HVAC Fuel Substitution Measure Research

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Date: July 14, 2023

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About Energy Solutions

Energy Solutions is a mission-driven clean energy implementation firm that specializes in programs that align with the market to deliver significant resource impacts. For 25 years we've been pioneering end-to-end, market-driven solutions that deliver reliable, large-scale, and cost-effective savings to our utility, government, and private sector clients across North America. Our passionate, smart employee-owners are committed to excellence and to building long-lasting, trusted relationships with our clients.

1. Executive Summary

Research Driver

Space heating is a significant source of California's statewide greenhouse gas (GHG) emissions. Cost-effective GHG emissions reductions can occur with fuel substitution if sufficient electric energy efficiency performance in the measure case is achieved. Within the framework of deemed and custom incentive offerings, these requirements are satisfied using CPUC-provided tools including the fuel substitution calculator, refrigerant avoided cost calculator (RACC), and cost-effectiveness tool (CET).

As of 2023, there are currently three HVAC fuel substitution measure packages active in the eTRM. These measures cover the core heat pump offerings currently available in the market:

- Residential ductless heat pumps
  - SWHC044
- Residential central heat pumps
  - SWHC045
- Commercial unitary heat pumps
  - SWHC046

This is a good starting point, however, there are many other types of electric space heating options that could be investigated for potential additional measure packages. This research identified HVAC decarbonization (though gas to electric fuel substitution) technologies and prioritized them using quantitative and qualitative methods.

This research centered on measures that directly or indirectly impacted space heating HVAC fuel substitution. Other adjacent measure ideas are discussed in passing (such as energy efficiency (EE) measures to support the actual space heating electrification) and could be the subject of future investigation. Overall, there are three main categories of electric space heating, namely heat pumps, heat recovery, and electric resistance heater that are discussed in detail in the report.

Key Findings

- "Partial fuel substitution" could allow the offloading but not decommissioning of the existing natural gas equipment for imminent advantages in specific situations.
- Shrinking space heating loads through aggressive deployment of EE measures (particularly building envelope and HVAC controls improvements) should be considered either before or in parallel with space heating electrification.
- Grouping the specific measure ideas by broad efficiency and technology patterns (especially on the commercial side) makes the exercise of estimating the source Btu and GHG savings more straightforward.
- Mechanical heat recovery (defined here as heat recovery from a compressor-based system) is a critical "piece of the puzzle" for commercial building fuel substitution, but it should ideally be paired with other equipment such as thermal energy storage and/or Air-Source Heat Pump (ASHPs) to form a complete system.

- Thermal energy storage (TES) for space heating has been identified as a promising technology to pair with heat recovery (especially mechanical heat recovery), it can be thought of as an extension of heat recovery. In addition to dramatic energy efficiency benefits, this technology will typically reduce the peak heat pump equipment capacity needs for the building. Our early assessment suggests that condenser water and ice TES are the two more promising strategies for TES applied to all-electric space heating.
- When deployed in a zone with very low space heating loads, the energy penalty of electric resistance (ER) heating is going to be limited and the benefits could be substantial. ER heating should be a consideration as a component to all-electric commercial buildings. Distributed generation (DG) technologies such as solar PV and battery storage could be considered with ER heating to help mitigate heating peak loads.

Top New Fuel Substitution Measure Opportunities

Residential

Table 1 shows the research study's recommendations for top priority new residential HVAC fuel substitution measure packages. The first item, combination space and Domestic Hot Water (DHW) heat pumps, are attractive because they would accomplish both space and water heating decarbonization in a single measure package and would capture an emerging product category that is gaining market share. The second item, micro heat pumps, are also an emerging category of residential heat pumps, and would particularly benefit renters and other low-to-moderate income (LMI) communities.

Table 1: Recommendations for New Residential Deemed Measure Packages

No.	Measure Name	Code(s) from Report
1	Combination of Space & Domestic Hot Water Heat Pumps	R1
2	Micro Heat Pumps (120V)	R2

Other residential technologies identified in the report are possible for deemed measure package development but would likely merit further investigation before we can feel confident that they are good candidates.

Commercial

As detailed in this report, the commercial sector is far more complex to analyze for potential fuel substitution measure package development than residential. This is mainly due to the likely need for multiple individual technologies being combined in a commercial building to create a complete all-electric space heating design. Due to this inherent complexity, the team identified 15 top-level measure opportunities, with many of them containing subcategories based on further nuances and details. We screened out a number of technologies as needing some additional research prior to measure packages, custom program promotion, or the need for more foundational research to understand the opportunity. However, we feel that some commercial measures are ready for new measure packages, shown in Table

2. We recommend pursuing these measure packages in the short term and conducting additional research on other opportunities for potential future measure packages.

Table 2: Recommendations for New Commercial Deemed Measure Packages

No.	Measure Name	Code(s) from Report
1	Air to Water Heat Pump (with and without Mechanical Heat Recovery; with and without Exhaust Air Heat Recovery, as a standalone system and as part of a Water Source Heat Pump retrofit)	C1.2, C9.2, C10, C7
2	Variable Refrigerant Flow (with and without Mechanical Heat Recovery, with and without Exhaust Air Heat Recovery)	C1.3, C9.3, C7
3	Mechanical Heat Recovery (i.e., Heat Recovery Chiller)	C2.1, C2.2

Item 1 from Table 2 would be a measure case of a hydronic air to water heat pump replacing a gas boiler. The measure package could include offerings with and without "mechanical heat recovery" (which would be accomplished with a heat recovery chiller in this context). Item 2 is a similar concept, except instead of an AWHP, the measure case would be a VRF heat pump (again, with separate offerings for VRF with and without heat recovery). Item 3 is a novel concept of 'partial electrification' whereby a heat recovery chiller (a.k.a. a 4-pipe air to water heat pump, dedicated heat recovery chiller, or water to water heat pump) would replace an existing chiller (either an air- or water-cooled chiller) and offload the boiler that would stay in place for trim heating. Over time, a future retrofit could replace the boiler with an air to water heat pump to complete the electrification process.

2. Glossary

AAHP	Air to Air Heat Pump
ACC	Air Cooled Chiller
ACEEE	American Council for an Energy-Efficient Economy
AHRI	Air-Conditioning. Heating and Refrigeration Institute
AHU	Air Handling Unit
ASHP	Air Source Heat Pump
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AS-VRF	Air Source Variable Refrigerant Flow
AWHP	Air to Water Heat Pump
BEM	Building Energy Modelling
CARB	California Air Resources Board
CBECS	Commercial Buildings Energy Consumption Survey
CEDA	California Energy Design Assistance
CEE	Consortium of Energy Efficiency
CET	Cost Effectiveness Tool
COP	Coefficient of Performance
CPUC	California Public Utilities Commission
CUAC	Commercial Unitary Air Conditioner
CUES	California Commercial End Use Survey
CUHP	Commercial Unitary Heat Pump
CW	Condenser Water
CWAF	Commercial Warm Air Furnace
DDC	Direct Digital Control
DEER	Database for Energy Efficient Resources
DHP	Ductless Heat Pump
DHW	Domestic Hot Water
DG	Distributed Generation
DOE	Department of Energy
EAHR	Exhaust Air Heat Recovery
EE	Energy Efficiency
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ER	Electric Resistance
ET	Emerging Technology
eTRM	California Electronic Technical Reference Manual
EUL	Effective Useful Life
FS	Fuel Substitution

GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HPWH	Heat Pump Water Heater
HR	Heat Recovery
HVAC	Heating, Ventilation and Air Conditioning
HW	Hot Water
HWST	Hot Water Supply Temperature
HWSS	Hot Water Storage System
IEER	Integrated Energy Efficiency Ratio
IMC	Incremental Measure Cost
NYSERDA	New York State Energy Research and Development Authority
PCM	Phase Change Material
PTAC	Packaged Terminal Air Conditioner
PTHP	Packaged Terminal Heat Pump
PUD	Public Utility District
PV	Photovoltaic
PVAV	Packaged Variable Air Volume
RACC	Refrigerant Avoided Cost Calculator
RASS	Residential Appliance Saturation Study
RECS	Residential Energy Consumption Survey
RTU	Rooftop Unit
SEER	Seasonal Energy Efficiency Ratio
SPVAC	Single Package Vertical Air Conditioner
SPVHP	Single Package Vertical Heat Pump
SSHP	Storage Source Heat Pump
TBS	Total System Benefit
TES	Thermal Energy Storage
TIER	Time Independent Energy Recovery
TRC	Total Resource Cost
UEF	Uniform Energy Factor
VAV	Variable Air Volume
WAHP	Water to Air Heat Pump
WCC	Water Cooled Chiller
WHP	Window Heat Pump
WSHP	Water Source Heat Pump
WWHP	Water to Water Heat Pump
WWHR	Wastewater Heat Recovery
ZNE	Zero Net Energy

3. Literature Review

We undertook a comprehensive literature review to understand the state of the market regarding fuel substitution in HVAC. There have been several studies published in recent years that collect the latest all-electric space heating design and construction trends in California and nationwide. These studies have been reviewed in-depth by the research team to inform our presentation of the potential HVAC FS measures. This section provides a condensed summary of the key findings from the literature. We also reviewed relevant "benchmarking" studies that seek to classify the existing energy usage patterns in California and nationwide and provided a summary along with some key data points.

Literature Describing Electric Space Heating Technologies

Redwood Energy's decarbonization guidebooks. Redwood Energy has undertaken comprehensive research to identify promising all-electric space heating technologies over the past several years by sector.

- Single Family Residential (2022): Redwood Energy has created a novel resource in the form of a "booklet" for homeowners, home renters, and utilities and policy makers to help them to replace their existing gas appliances with efficient electric alternatives. The booklet explains the costs, benefits, and strategies for electrifying a home, the lessons learned from case studies of retrofitted homes, and an extensive product guide to help choose your electrification appliances.
- Multifamily (2019): Redwood Energy Guide for Multifamily presents the trend towards all-electric multifamily housing, summarizes best practices and provides designers a useful catalogue of electric products.
- Commercial (2022): The Redwood Energy "pocket guide" to all-electric commercial retrofits helps one identify trends in commercial electrification, presents case studies to learn best practices, and shares an extensive product catalog of commercial appliances and equipment.

