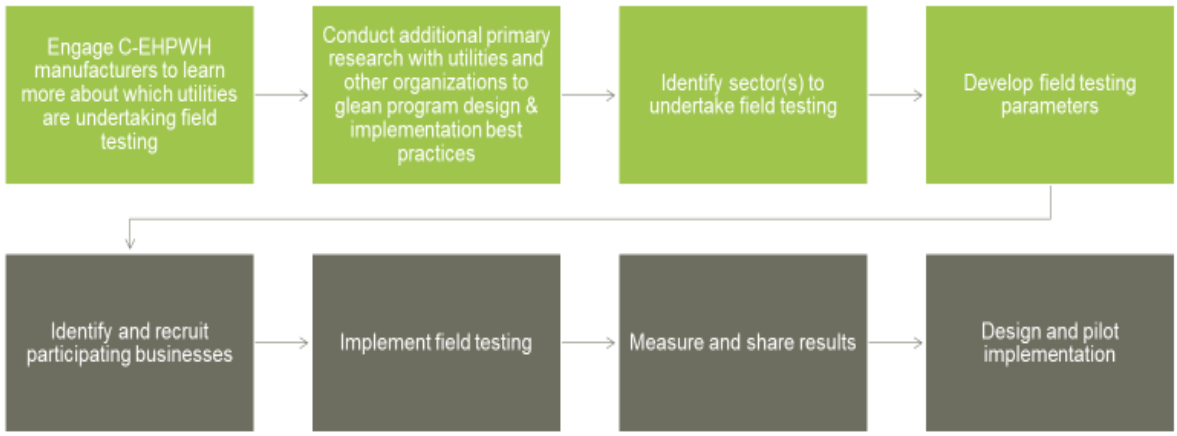
- ELECTRIC POWER RESEARCH INSTITUTE
- BONNEVILLE POWER ASSOCIATION
- US DEPARTMENT OF ENERGY
- NORTHWEST ENERGY EFFICIENCY ALLIANCE
- HYDRO ONE

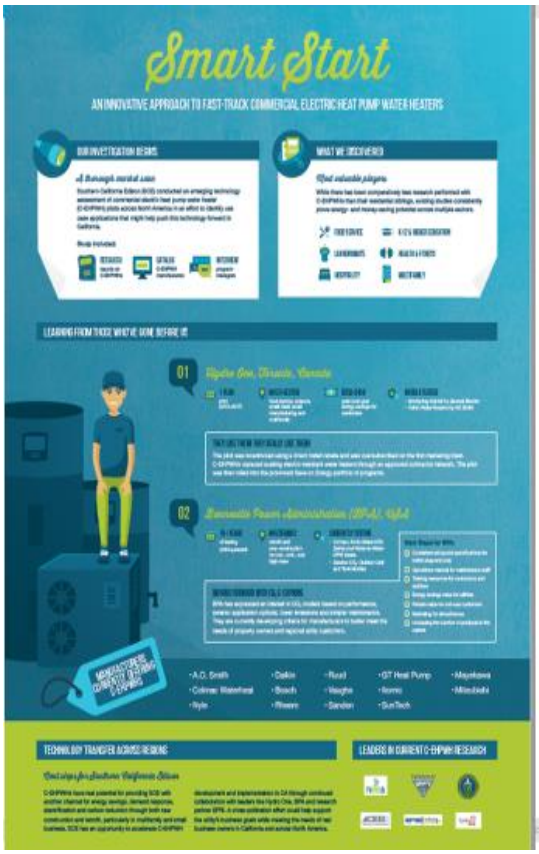
Ideas for next steps

path forward

path forward

potential next steps





Utility Energy Forum 2019

EPRI ELECTRIC POWER RESEARCH INSTITUTE

secondary research

Slide 10:

https://www.hotwater.com/lit/spec/com_elec/aosze15000.pdf
https://www.hotwater.com/news/a-o-smith-introduces-new-commercial-electric-heat-pump-water-heaters/
https://aceee.org/files/pdf/conferences/hwf/2010/6D_Greg_Wilson.pdf
https://www.businesswire.com/news/home/20160705005188/en/New-Heat-Pump-Water-Heater-Game
http://www.gtheatpump.com/commercial-heat-pump-gt-skr40kp-10.html
http://colmacwaterheat.com/
http://heatpumpindonesia.com/products/colmac/
https://www.nyle.com/water-heating-systems/air-source/
https://www.nyle.com/wp-content/uploads/2017/04/Reduced-Nyle-Presentation-for-website.pdf
http://www.daikin.com/products/ac/lineup/heat_pump/index.html
https://www.daikin.com/csr/environment/climatechange/heat_pump.html
https://www.prowaterheatersupply.com/PDFS/Bosch_Therm_Commercial_Catalog.pdf
https://www.rheem.com/group/rheem-commercial-electric-water-heaters-hybrid/
https://www.ruud.com/product/ruud-commercial-electric-water-heaters-hybrid/
http://www.vaughncorp.com/commercial/
http://www.vaughncorp.com/products/hybrid-heat-pump/#.XABDeJNKjVo