DOE Appliance Standards for heat pumps. Since 1987, Congress has directed the U.S. Department of Energy (DOE) to set efficiency standards for more than 55 products, who also reviews and updates all standards to keep pace with technological change. Energy Conservation Standards apply to products manufactured or imported for sale into the United States while state standards apply to products sold or installed in a given state.

Relevant residential covered products include:

- Central Air Conditioners and Heat Pumps
- Room Air Conditioners and Heat Pumps

Relevant commercial covered products include:

- Air Cooled Unitary Air Conditioners and Heat Pumps
- Packaged Terminal Air Conditioners and Heat Pumps
- Single Package Vertical Air Conditioners and Heat Pumps
- Variable Refrigerant Flow Air Conditioners and Heat Pumps
- Water Source Unitary Heat Pumps

- Direct Expansion Dedicated Outdoor Air Systems

These appliance standards provide a robust framework upon which above-code incentives can be offered. The appliance standard and underlying test procedure ensure that all products are rated to the same test conditions and can therefore effectively be sorted from low to high efficiency. The energy conservation standard set by DOE becomes the floor, and incentive offerings can push the market toward higher efficiency offerings.

Electrification, Heat Pumps and Thermal Energy Storage (MacCracken 2020)

This ASHRAE Journal article brought the benefits of thermal energy storage to the public's attention. Energy is wasted when the daily heating and cooling loads are not simultaneous and balanced, however, thermal storage (e.g., Ice) allows a system to save today's waste energy for tomorrow morning's heating needs. In winter, the ice storage is charged during off-hours while the system supplying heat to the building and is discharged by providing cooling to the building in the afternoon when the heat load is high. The natural gas fired boilers operate at about 0.8 COP while the storage source heat pump (SSHP) can operate at a COP above 5 or SSHP can operate at least 250% more efficiently than on site boilers.

Solving the Large Building All-Electric Heating Problem (Gill 2021)

This ASHRAE Journal article further expands on the details of how different all-electric space heating systems can be compared for large buildings. The push for building HVAC electrification (i.e., eliminating on-site fossil fuel consumption) poses new challenges for heating large buildings and campuses in a practical and efficient way. Common small- and medium-building all-electric solutions such as air-to-air heat pumps and variable refrigerant flow systems do not scale well for large building applications, and most existing large-building solutions require compromises. The paper highlights four "existing" options for large buildings: air to water heat pumps, electric resistance boilers or wire-to-air resistance heating, and heat recovery chillers. The paper describes a novel solution, which is named time-independent energy recovery (TIER). TIER is an all-electric central plant design that combines thermal energy storage and energy recovery to improve on existing alternatives for large commercial and mixed-use buildings with respect to energy efficiency, cost-effectiveness, equipment spatial requirements and support of grid-interactive efficient building initiatives.

All TIER plants have three components in common: a TES component, an energy recovery component (heat recovery chillers) and a trim heat source component (usually ASHPs, but these can be electric boilers in cold climates or where roof space is limited). During winter mornings when the building is heating dominated, the tank discharges; in the afternoon when combined building heat recovery and trim ASHP capacity exceeds heating load, the tank charges.

Title 24 2025 CASE studies. Ongoing studies related to residential and commercial heat pumps are referenced in the bulleted list below. These reports are part of advocacy efforts by the Investor-Owned Utility (IOU) Codes and Standards Enhancement (CASE) team to improve building energy efficiency and reduce GHG emissions by proposing modifications Title 24 Part 6.

- Residential – measures within this study focus on improving the efficiency of heat pump systems and should be referenced if enhancements to the current ductless and ducted heat pump measure packages are pursued.
- Nonresidential – measures within this study focus on improving the efficiency of nonresidential all-electric designs in new construction. In addition, there are measures to place a mandatory 130

°F limit to hot water supply temperatures and allowing a new prescriptive pathway for wire-to-air resistance heating.

Electrification of Nonresidential Space Heating: Designer Interview Report (Bulger 2023). In this report, researchers interview designers currently working with all-electric HVAC systems to learn about barriers to successful installations. The report focuses on describing the best practices, design strategies, challenges, technological limitations, and perceived barriers to widescale adoption of all-electric HVAC designs.

Electrifying Space Heating in Existing Commercial Buildings: Opportunities and Challenges (Nadal 2020). This report looks at the opportunity to electrify existing commercial buildings from a national lens. The report provides some useful descriptions of different system opportunities and high level cost and benefit information to electrify the nonresidential building stock.

Relevant Benchmarking Studies

The following section highlights a few relevant benchmarking studies that informed this team's analysis, particularly on the estimated statewide impacts of fuel substitution interventions.

RASS 2019: The California Residential Appliance Saturation Study (RASS) is a comprehensive database of residential energy use. For the 2019 study, the survey was sent to 300,000 selected California households from August 2019 through February 2020. The residents were asked to provide information about their appliances, heating and cooling equipment, use of solar or electric vehicles, and general energy use.

RASS data shows that residential heating in California is primarily satisfied by gas and electric resistance with under 5% of households using a heat pump as the primary method of building heat. This is summarized in Table 3.

Table 3: RASS 2019 Residential Heating System Saturation

Heating Technology	Residential Saturation (%)
Gas Furnace	55.9
Floor/Wall Furnace	10.1
Gas Hydronic System	1.0
Electric Resistance	4.2
Electric Forced Air	7.6
Electric Heat Pump	4.3
Portable Electric	3.7
Other Gas	1.0
Other Electric	0.6

Table 4 and Table 5 show the saturation of primary heating fuels in relation to residence type and building vintage, respectively. What these numbers demonstrate is that single family homes are more likely to be served with natural gas for space heating than multifamily buildings. Older buildings are more likely to be served by natural gas than newer buildings. This information could be used to assist with prioritizing which measure packages should be developed first, so that the greatest impacts can be achieved.

Table 4: RASS 2019 Gas/Electric Breakout by Residence Type

Building Type	Natural Gas Saturation (%)	Electric Saturation (%)
Total	68.1	20.7
Single Family Detached	77	13
Townhouse, Duplex, or Row House	69.4	21.9
Apartment or Condo (2-4 Units)	55.6	34.1
Apartment or Condo (5+ Units)	43.4	42.1
Mobile Home	58.1	8.3

Table 5: RASS 2019 Gas/Electric Breakout by Building Vintage

Building Vintage	Natural Gas Saturation (%)	Electric Saturation (%)
Before 1975	72.6	19.1
1975-1978	66.3	24.5
1979-1983	68.2	21.6
1984-1991	70.8	17.7
1992-1999	64.1	27.4
2000-2005	68.4	19.6
2006-2012	61.1	32
After 2012	63.3	26.8

RECS 2020: The Energy Information Administration (EIA) administers the Residential Energy Consumption Survey (RECS) to a nationally representative sample of housing units. This information is combined with data from energy suppliers to these homes to estimate energy costs and usage for heating, cooling, appliances and other end uses — information critical to meeting future energy demand and improving efficiency and building design (EIA (2020).

CSS 2014: The California Commercial Saturation Survey (CSS 2014), completed in 2014, describes the saturation, age, condition, and efficiency levels of electric and gas measures in businesses in Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E) territories. The CSS study spanned the period from November 2011 to May 2013 and was reviewed by the CPUC and the CA IOUs before publication.

CSS data indicates that commercial heat pump adoption is higher than that of residential, with 31% of businesses using electric heat pumps for space heating. Gas furnaces remain the most used type of space heating appliance in the commercial sector. This is shown in Table 6.

Table 6: CSS Heating Fuel Saturation

Heating Fuel Type	Percent of HVAC Units	Relative Precision
Natural Gas	49%	6%
Electric	33%	8%
No Heating	14%	13%
Other	3%	30%
Total	**100%**	
Gas Heating Distribution		
Furnace	44%	7%
Boiler	3%	102%
Radiant Heater	2%	37%
Electric Heating Distribution		
Heat Pump	31%	8%
Electrical Resistance	2%	37%
Other	1%	92%
n	**14,302**	

Source: Itron Inc.

CEUS 2022: The California Commercial End-Use Survey (CEUS 2022) is a comprehensive data of commercial sector energy use and end-use profiles. Survey project participants include California's investor-owned utilities, such as PG&E, SCE, SCG, and SDG&E, and the publicly owned utilities, such as the Los Angeles Department of Water and Power (LADWP) and the Sacramento Municipal Utility District (SMUD). The 2018-2022 CEUS was completed in June 2022 and may be available on their website soon. Once released, CEUS 2022 is expected to become an important resource for future fuel substitution measure package development efforts.

CBECS 2018: The 2018 Commercial Buildings Energy Consumption Survey (CBECS 2018) estimated that 5.9 million U.S. commercial buildings consumed 6.8 quadrillion British thermal units of energy and spent $141 billion on energy in 2018. Electricity and natural gas were the main energy sources. Space heating accounted for close to one-third of end-use consumption in 2018.

Finally, we are aware of NREL's products that virtually represent the building stock in BEM models, namely ResStock and ComStock. These resources were not investigated in-depth but may be leveraged for future measure package development which is why they are noted.

4. Current Incentive Offerings in California

The information below summarizes our understanding of the current incentive offerings in California that either focus on gas to electric fuel substitution or include this type of offering as part of a larger program design. These programs are important benchmarks to get a sense of what products are being incentivized and where gaps may exist.

Residential Incentive Programs

- Comfortably CA – Comfortably CA is the primary statewide upstream HVAC program in CA. Beginning in 2021, this program superseded the upstream HVAC programs that were run by the individual IOUs.
- TECH Clean California – TECH Clean California is a statewide initiative that aims to accelerate the adoption of heat pump technologies for residential space heating and water heating. The program launched in 2022 and customers in any of the IOU territories are eligible for incentives.
- BUILD – BUILD is a statewide initiative that provides that provides incentives and technical assistance to support the adoption of advanced building design and all electric technologies in new, low-income all-electric homes and multifamily buildings. Projects located in any of the IOU gas service territories are eligible for BUILD incentives.
- SMUD – The Sacramento Municipal Utility District (SMUD) Home Performance Program provides incentives for gas-to-electric heat pump HVAC and water heating projects. Both single family and multifamily locations are eligible for incentives.
- Electrify Marin – Electrify Marin is a county wide program offering rebates to single family property owners for the replacement of natural gas appliances with efficient all-electric units, including water heaters, furnaces, ranges and cooktops.
- LADWP – LADWP's AC Optimization program provides incentives for residential and commercial customers to replace a central air conditioner and gas furnace with a high efficiency heat pump.
- BayRen – BayRen implements energy savings programs on a regional level in collaboration with the nine bay area counties. They offer incentives to replace electric and gas furnace and air conditioner systems with heat pumps meeting their efficiency criteria for single-family homes, multi-family homes, and small/medium businesses.
- Alameda Municipal Power – This program is for residential customers of Alameda Municipal Power. The program offers incentives for complete replacement of gas furnace equipment with a heat pump HVAC system. Customers are eligible for 3 heat pump HVAC system rebates every 10 years. New construction is not eligible.
- Silicon Valley Clean Energy – SCVE rebates are available for single-family homes, accessory dwelling units (ADUs), and multi-family homes (4 dwelling units or fewer) swapping out

existing equipment, not for completely new building construction. Incentives are provided for gas furnace replacement with a heat pump HVAC system.

- Peninsula Clean Energy – PCE offers incentives to residents of San Mateo County or the City of Los Banos for the substitution of gas-heating units with qualifying heat pump HVAC systems. They collaborate with the BayRen program to maximize customer incentives.
- Truckee Donner PUD – TD PUD provides rebates for heat pumps on a per/ton basis to its residential customers. Additional rebates are available when replacing and eliminating gas furnaces. No restrictions specified for building type other than residential properties.
- Roseville Electric Utility – REU provides incentives for HVAC equipment replacement with heat pumps with additional rebates for conversion from gas to electric for residential and commercial buildings.
- IID – The Imperial Irrigation District (IID) offers residential and industrial customers rebates for a variety of qualifying efficient HVAC equipment with higher rates offered when converting from gas to electric heating.
- Azusa – Rebates are available for Azusa residents who weatherize their homes and purchase various ENERGY STAR® rated appliances for their homes. Gas to electric incentives are offered for packaged and ductless heat pump systems.
- City of Healdsburg – The city of Healdsburg offers residential and commercial customers incentives for air source/cooled heat pumps with a tiered approach for construction projects, existing electric heat upgrades, and gas-to-electric conversions of heating units for residential properties.
- Electrify Santa Monica – Electrify Santa Monica offers rebates for electric appliances and EV chargers. New electric equipment must replace existing gas equipment. One rebate is available for each appliance type and may be stacked with other rebates.
- Sonoma Clean Power – Sonoma Clean Power offers incentives to residential customers in Sonoma and Mendocino Counties who are improving the energy efficiency of their homes by purchasing and installing efficient appliances and equipment. Heat pumps systems paired with a gas heating element are ineligible for rebates.
- Trinity PUD – Trinity PUD is offering a "cleaner heating" incentive in the form of a rebate/credit of $700 to a limited number of qualified District customers who purchase an energy efficient, electric heat pump for their home. Dual fuel units are ineligible.

Commercial and Large Multifamily Incentive Programs

- CEDA – The California Energy Design Assistance (CEDA) program provides comprehensive analysis of different energy efficiency options for new construction or major alteration commercial and large multifamily projects in the early design phases. Projects located in PG&E, SCE, SCG, or SDG&E service territory with an eligible rate structure are eligible for this program.
- Comfortably CA - Comfortably CA is the primary statewide upstream HVAC program in CA. Beginning in 2021, this program superseded the upstream HVAC programs that were run by the individual CA IOUs. Unitary packaged and split heat pumps are available for fuel substitution incentives.
- LADWP – LADWP's AC Optimization program provides incentives for residential and commercial customers to replace a central air conditioner and gas furnace with a high efficiency heat pump.

- MCE – MCE offers up to $7,200 in rebates, comprehensive assessments, and technical assistance for energy- and water-saving measures to eligible multifamily property owners across four Bay Area counties: Contra Costa, Marin, Napa, and Solano.
- BayREN – BayRen implements energy savings programs on a regional level in collaboration with the nine bay area counties. They offer incentives to replace electric and gas furnace and air conditioner systems with heat pumps meeting their efficiency criteria for single-family homes, multi-family homes, and small/medium businesses.
- CPAU – The City of Palo Alto offers incentives for the substitution of air conditioner and furnace units with a qualifying heat pump for business customers.
- Roseville Electric Utility – REU provides incentives for HVAC equipment replacement with heat pumps with additional rebates for conversion from gas to electric for residential and commercial buildings.
- IID – The Imperial Irrigation District (IID) offers residential and industrial customers rebates for a variety of qualifying efficient HVAC equipment with higher rates offered when converting from gas to electric heating.
- City of Healdsburg – The city of Healdsburg offers residential and commercial customers incentives for air source/cooled heat pumps with a tiered approach for construction projects, existing electric heat upgrades, and gas-to-electric conversions of heating units.
- Redwood Coast Energy Authority – Redwood Coast Energy Authority is a local, not-for-profit government agency that procures electricity. RCEA incentivizes fuel substitution of commercial packaged or split heat pumps in place of gas/propane furnaces and AC for commercial customers in territory.

5. Discussion of Identified Technologies

Despite there being many subcategories of equipment and unique nuances, HVAC fuel substitution is ultimately a relatively straightforward concept: a baseline system containing natural gas-fired equipment (essentially boilers, furnaces, or unit heaters) providing space heating undergoes a retrofit and is replaced with an electric-powered replacement. Electric space heating equipment can also be classified in several broad categories, though numerous nuances and subcategories exist. These broad categories are heat pumps, heat recovery (from the building internal loads – including thermal energy storage), and electric resistance. Especially on the commercial side, future systems are likely to include more than one of these types of electric options to make a complete all-electric space heating system.

An important detail to keep in mind is that any all-electric space heating system option will likely need to be approached differently than the standard gas boiler/furnace technologies of today. For example, the current habit of oversizing, which isn't a big deal with gas, will bring more challenges with electric. The space/cost limits of electric options makes oversizing more challenging when an all-electric system is being pursued. Further, controls habits for gas systems such as overnight setback and the subsequent morning warm-up period (typically occurring over 2-4 hours today) may not be the best choice for all-electric designs (since peak capacity comes at a premium for all-electric). Some initial research is showing that morning warmup can be extended over a longer period for all-electric without much of an energy penalty or eliminated altogether for design heating days. These and other changes to design best practices are likely going to be important to really dial in the value proposition of all-electric designs relative to gas.

Heat pumps are well positioned to become the "workhorse" of all-electric space heating systems. A heat pump leverages the vapor-compression cycle to "pump" heat from a lower temperature source to a higher temperature sink using a refrigerant loop powered by a compressor. The energy reservoir (i.e., source) can be ambient air, a body of water, the ground, or some type of thermal energy storage tank located in or near the building. When applied to space heating, the destination of this energy is the conditioned indoor space. Systems can involve a single loop or a cascading series of loops for higher lift applications. A well-known benefit of heat pumps is the fact that their coefficient of performance (COP) is nearly always greater than 1.0 (with COP being a function primarily of compressor lift and efficiency but also fan and pump efficiency when applicable). This is in contrast with natural gas-powered equipment, which is always going to have a thermal efficiency less than 100%. Of course, this is the site energy comparison, when comparing source energy, the efficiency improvement of heat pumps is adversely impacted by the transmission and distribution electrical losses. These calculations are handled in the CPUC fuel substitution calculator, which determines if a given measure can reduce source energy consumption and greenhouse gas emissions.

Other electric space heating options include heat recovery and electric resistance. Our research findings indicate that these technologies, while also important for consideration, will likely complement heat pumps in a given system or be more applicable to niche applications. However, for large commercial buildings, our research points to heat recovery (potentially with thermal energy storage) as being a critical supporting component to a heat pump system. Similarly, for electric resistance, in large buildings with internal zones that rarely encounter much if any space heating loads, electric resistance could be a compelling option to cost-effectively electrify space heating. This option would not only cost less than the heat pump equipment but would also avoid expensive piping in the building and avoid the need to leverage refrigerant (which can itself contribute significantly to GHG emissions if high GWP refrigerant is used) in the measure case. Having said that, electric resistance is inherently a less efficient option than a heat pump, so this will only make sense in targeted applications.

Regarding measure application type (MAT), we recommend pursuing normal replacement (NR) as well as accelerated replacement (AR) for all of the proposed measures. NR and AR are both likely important MATs going forward and may even need to be combined in individual projects. For example, more complex commercial systems may only have a portion of the plant's HVAC equipment is at the end of its effective useful life, pointing to both NR and AR for different parts of the system.

Innovation and Out-of-scope opportunities

It is important to emphasize that energy efficiency measures are a critical component to cost-effective space heating fuel substitution. Energy efficiency is not the focus of this research effort, but should any of these measures move forward, complementary energy efficiency measures should be strongly considered as either prerequisites or as components to the measure package. Most electric space heating options (apart from electric resistance heating) come with a moderate to significant upfront cost premium relative to their natural gas counterparts, and EE measures can help narrow that gap by shrinking down the building's space heating loads, and thus, reducing the required amount of installed capacity of the electric space heating equipment. The most relevant EE measures include building envelope upgrades and HVAC controls upgrades. HVAC controls is a broad term, and again, EE measures are not the focus of this research. Specific HVAC controls measures include the addition of

DDC, programming sequences to comply with ASHRAE Guideline 36, and generally bringing the building's controls performance up to those specified for new construction in Title 24 (e.g., demand-controlled ventilation, duct static pressure reset, supply air temperature reset, hot water supply temperature reset). Buildings with HVAC controls that merely comply with Title 24 requirements are likely to perform very efficiently.