EPRI ELECTRIC POWER RESEARCH INSTITUTE

secondary research

Slide 11:
https://www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/considerations

Slides 12 & 13:
https://www.epri.com/#/pages/product/3002005496/?lang=en-US
https://www.advancedenergy.org/2015/07/22/commercial-heat-pump-water-heater/
https://www.jase-w.eccj.or.jp/technologies/pdf/office/O-03.pdf
https://www.epri.com/#/pages/product/1021970/?lang=en-US
https://www.epri.com/#/pages/product/1024336/?lang=en-US
https://aceee.org/files/pdf/conferences/hwf/2010/6D_Greg_Wilson.pdf
https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/BBA%20HPWH%20Demo%20Opportunity%20Fact%20Sheet.pdf
https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Field-Test-of-High-Volume-Heat-Pump-Water-Heaters-.aspx
https://neea.org/img/documents/water-heater-market-characterization-report.pdf

Let's talk

update on BPA pilots

MF DHW MARKET

BPA Interest?

- New EE acquisition opportunities
- DR is not the driver, but is a consideration
- EE savings potential is several hundred aMw
- 2018 utility EE savings are .003 aMw
- Untapped market

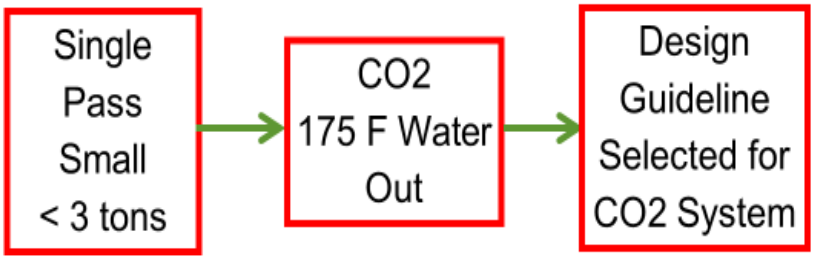
GOAL

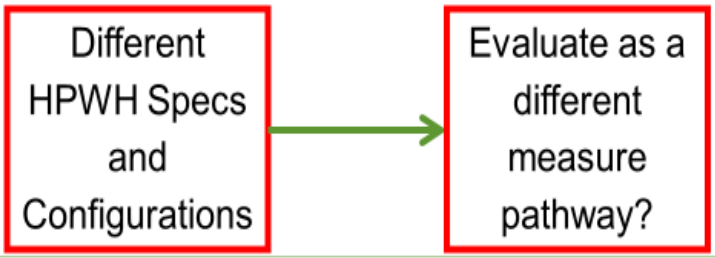
- Develop Utility EE incentives

HPWHS CONFIGURATIONS

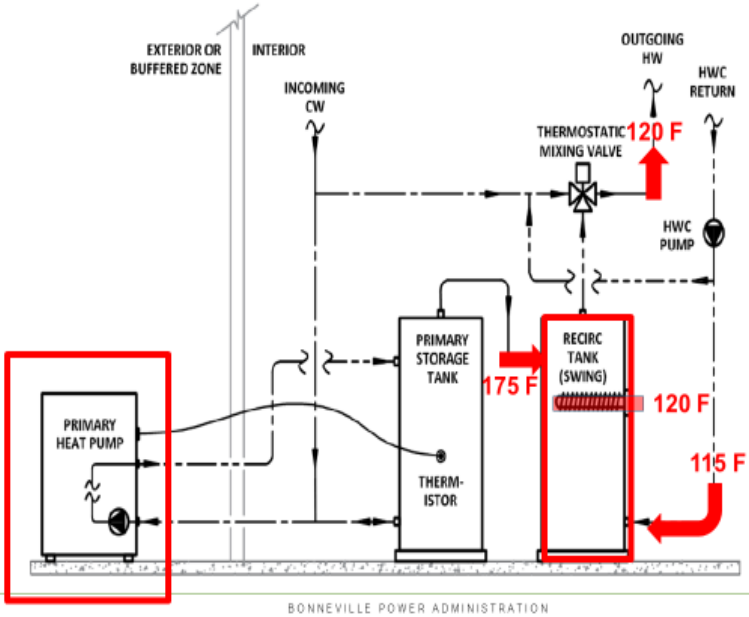
System Type	Building Type	Product	BPA Action
Integrated HPWH	Low Rise Mid Rise Manufactured Homes	NEED 1:1 Integrated Product	Collaborative scanning looking for new form factor HPWH
Single Pass Small < 3 tons	Low Rise Mid Rise	Sanden CO2	1 : 5 Townhouse - current 4 : 60 Low income Senior - current 1 : 6 30 unit new construction cluster design - 2020
Single Pass Large > 3 tons	Mid Rise High Rise Central Systems 25-500 units	Mayekawa CO2 Colmac	Seattle MF new construction 2 Colmacs - current Mayekawa site demonstration - TBD
Multi Pass	Mid Rise High Rise Central System 5-200 Units	Colmac, Versati, Phnix, Aermer, Nyle, AD, AO Smith, …	Prior pilot testing, no current activity
Split Combi System			No current activity.