HVAC controls geared specifically toward all-electric space heating systems are also very likely important elements to an effective system. For example, it is common today for a building to set back space heating temperature setpoints overnight to reduce gas fuel consumption. During the next morning warm-up period, the gas equipment can be fired up without any concern to the impact on the electric grid. This is not the case for electric space heating. Research points to the possible benefit of extending the morning warmup period over a longer duration to reduce the peak electric demand. And during design days (i.e., the coldest days of the year), it may be beneficial to simply not do the overnight setback at all. All-electric space heating HVAC controls opportunities are not explored in this research, which focused more on HVAC system and equipment considerations. All-electric space heating controls considerations could be the subject of future research for potential custom or deemed measures.

Distributed generation measures (e.g., solar PV, batteries) are also likely going to be important components to the all-electric building of the future. These measures, when controlled appropriately, can help offset potential winter morning electric demand on the grid and also provide the building owner with a more cost-effective project overall to offset the net increase in electric annual energy consumption that inevitably results from gas-to-electric fuel substitution.

The rest of this section provides a discussion of the identified in-scope options (including a framework that breaks out the overarching heat pump and heat recovery categories into appropriate subcategories), broken out into residential and commercial applications.

Residential

From the perspective of technological development and market readiness, the residential sector is clearly further along than commercial. This reality is reflected by the existing measure packages for residential fuel substitution (i.e., SWHC044 and SWHC045), which cover the most frequent retrofit types. Table 7 shows the full list of residential technologies that were investigated.

Table 7: Residential HVAC Fuel Substitution Options

Measure No.	Measure Name	In eTRM?	Included in Projection
R1	Combination DHW + Space Heating Heat Pumps	No	Yes
R2	120V heat pumps	No	Yes
R3	Air to Water Heat Pumps (AWHP)	No	Yes
R4	Ground Source Heat Pumps (GSHP)	No	Yes
R5	Ductless Heat Pumps (DHP) SWHC044	Yes	No
R6	Central Ducted Heat Pumps (DHP) SWHC045	Yes	No
R7	Electric resistance (ER) heating	No	No
R8	Dual fuel heat pumps	No	No

R1. Combination DHW + space heating heat pumps

Combination Heat Pumps or "Multi-function heat pumps" provide space heating and water heating functionality within the same product through use of a heat pump. The basic design revolves around using a domestic hot water tank as a thermal battery to store the heat needed for both space heating and domestic hot water. In certain configurations, space cooling can also be added which allows the water tank to also operate as cooling heat sink which can further increase system efficiencies. The thermal storage capabilities allow the heat pump compressor to spend the bulk of its operation during warmer daytime conditions which has two major benefits, (1) it allows for higher thermodynamic operating efficiencies and (2) daytime operation coincides with higher solar energy production (lower electrical rates).

Multifunction systems make a lot of sense for California's combination of low space heating needs, predictable renewable energy availability, and strong emphasis on fuel substitution from gas to electric. While there are currently systems that are commercially available in California, they are in a nascent stage relative to other global regions. Several global HVAC manufacturers produce these products elsewhere and are in various phases of development for the North American market. One key barrier relevant for measure packages is that multifunction heat pumps lack a standardized test method and the existing performance ratings (UEF for water heating and HSPF2 for heat pumps) do not map well making it difficult to compare performance. Furthermore, these metrics do not capture the added benefits of load shifting from these products.

Initial estimates from a UC Davis study [Vernon (2022)] on these products estimate 79% space heating energy use reduction compared to a new code compliant furnace and an 85% water heating energy use reduction compared to a new code compliant gas-fired water heater.

Example manufacturers include:

- Harvest Thermal HarvestPod Duo (US)
- Villara Building Systems Aquathermaire (US)
- Daikin Altherma (EU)
- Panasonic Aquarea (EU)
- Fujitsu Waterstage (EU)

R2. Micro heat pumps (120V heat pumps)

While the states adopt more ambitious GHG emissions reduction goals, the current offerings of heating and cooling technologies for multifamily housing suffer from numerous drawbacks, including high installation costs and invasive construction requirements to run refrigerant linesets and condensate drains, and the requirement of 208V operation. As a result, the building owners may opt for in-kind replacement of existing electric baseboard or fossil fuel systems with more efficient and less carbon intensive options.

The State of California has an ambitious goal of installing at least 6 million heat pumps by 2030. To address this need, several cold-climate capable, variable-speed Window Heat Pumps (WHPs) are entering the market that enables a customer to buy a small capacity WHPs and install it without the need for a contractor [Jenkins (2022)]. These systems can be a potential game-changer to address the decarbonization challenge of the millions of gas-fired heating appliances or electric-resistance space-heaters in multi-family buildings across California.

Window heat pumps are small, efficient, capable of proving both heating and cooling, and ergonomic in design. As is evident from the name, window heat pumps fit in a window frame without any hassle or extensive installation procedure. They cool/warm the entire room rather than a limited space at a much lower cost.

There are various versions of room air conditioners in the market including window, through-the-wall, and portable air conditioners. Such Units [CEE (2022)] are desired to minimize on-site labor and service upgrades and may potentially offer several features such as (a) 115V, single phase, 60Hz, 15amp socket, (b) Operate down to 0 °F without requiring backup electric resistance heat for space heating, (c) Come with a variable speed compressor, (d) Offer a vent through the bottom of window opening. A few example products are shown in Figure 1.

		
Source: Gradient WHP	Source: Midea WHP	Source: Islandaire WHP (PTHP)

Figure 1: Examples of 120V Heat Pumps

R3. Air to water heat pumps (AWHPs)

AWHPs can provide space heating, space cooling and domestic hot water in one packaged solution with quiet operation down to -25°C low ambient temperature. Although AWHPs offer an all-electric heating, ventilation, and air conditioning (HVAC) solution, the residential AWHP market in California is relatively small with sales of less than a thousand units annually, while only less than 1% homes have hydronic heat. This is due to a variety of factors including the widespread market acceptance of conventional central forced air HVAC systems, the existing Title 24 compliance penalties, and limited contractor familiarity with AWHP technology.

AWHPs extract heat from outside air and transfer it to a fluid outdoors- typically water or a mix of water and glycol – and transport this fluid into a home to provide space heating through hydronic distribution (e.g., radiant floor, radiator, or baseboard water circulation systems). These systems can also be used in a cooling mode creating chilled fluid and running it through an air coil to distribute air conditioning to a home or business.

AWHPs offer numerous applications with advantages over traditional hydronic systems in new and existing homes. For example, they can offer energy savings up to 47% (ENERGY STAR 2019-20) with a seasonal Coefficient of Performance (COP) of 1.7 - 3.0 over a typical gas condensing boiler system (which inherently has a thermal efficiency of less than 1.0). Additionally, AWHPs can provide the following benefits:

- Adding a storage tank to the system will provide homeowners with efficient domestic water heating.
- Quite operation since all fans are located outside the home.
- Allows a retrofit to provide cooling in hydronically heated homes, without running extensive ducts through the home.

As a result, AWHPs can save energy, even in cold climates where many air-to-air heat pumps perform poorly, provide space conditioning and hot water heating, as well as several other benefits for the consumer. However, it may be noted that they are not typically a cost-effective option when compared with natural gas or air-to-air heat pump alternatives, and they may only cater for partial heating load. Several example products are shown in Figure 2.

		
Source: Midea AWHP	Source: Apollo 6 Ton AWHP	Source: Solstice AWHP

R32, Heating Capacity:15.5kW	R410A; Variable speed fan	EPA awarded Energy Star award to its model LAHP48

Figure 2: Examples of Residential Air to Water Heat Pumps

Overall, residential AWHPs are a very promising FS technology but is likely not going to become a major factor in California since most of the single-family building stock is currently served by forced air furnace systems. For the small fraction of California homes that currently use boilers or other hydronics, AWHPs are an excellent retrofit opportunity. Therefore, this technology should stay under consideration for a future measure package but is not the highest priority from an impacts perspective. Perhaps a future research effort could zero in on the market opportunity for residential AWHPs.

R4. Ground Source heat pumps (GSHPs)

A ground source heat pump (GSHP), also known as geothermal heat pumps, takes advantage of the naturally occurring temperature difference between the above-ground air and the subsurface soil to move heat in support of end uses such as space heating, space cooling (air conditioning), and even water heating [EPA, 2022].

A ground source system consists of a heat pump connected to a series of buried pipes. There are four basic types of ground loop systems [DOE, 2023] that one can install pipes. Three of these are closed-loop systems, namely horizontal (just below the ground surface), vertical (that can go several hundred feet below the ground), and pond/lake (immersed in pond water), while the fourth type is the open-loop (where water is circulated through the heat exchangers). Several factors such as climate, soil conditions, available land, and local installation costs determine which is best for the site. The heat pump circulates a heat-conveying fluid, sometimes water, through the pipes to move heat from point to point. If the ground temperature is warmer than the ambient air temperature, the heat pump can move heat from the ground to the building. The heat pump can also operate in reverse, moving heat from the ambient air in a building into the ground, in effect cooling the building.

Relative to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not depend on the temperature of the outside air. The installation cost of a GSHP system can be several times that of an air-source system of the same heating and cooling capacity, particularly in California, due to the rocky soil and associated drilling and componentry costs. However, the additional costs may be returned in energy savings in 5 to 10 years, depending on the cost of energy and available incentives in the area. System life is estimated at up to 24 years for the inside components and 50+ years for the ground loop. However, market adoption of GSHP technology has been slow largely due to the significant cost of installing the ground heat exchangers. Typical California valley soil conditions require 200 foot-deep bores for each ton of heat pump capacity, meaning a three-ton system would cost at least $9,000 [Harrington et al (2021)].

After researching residential GSHPs, we conclude that some further work should be done to quantify the installation costs (particularly the drilling costs in California relative to other states) and ongoing savings potential for the technology prior to a full measure package is pursued.

R5. Ductless Heat Pumps

Residential ductless heat pumps are one of the few HVAC FS measure packages in the eTRM. This measure is an appealing candidate for older residential buildings that currently do not have a ducted central system. These buildings may or may not have any air conditioning, and may be served by single zone wall furnaces. These systems can be replaced with more energy efficient mini-split heat pumps that are all electric ductless heating and cooling systems that control the temperature in one or more rooms.

A mini-split system consists of two main components: an indoor air-handling unit and an outdoor heat pump. The indoor unit includes a fan and an evaporator coil and the outdoor unit includes a compressor, condensing coil, and fan. The indoor and outdoor units are linked via a conduit, which encases the power cable, refrigerant and suction tubing, and a condensation drain line. Mini-split heat pumps pull heat from the inside air and move it outside via the refrigerant to provide cooling. Conversely, they extract heat from the outside and move it inside to heat the space by compressing and expanding the refrigerant. Mini-splits typically have no ducts, which reduces the energy lost through leaks and cracks in the duct systems. On the other hand, these systems contain long refrigerant runs, which increases the total volume of refrigerant in the system relative to centrally ducted split systems (which can be optimized to reduce the refrigerant piping). Lower GWP options such as R-32 are emerging on the market, reducing the refrigerant emissions penalty. The CPUC RACC should be properly leveraged to fully quantify this impact of adding refrigerant to the system as part of the measure.

Since there is an existing measure package (SWHC044), we did not quantify savings in this report. The measure package could be updated with new equipment performance maps to better reflect the recent SEER2/EER2/HSPF2 ratings changes, as well as include new offerings to better capture inverter driven variable speed compressors. Offerings that can claim greater savings per unit can be correspondingly incentivized at a higher rate and provide more benefits for the IOU portfolio.

R6. Central Ducted Heat Pumps

A central heat pump distributes cooled and heated air throughout the house through ductwork. Typically, a residential central heat pump is served by a single-phase circuit. The efficiency of a central heat pump is defined by a seasonal energy efficiency ratio (SEER) rating for cooling mode and a heating seasonal performance factor (HSPF) rating for the heating mode. This measure replaces the existing central air conditioner used for cooling and the existing gas furnace used for heating with central heat pump.

This measure can truly be considered the “bread and butter” of residential single family fuel substitution, due to the massive amount of existing residences that are currently served with central ducted air conditioner + gas furnace systems. Many current programs exist to promote this all-electric space heating system configuration.

Since there is an existing measure package (SWHC045), we did not quantify savings in this report. The measure package could be updated with new equipment performance maps to better reflect the recent SEER2/EER2/HSPF2 ratings changes, as well as include new offerings to better capture inverter driven variable speed compressors. Offerings that can claim greater savings per unit can be correspondingly incentivized at a higher rate and provide more benefits for the IOU portfolio.

R7. Electric Resistance (ER) Heating

Although our research points to potential commercial ER space heating opportunities, by contrast, we do not recommend further research into this measure for residential measures. The primary difference is that residential buildings are much smaller and therefore all zones must contend with the outdoor ambient conditions. ER heating may be an appealing option in interior zones of large commercial buildings (with very low space heating loads), but this situation is generally never present for residential houses or dwelling units. This option is qualitatively superseded by heat pump-based options (including ductless, central ducted, 120V, and geothermal). ER heating is generally undesirable in residential space heating design. Currently, many whole-house heat pump designs include ER as a second stage of heating, although this should be avoided if possible. System options that limit second stage ER heating in favor of more appropriately sized heat pumps should be promoted.

Although it's possible that in some isolated cases, a small 120V ER space heater may be an appropriate space heating solution, this option is commercially available, cheap, and is therefore not in need of program promotion.

Due to these factors, we did not further analyze this technology.

R8. Dual Fuel Heat Pumps

Dual fuel heat pumps are an option for existing buildings with substantial peak space heating loads. The premise of the technology is that the heat pump is sized for most days of the year, but the second stage is covered by a gas furnace. This technology is likely a more favorable option on a source Btu basis compared to an equivalently sized heat pump with ER heating as the second stage. However, there are challenges with creating a FS measure that does not fully decommission the gas system. As the DNV PY2020 Fuel Substitution Impact Evaluation documented, decommissioning of gas systems presents a challenge to ex-post evaluated savings. In addition, the recent CPUC proposed decision to limit gas incentives may provide an insurmountable hurdle to offering dual fuel heat pump incentives in the coming years. Our understanding is that a Viable Electric Alternatives working group has been forms as of 2023 and is working through technologies such as dual fuel heat pumps to determine if they can be incentivized. Beyond these regulatory challenges, it is also the case that heat pump technology is improving (i.e., becoming better optimized for winter heating loads) and other strategies such as EE improvements can help shrink peak space heating loads.

If this technology is determined to be eligible for future incentives by the Viable Electric Alternatives working group, then it should be further evaluated.

Commercial

Commercial technologies are complex and frequently combined in different ways based on individual site conditions. However, themes and patterns can be isolated. There are ways to describe different types of heat pumps, one being by categorizing the type of fluid to refrigerant heat exchanger at the source and sink of the unit. For example, an outdoor air source heat pump (ASHP) unit can provide conditioned air, water, or refrigerant to the building. These subcategories are respectively known as commercial unitary heat pumps (CUHP), air to water heat pumps (AWHP), and commercial multi-split air-source variable refrigerant flow (VRF) heat pumps. But the common theme is that all these subcategories require an air to refrigerant heat exchanger to interact with the ambient environment. And although there are obvious differences in equipment efficiency across these three subcategories, in general, the air to refrigerant heat exchanger is going to cap the upper limit of these heat pumps' coefficient of performance to roughly 3.0 – 3.5 in milder conditions, and closer to 2.0 – 2.5 during design conditions.

Contrast an ASHP-only system with a heat pump system that leverages an amount of ASHPs but is combined with mechanical heat recovery. This type of system will likely experience a leap in system COP due to the ability to capture and reuse the building waste energy. The COP of a heat recovery chiller when it is making productive use of both the evaporator and condenser energy (i.e., a heat recovery chiller that is delivering chilled water and hot water streams into the building's interior zone coils when simultaneous demand exists) would have double the COP of a system with a separate water-cooled chiller and AWHP both operating simultaneously. When a thermal energy storage tank is added to the system, then heat recovery can be successfully employed even when building heating and cooling loads are not simultaneously present due to the TES tank's ability to store the waste heat from mechanical cooling and reuse it later in the day (or the next morning) for space heating or service water heating applications. Systems that optimally combine ASHPs, heat recovery, and TES are likely the most efficient option of all, which is why this system is called out separately in our analysis. It is possible that for a system with significant process heating loads and average cooling loads, ASHPs could be entirely unnecessary with only heat recovery + TES sufficing to provide the space heating.

Throughout this section, the different commercial fuel substitution technologies are grouped together whenever there is a pattern in the equipment's technical configuration or if efficiency performance is expected to be roughly similar. We are not arguing that all of the subcategories of ASHPs (for example) will perform at the same efficiency level, and we are certainly not arguing that the entirety of ASHPs should be captured in the same measure package. The ideal application of a CUHP is most likely not going to be the same as an AWHP or a VRF. The technologies in a grouping could be at different stages of commercial readiness, and the resulting program design/measure package specifications may need to be tailored for each subcategory. However, for the purposes of this broad survey of all fuel substitution options, we feel that grouping the specific measure ideas by broad efficiency and technology patterns makes the exercise of estimating the source Btu and GHG savings more straightforward.

The Concept of "Partial Fuel Substitution" - We reiterate that the commercial sector is inherently more complex and sophisticated than residential. This leads us to postulate that fuel substitution projects may need to be "phased" over multiple building retrofits and the concept of a "partial fuel substitution" measure may be appealing. The idea would work like this: a partial fuel substitution measure would not involve installation of new natural gas equipment (or dual fuel heat pumps), but rather, the existing natural gas equipment is partially offloaded but not entirely decommissioned. An ideal example would be the addition of heat recovery equipment into the building that can reduce a fraction of the natural gas equipment energy consumption. Consider a building that needs to replace water-cooled chiller equipment at the end of its EUL but still has a boiler system with some remaining years of EUL. The WCC system would be replaced by a HR chiller or combined WCC + HR chiller system (depending on site-specific conditions), but the boiler would remain intact (though its runtime hours would decrease after the retrofit, and this reduction would represent the natural gas therms savings for the measure analysis). Then at a later date, the boiler could be replaced by an appropriate amount of AWHP equipment. Current CPUC fuel substitution rules may prevent this type of measure. If that is the case, then a policy change could be proposed to enable this measure type, since for many large commercial buildings, full fuel substitution in one retrofit may not be financially feasible, even with incentives.

The technologies listed in nt are a mixture of "partial" and "full" fuel substitution solutions. Some solutions could be partial or full solutions depending on the building owner's appetite for system complexity and desire for overall system efficiency. As an extreme example, a commercial building currently served by a gas boiler powered VAV reheat system could be fully retrofitted to be served with electric resistance reheat in the VAV boxes. This would be a cheap and simple solution, but also most likely very inefficient and a potential measure would likely have trouble passing the fuel substitution test due to the significant increase in electric load in the measure case. However, a more complex system that leverages heat pump technology for the building zones with larger space heating needs (e.g., perimeter zones) and then leverages electric resistance for interior zones with small space heating loads could provide the best of both worlds in terms of system cost and efficiency. So in this case, ASHPs and ER heating are both “partial” components to a “full” all-electric space heating system. nt and the resulting discussion sought to identify as many components and the most promising (in our view) full system options as is reasonable, but it should be acknowledged that additional combinations of components could result in further systems not listed. However, these additional theoretical systems are unlikely to become major options for commercial buildings in the near term, making us confident that we have identified the most important categories for near term fuel substitution measure development.