DESIGN PATH DEVELOPMENT



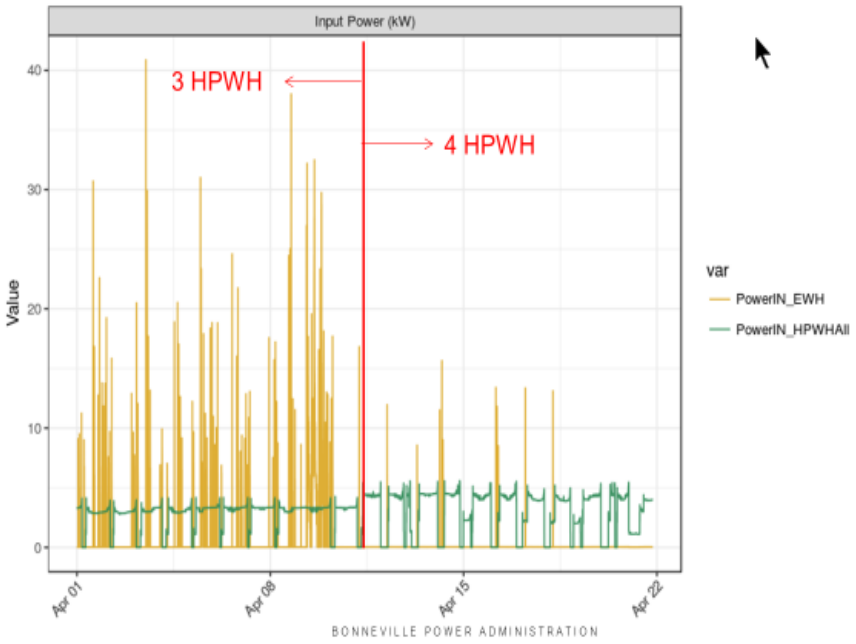


DESIGN FOR SINGLE PASS CO2 HPWH



ELIZABETH JAMES BUILDING
4 SANDEN CO2 TO 60 APARTMENTS

POWER IN



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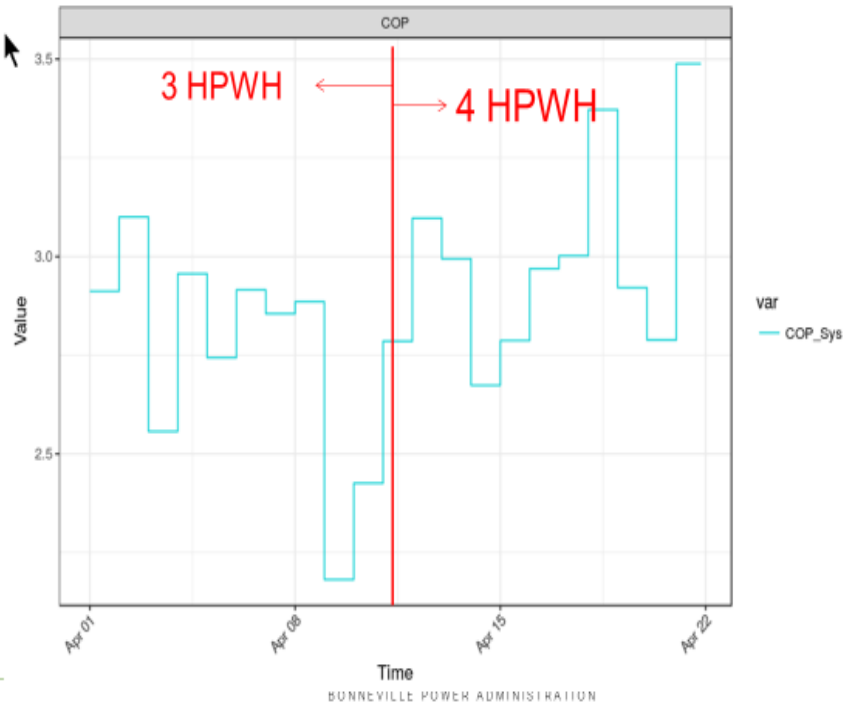
TOTAL SYSTEM COP