Table 8: Commercial HVAC Fuel Substitution Options

No	Measure Name	In eTRM?	Solution Type	Included in Projection	Notes
C1	Air Source Heat Pumps (ASHP) C1.1: Air to air heat pumps (a.k.a. commercial unitary heat pumps or CUHP) C1.2: Air to water heat pumps (AWHP) C1.3: Air source VRF heat pumps without heat recovery	Yes (C1.1 only)	Partial or Full	Yes	C1.1 currently covered by SWHC046; we propose adding offerings for variable speed equipment.
C2	Mechanical Heat Recovery (Mech HR) C2.1: Air source HR chillers C2.2: Water source HR chillers C2.3: VRF with HR	No	Partial (usually) or Full	Yes	Heat recovery using the vapor-compression cycle (i.e., making productive use of both evaporator & condenser energy).
C3	Water Source Heat Pumps (WSHP) C3.1 Water to air heat pumps (WAHP) C3.2 Water to water heat pumps (WWHP) C3.3 Water source VRF (WS-VRF)	No	Partial	No	Considered "partial" because of the lack of an interface between air or ground for ultimate heat addition/rejection to the environment.
C4	Ground Source Heat Pump (GSHP)	No	Full	No	Similar technology to C3, but presence of ground loop makes this a complete system.
C5	Thermal Energy Storage (TES)	No	Partial	No	Primary benefit is ability to time shift heating/cooling loads to enable complete heat recovery.
C6	Electric Resistance (ER)	No	Partial or Full	No	ER alone as a full system is unappealing without other EE measures due to the concern with peak space heating loads.
C7	Waste fluid heat recovery C7.1: Exhaust air heat recovery C7.2: Wastewater heat recovery	No	Partial	No	Distinct from C2 because this is simply leveraging an energy stream leaving the building for heat addition/rejection.
C8	Single zone wall-mounted equipment C8.1: Package Terminal Heat Pump (PTHP) C8.2: Single Package Vertical Heat Pump (SPVHP)	No	Full	Yes	Is essentially another subcategory of C1 but is being called out separately due to equipment form factor and strong potential as a full system option.
C9	ASHP + Mech HR C9.1: CUHP + Mech HR C9.2: AWHP + Mech HR C9.3: VRF+ Mech HR	No	Full	Yes	Envisioned as a system consisting of measures drawn from C1 + C2.

No	Measure Name	In eTRM?	Solution Type	Included in Projection	Notes
C10	ASHP + WSHP	No	Full	Yes	Envisioned as a system consisting of measures drawn from C1 + C3.
C11	ASHP + Mech HR + TES	No	Full	Yes	Envisioned as a system consisting of measures drawn from C1 + C2 + C5.
C12	ASHP + Waste fluid heat recovery	No	Full	No (future research)	Envisioned as a system consisting of measures drawn from C1 + C6.
C13	Electric Resistance bundled with additional measures (envelope improvement, HVAC controls upgrade, solar PV, battery)	No	Full	No (future research)	Measure C6 + additional measures.
C14	ASHP + Mech HR + TES in exterior zones and ER for interior zones	No	Full	No (future research)	Envisioned as a system consisting of measures drawn from C1 + C2 + C5 + C6.
C15	EE/DG measures Lower hot water supply temperature (HWST) Add DDC, include all T24 resets, use ASHRAE Guideline 36 sequences Building envelope improvement PV+Storage Solar Thermal assisted hot water	No	Full	No (future research)	Shrinking space heating loads through EE is anticipated to become an important aspect of HVAC decarbonization. Adding distributed generation to offset the electric load addition of heat pumps/heat recovery/resistance equipment is also likely to be an important piece of the puzzle.

As noted elsewhere in this report, it is not realistic to try and capture every single variation on the all-electric space heating system options for commercial buildings. There can always be edge cases and specific sites that dictate some type of unique solution that mixes and matches from the measures that the study has identified. However, we feel confident that nt captures what are likely to be the most popular all-electric space heating system options in the coming years.

C1: Air Source Heat Pumps (ASHP)

The term "air source heat pump" is an umbrella term for any equipment that includes an air source heat exchanger as part of the unit. This heat exchanger can be used to draw or reject heat to the ambient environment. Included within this umbrella category are three subcategories: 1) air to air heat pumps (more commonly referred to as commercial unitary heat pumps or heat pump rooftop units), 2) air to water heat pumps, 3) and air to refrigerant heat pumps (i.e., split system heat pumps or variable refrigerant flow heat pumps). These types of equipment span a wide range of applications and their characteristics (including capacity and efficiency) vary widely, but again, are grouped together because of the common trait of including an air-source heat exchanger.

Air source heat pumps are an important component to a fully electrified space heating system but are typically best deployed with a combination of water source heat pumps (a.k.a. heat recovery) and thermal energy storage. A few examples are shown in Figure 3.

C1.1: Commercial Unitary Heat Pump	C1.2: Air to Water Heat Pump	C1.3: Air-source VRF HP
		
Trane Precedent (Heat Pump)	Aermec NRL_H, NRB-H	LG Multi V 5 (ARUM)

Figure 3: Examples of Air Source Heat Pumps

C1.1 COMMERCIAL UNITARY HEAT PUMPS (CUHP)

Commercial unitary heat pumps (CUHP) or heat pump rooftop units (HP RTUs) are expected to become a major all-electric space heating solution for small and low-density commercial buildings. In essence, any building currently served by a commercial unitary air conditioner (CUAC) paired with a commercial warm air furnace (CWAF) is a great candidate for an all-electric CUHP system. A snapshot of this measure opportunity is provided in Table 9. The equipment could technically be described as an "air-to-air heat pump," though this term is rarely encountered in the market. This equipment is captured by SWHC046, but only captures low-medium efficiency CUHP equipment.

Table 9: CUHP Snapshot

Measure Aspect	Description
Base case	CUAC + CWAF
Measure case	CUHP
Building types	Small/light commercial, low-density medium/large commercial, any building currently served by rooftop units.
C&S information	Tested to AHRI 340/360 (>65 kBtu/h) and AHRI 210/240 (<65 kBtu/h). Regulated by DOE in 10 CFR 431.
Other information of note	Captured by SWHC046 making this opportunity less of a priority, though a higher efficiency tier is clearly absent from the measure package when researching the upper end of the market.

Due to its strong fuel substitution potential, it is unsurprising that CUHPs are currently the only technology covered by an active eTRM measure package (i.e., SWHC046). However, it should be noted that SWHC046 only captures medium efficiency CUHP equipment.

Though this is not a top priority relative to introducing other types of commercial fuel substitution measure packages, we propose eventually adding a higher efficiency tier for SWHC046 that would capture the upper end of the market. This inclusion would provide for additional energy efficiency benefits beyond what SWHC046 is currently capturing for when very high efficiency equipment is incentivized during program implementation.

The current highest efficiency tiers by size category for SWHC046-02 (in effect for program year 2023) are shown in Table 10.

Table 10 SWHC046-02 Highest Efficiency Tiers

Capacity Range (kBtu/h)	Highest Tier Efficiency Rating
<65	18.0 SEER
65-135	16.0 IEER
135-240	15.5 IEER
240-760	14.0 IEER

Source: California eTRM

By contrast, manufacturers are selling CUHP equipment with significantly higher IEER ratings, enabled by variable speed inverter driven compressors and fans. The Daikin Rebel DPSA/DFSA line (covering 20-52 tons or 240-624 kBtu/h) can achieve IEER ratings of up to 20.0. Similarly, AAON model number RN-016-3-0-CBAC-V0-21-000-A offers a capacity of 182 kBTU/h capacity with an IEER of 20.3. A review of the AHRI Directory shows that the product availability is limited but present for this slice of the market (see Figure 4). A "stretch tier" for variable speed equipment within SWHC046 could encourage manufacturers to produce additional models and help transform the market toward high efficiency unitary heat pumps.

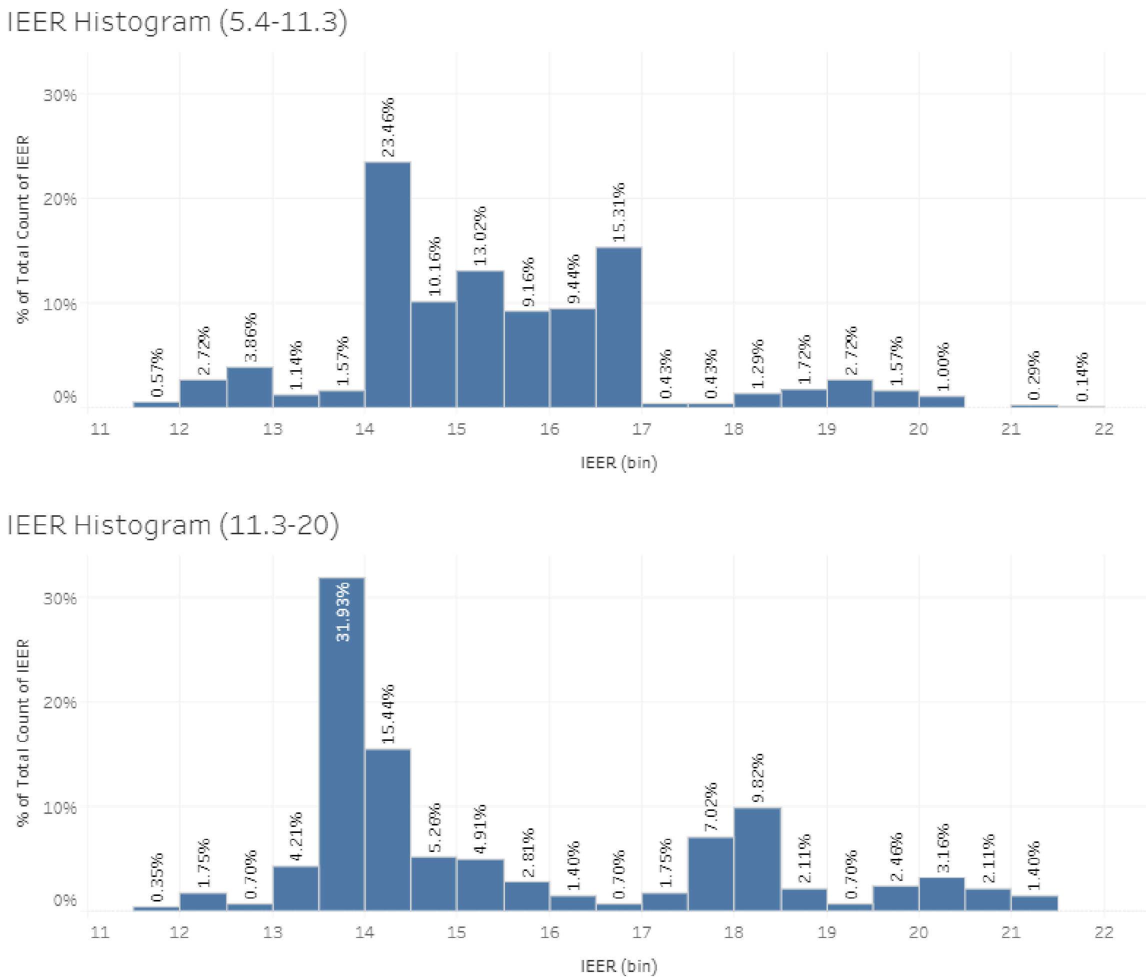

Figure 4: Histogram of IEER for two size categories for CUHPs

Source: AHRI Directory of Certified Product Performance

C1.2 AIR TO WATER HEAT PUMPS (AWHP)