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CO2 HPWH

- Refrigerant
- Low temperature operating range 14F or lower
  - Installation flexibility
  - Demand – reduces potential of ER demand issue in cold weather
- Demonstrated COP

UTILITY INCENTIVE CONSIDERATIONS

- Demonstrated Reliability** *units unexpectedly going offline-Determine Cause*
- Validate EE Savings and utility cost effectiveness
- Evaluate incentive delivery mechanism

1. EE UES Measure
2. Protocol or…
3. Custom with design support
4. Custom

Incentive Considerations

- Strive for plug and play
- Identify different potential design configurations
- Contractor adoption tools and considerations
- Develop design guidelines, sizing calculators ….
- Consider DR

Let's talk

Q&A

1 ..... 2 ..... 3 ..... 4 5

Q&A

Together...Shaping the Future of Electricity

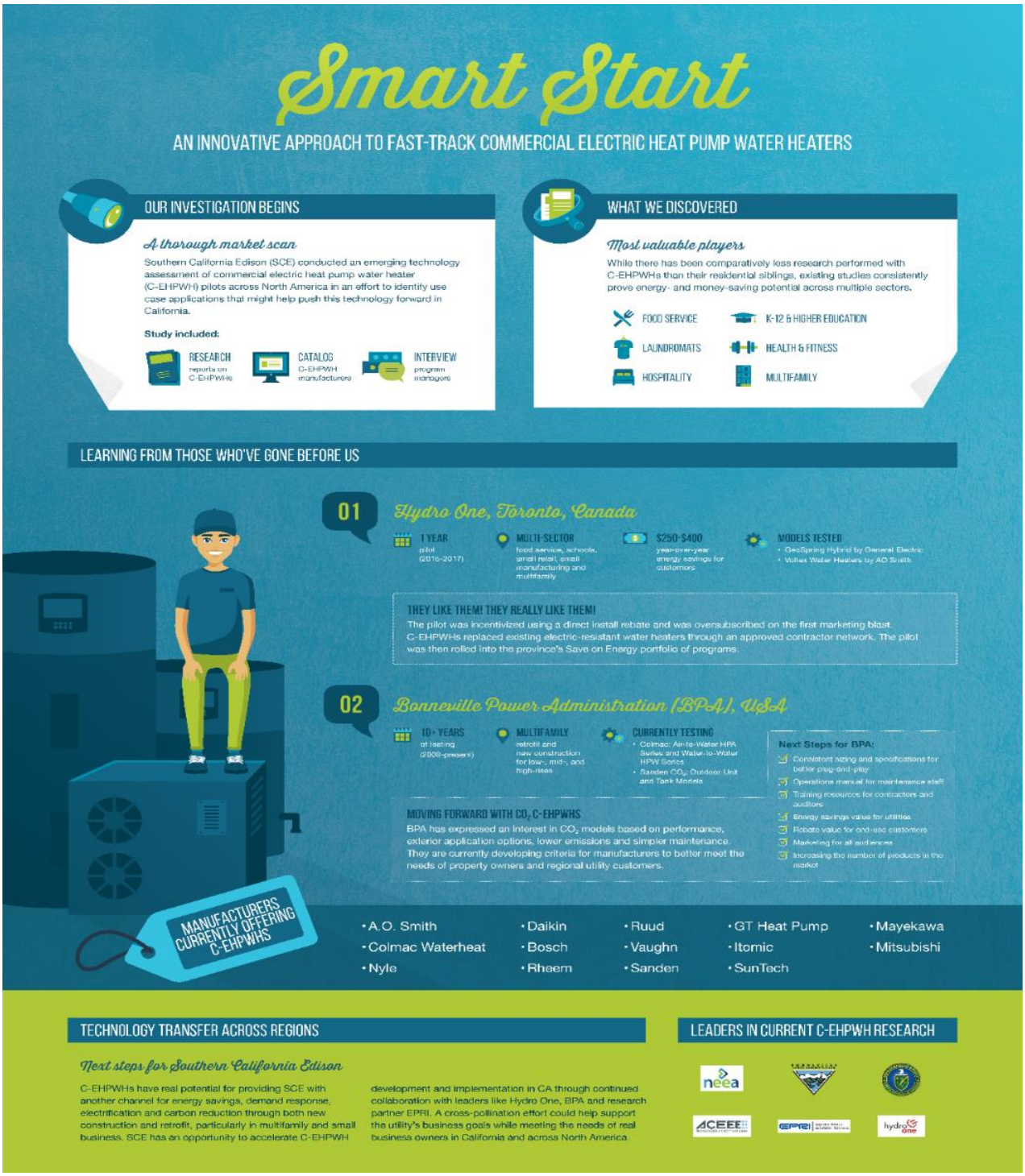

Figure B-2: 2019 Utility Energy Forum Poster Presentation, https://app.box.com/file/451485405322