AWHPS are a subset of ASHPs and are physically similar to heat pump water heater (HPWH) equipment, though the term AWHP is typically applied to space heating whereas HPWH is typically applied to domestic hot water. A snapshot of this measure opportunity is provided in Table 11.

Table 11: AWHP Snapshot

Measure Aspect	Description
Base case	Boiler
Measure case	A packaged unit containing an air-to-refrigerant heat exchanger to transfer energy to and from the ambient air and refrigerant-to-water heat exchanger to supply or receive energy from the building. Units that can be configured to cooling or heating mode could be thought of as an air-cooled chiller with a refrigerant reversing valve. Heating only AWHPs are the space heating analog to domestic hot water HPWHs.
Building types	Medium to large commercial buildings. Any building with an existing boiler.
C&S information	Tested to AHRI 550/590. Efficiency performance regulated by Title 24 Table 110.2-N.
Other information of note	Except for relatively simple fuel substitution retrofits where AWHPs become the entire space heating system, this equipment should be paired with heat recovery or other measures to build up a more efficient system. AWHP efficiency is limited by the high lift needed to deliver hot water to the building during design winter conditions.

AWHPs without heat recovery are an important technology as a component of commercial space heating decarbonization, but as noted elsewhere, they are unlikely to be the most efficient choice for most buildings. In addition to efficiency challenges, AWHPs also present a cost and space penalty for the building. It is undeniable that for the equivalent amount of capacity, AWHPs are significantly more expensive than gas boilers. And further, at an equivalent capacity level, the AWHP option would occupy significantly more space in the building than the gas boiler. Of course, the IMC can be overcome by an incentive, and certain buildings might not be space constrained, so these barriers are not insurmountable for an AWHP-only measure design. But they need to be considered as part of the measure design process.

Manufacturers produce highly valuable “application guides” for their products, and the Trane application guide for its Ascent AWHP line contains useful information on how to design around an AWHP system.

AWHPs as a standalone heating solution are an appealing retrofit opportunity for small/medium buildings currently using gas boilers for VAV reheat. As the buildings become larger and more diverse in heating/cooling load profiles, mechanical heat recovery becomes a very attractive addition to the system. This opportunity is further discussed in the “C2: Mechanical Heat Recovery” section. AWHPs supplying radiant heating would enable the equipment to supply lower hot water supply temperatures and improve system efficiency.

C1.3 VARIABLE REFRIGERANT FLOW (VRF) HEAT PUMPS

Air-source VRF heat pumps without heat recovery are a frequently installed all-electric space heating option in commercial buildings due to their familiarity in the market and significant utility incentive efforts to promote them in the 2010s. A snapshot of this measure opportunity is provided in Table 12.

Table 12: AS-VRF w/o HR Snapshot

Measure Aspect	Description
Base case	Furnace (such as when building is served by CUACs) or boiler (such as when the building contains PVAV with reheat). VRF air conditioners with either furnaces or boilers may exist in the field that could be retrofitted to VRF heat pumps.
Measure case	A multi-split heat pump with an outdoor condenser unit attached to >1 indoor unit. By definition, VRFs contain variable speed fans and compressors, though in practice the number of capacity steps varies by manufacturer.
Building types	Small to medium commercial buildings. Midrise and high-rise multifamily.
C&S information	Tested to AHRI 1230, efficiency regulated by DOE. Other aspects of larger VRF HVAC system (such as DOAS) regulated by Title 24 Part 6.
Other information of note	VRFs are a decoupled system, meaning they must be installed with a separate ventilation system. VRFs contain significant amounts of refrigerant charge and faces challenges with complying with upcoming EPA and CARB low-GWP refrigerant standards. Refrigerant leakage can offset GHG benefits of fuel substitution.

VRFs have been commercially available in Asia since the 1980s and in North America since the 2000s. This technology is highly commercially proven but notably absent from the CA eTRM portfolio. This is an artifact of the 2017 CPUC VRF Disposition and the 10% above code EER requirement for VRFs in DEER Resolution E-4867 (though Energy Solutions demonstrated to CPUC in 2022 that both issues do not inhibit VRF FS measures, since the three prong test has been replaced by the fuel substitution test, which Energy Solutions demonstrated that VRFs can pass, and kW savings (in the form of EER requirements) are not applicable to FS measures, and E-4867 was passed prior to the 2019 CPUC fuel substitution test decision).

VRFs can be broadly divided into four categories, based on two aspects, 1) type of energy source/sink (air or water) and 2) presence or absence of heat recovery capabilities. Air-source VRFs are better suited for small and medium buildings (e.g., below 200,000 ft^2), while water-source VRFs are more common in large buildings. For the purposes of this analysis, air-source and water-source VRFs are treated separately because AS-VRFs are a more complete system, whereas WS-VRFs need an additional unit connected to the water loop to either exchange heat with the ambient air or the ground, making them similar to water-to-water heat pumps.

VRFs contain large quantities of refrigerant in piping networks distributed throughout the building. Current offering of R-410A will be sunset per CARB rules by 1/1/2026 in favor of options with an upper limit of 750 GWP.

In 2018, the U.S. DOE initiated a working group to negotiate updated test procedures and energy conservation standards for VRFs. At the time, VRFs were rated to AHRI 1230-2010 and ECS requirements were based on EER. The working group overhauled AHRI-1230 (resulting in [AHRI 1230-2021]) and crucially added a "controls verification procedure" which established a process to ensure that VRF compressor speeds, outdoor fan speeds, and EEV positions aligned in laboratory and field conditions. In addition, sensible heat ratio (SHR) requirements were added for the 100% and 75% load conditions to ensure representative levels of latent cooling were tested. These changes were necessary to ensure that VRF product ratings were aligned with in-field performance. CA IOU test data and analysis was critical in raising the issue to DOE's attention. Starting in 2024 (when the standards take effect), VRF ratings should become more reflective of field performance.

In 2023, VRFs are commonly specified and installed pieces of equipment. The product is appropriate for an appropriately designed deemed eTRM measure. Any deemed measure must consider factors such as the potential for refrigerant emissions and updated equipment performance data considering AHRI 1230-2021 testing requirements. The RACC will be a critical tool for properly accounting for the increased volume of refrigerant that is necessitated by VRF system layouts.

C2: Mechanical Heat Recovery

We use the term "mechanical heat recovery" to refer to any piece of equipment that uses the vapor-compression cycle to simultaneously provide space cooling and space and/or domestic hot water heating. This technology option can produce HVAC systems that achieve very high COPs, because the energy transferred across the evaporator as well as the condenser "counts" in the numerator of the COP ratio, in contrast to a regular chiller that can only "count" the evaporator energy since the condenser energy is waste heat. This benefit is reflected in the higher minimum COP requirements that were recently added for heat recovery chiller equipment, a snapshot of which is shown in Figure 7. Zeroing in on a specific comparison, for the <75 ton positive displacement equipment with a 120 F leaving hot water temperature, the heat pump heating COP must meet or exceed 3.68, while for the same size category and leaving hot water temperature for heat recovery, the COP must achieve 6.41 or greater. This is a result of the benefit of mechanical heat recovery, again, the productive use of both energy eliminated from a chilled water stream by the evaporator and added to the hot water stream by the condenser.

Mechanical heat recovery is being classified in this report as a "usually partial" fuel substitution solution due to the reality that it can only be leveraged when both heating and cooling end uses are present. One can fairly easily imagine a scenario in which either the cooling or heating loads exceed the other, in which case some dedicated cooling or heating solution would be required. In some scenarios with very low space heating loads and very high process cooling loads, a heat recovery chiller could fully satisfy the building space heating loads. An example would be a data center located in a very mild climate. The data center would need near continuous cooling (which generates waste heat), and if the space heating loads are low enough, then there would be ample excess heat all throughout the year to meet heating needs. But these types of examples are going to be relatively rare, which makes the "usually partial" solution an apt classification for mechanical heat recovery. Mechanical heat recovery is a critical "piece of the puzzle" for commercial building fuel substitution, but it should ideally be paired with other equipment such as thermal energy storage and/or ASHPs to form a complete system. These options are captured by measures "C9: ASHP + Mech HR" and "C11: ASHP + Mech HR + TES."

In the subsections below, we provide some more discussion of the different types of mechanical heat recovery equipment, considering air source, water source, and refrigerant source separately.

Although it is an incomplete FS solution, HR chillers may be an important "steppingstone" toward fully electrified commercial buildings. The technology is an important component to leading all-electric system options and can be incentivized as part of a staged conversion over to all-electric space heating. We feel that the challenges with decommissioning the gas system described in R8 are less pressing for this option, since we feel that the strategy of using the HR chiller to offload a gas boiler has a solid theory behind it and should provide solid ex-post savings.

C2.1: AIR SOURCE HEAT RECOVERY CHILLERS

Air source heat recovery (ASHR) chillers, sometimes referred to as 4-pipe ASHPs, are equipment that include an air-to-refrigerant heat exchanger and then two supply pipes and two return pipes. The equipment can be configured to supply hot water from ambient air as the source or the waste heat from a chilled water loop. Further, the unit can operate similar to an Air-cooled Chiller (ACC) if the loads are cooling dominated. An example product would be the Multistack ARA line. Though products exist in the market, ASHRAE 90.1 and Title 24 do not include efficiency rating requirements at this time.

A combination of ACCs, AWHPs, and ASHR equipment could comprise an entire HVAC system and is becoming more popular in the market. This system is captured in "C9: ASHP + Mech HR."

C2.2: WATER SOURCE HEAT RECOVERY CHILLERS

Water source heat recovery chillers are a well-established product in the market. Historically, the equipment was primarily marketed as a water-cooled chiller with heat recovery capabilities, implying that the cooling function takes priority over heating. Figure 5 provides a snapshot of some existing heat recovery chiller products.

		
Trane CenTraVac with Heat Recovery	York YK Centrifugal with Heat Recovery	Carrier AquaForce 30HX, 30XW

Figure 5: Examples of Water-cooled chillers with heat recovery

"Double bundle" heat recovery chillers are an established technology that is offered by major chiller manufacturers. The term "double bundle" refers to the fact that there are two condenser coils, one for sending excess energy to a cooling tower, the other for returning energy to the building. Sometimes this equipment is referred to in the industry as "6-pipe" units. Manufacturers produce "application guides" and other documentation regarding heat recovery chillers, which are highly valuable documents. Trane discusses water-side heat recovery in this 2007 newsletter, and Carrier publishes a variety of materials on its heat recovery homepage, including white papers for both air-source and water-source heat recovery equipment.

A rapidly growing category of heat recovery chillers can be classified as “dedicated” or “modular” equipment. This market is dominated by manufacturers such as Aermec, Multistack, and ClimaCool, and some example products are shown in Figure 6.

		
Multistack VME II	Aermec NXP	ClimaCool UCH

Figure 6: Examples of Dedicated Heat Recovery Chillers

Both the “double bundle” heat recovery chillers and dedicated/modular heat recovery chillers are largely accomplishing the same task – namely – delivering condenser heat to the building and absorbing energy from the building in the evaporator – but the differences stem from sizing, controls, and amount of heat recovery capability. A double bundle chiller may only be able to provide “partial” heat recovery, depending on the capacity of its second heat exchanger. This means that the refrigerant doesn’t fully condense in the heat recovery portion and must send the remainder of its waste heat to the condenser loop/cooling tower.

Heat recovery chillers can be in the condenser water or chilled water loops (in both cases, delivering hot water). A heat recovery chiller can recover condenser waste heat by being in the condenser loop, or they can also recover building waste heat by being placed in the chilled water return loop. This configuration is slightly more efficient, because the HR chiller can offload the regular WCC chiller by cooling down the return CHW temperature before it hits the cooling only WCC equipment. Generally, HR chillers are most effective when they are first in the loading order, which ensures that the heat recovery is maximized throughout the year.

Figure 7 shows an excerpt from Title 24 2022 Section 110.2 Table N, showing AWHP and heat recovery chiller efficiency ratings. Note that since this table was published, ASHRAE 90.1-2022 Table 6.8.1-16 slightly modified the values within the tables, and Title 24 2025 is expected to follow ASHRAE 90.1-2022.

TABLE 110.2-N Heat Pump and Heat Recovery Chiller Packages – Minimum Efficiency Requirements

Equipment Type	Size Category, (tons)	Cooling-Only Operation Cooling Efficiency [a] Full Load Efficiency (EER orkW/ton) IPLV (EER or kW/ton)		Heating Operation									Test Procedure
				Heating Source Conditions [d,e]	Heat-Pump Heating Full-Load Efficiency (COP_H)[b]				Heat Recovery Chiller Full-Load Efficiency (COP_{HR})[b, c] Simultaneous Cooling and Heating Full-Load Efficiency (COP_{SHC})[b]				
					Leaving Heating Water Temperature				Leaving Heating Water Temperature				
					Low	Medium	High	Boost	Low	Medium	High	Boost	
		Path A	Path B		105°F	120°F	140°F	140°F	105°F	120°F	140°F	140°F	
Air source	All sizes	≥9.595 EER ≥13.02 IPLV	≥9.215 EER ≥15.01 IPLV	47°F [d] / 43°F [d]	≥ 3.290	≥2.770	≥2.310	NA	NA	NA	NA	NA	AHRI 550/590
		≥9.595 EER ≥13.30 IPLV	≥9.215 EER ≥15.30 IPLV	17°F [d] / 15°F [d]	≥2.230	≥1.950	≥1.630	NA	NA	NA	NA	NA	
Water source electrically operated positive displacement	<75	≤0.7885 kW/ton ≤0.6316 IPLV	≤0.7875 kW/ton ≤0.5145 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	AHRI 550/590
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥75 and <150	≤0.7579 kW/ton ≤0.5895 IPLV	≤0.7140 kW/ton ≤0.4620 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥150 and <300	≤0.6947 kW/ton ≤0.5684 IPLV	≤0.7140 kW/ton ≤0.4620 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥300 and <600	≤0.6421 kW/ton ≤0.5474 IPLV	≤0.6563 kW/ton ≤0.4305 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	
	≥600	≤0.5895 kW/ton ≤0.5263 IPLV	≤0.6143 kW/ton ≤0.3990 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	

Figure 7: Excerpt from Title 24-2022 Table 110.2-N Showing AWHP and HR Chiller Efficiency Requirements

Source: California Energy Commission

C2.3: VRF WITH HEAT RECOVERY

VRF is manufactured with or without heat recovery. VRF without heat recovery means that all indoor units are in heating or cooling mode simultaneously. VRF with heat recovery can assign individual indoor units to operate in cooling or heating mode, depending on the zone space conditioning needs. The underlying concept is a manifestation of "mechanical heat recovery" applied to refrigerant-based multi-split systems. Heat recovery when applied to VRFs, however, comes with several disadvantages relative to hydronic heat recovery. First, with potentially long refrigerant lines throughout the building, the pressure losses that must be overcome by the VRF compressor are significant. Hydronic pumps move water at lower pressures than VRF refrigerant lines. The second disadvantage is the fact that the refrigerant temperature and pressure is set by the highest demand zone in the building, making the system overall operate at a much higher lift than a potential hydronic equivalent heat recovery system. Third (and related), hydronic heat recovery can be configured to operate between condenser and hot water temperatures, which is going to produce low lift on the chiller, whereas VRF heat recovery must always be configured for high lift (since it must produce both ~40 °F and ~120 °F refrigerant to provide space cooling and space heating, respectively. This limits the opportunity for reset when portions of the building are in part-load. Finally, the benefits of VRF with heat recovery are overstated by its metric, simultaneous cooling and heating efficiency (SCHE). SCHE is tested when exactly half of the units are in cooling mode and the other half are in heating mode, which puts no load on the condenser fan. This is a very specific load condition that is almost never achieved in the field (and when it does, it is likely only for short periods of time). Manufacturers have reported heat recovery efficiencies of 30+ SCHE but again, this condition is rarely experienced in the field.

Despite these challenges, VRF with heat recovery is commercially available and widely installed. As with any mechanical heat recovery option, the presence of significant cooling and heating loads must be present for this system type to make sense. Since heat recovery is never going to equal 100% over the course of the year, a more ideal type of VRF system includes both heat pump with and without heat recovery, depending on the building load profiles. This combination is captured in this analysis under "C9: ASHP + Mech HR."

C3: Water Source Heat Pumps (WSHP)

The category of water source heat pumps encompasses any equipment with a water-to-refrigerant heat exchange as the heat source or sink, and then either a refrigerant-to-air, refrigerant-to-water, or refrigerant-to-refrigerant heat exchanger delivering or accepting heat from the conditioned spaces. This product category is quite mature overall, since large buildings have long needed water source systems to accommodate the large volume of conditioned air to roof area ratios. The common trait of any WSHP system is that the water loop serving as the heat source/sink must be connected to some other equipment (such as an ASHP or GSHP) to ultimately provide as the energy source/sink. This makes all systems that include WSHPs more complex than simpler systems such as CUHPs or PTHPs. WSHP equipment has been identified as an opportunity particularly for "cascading systems" that leverage a combination of ASHPs and WSHPs. WSHPs are an important component in large buildings and fuel substitution measure opportunities are present.

C3.1 WATER TO AIR HEAT PUMPS (WAHP)

Water-to-air heat pumps (WAHPs) are a very established technology that has been in the market for decades. Many WAHP systems (in fact, the umbrella term 'WSHP' usually refers to WAHPs since WAHPs are the most common type of WSHP) have been installed throughout California.

WAHPs are available in capacities ranging from less than one to around 20-25 tons (Carrier's Aquazone line goes up to 20 tons, Daikin's Large Capacity WSHP line goes up to 25 tons, Trane's Axiom line goes up to 25 tons). As shown in Table 13 along with WAHP efficiency requirements, DOE appliance standards only cover up to 135,000 Btu/h (11.25 ton) equipment.

Table 13: Water to Air DOE Federal Minimum Efficiency Requirements

Size Category (Btu/h)	Cooling Efficiency (EER)	Heating Efficiency (COP)
<17,000	12.2	4.3
≥17,000 and <65,000	13.0	4.3
≥65,000 and <135,000	13.0	4.3

Source: 10 CFR 431.97 Table 3 and 4

The current default system design involving WAHPs is for them to be located in the building interior, serving one or several zones, and then there is a water loop running throughout the building, either accepting or rejecting heat to the individual WAHPs depending on if the zones require cooling or heating. The water loop also includes a boiler and cooling tower to provide "trim" heating or cooling if the overall building demands it. The fuel substitution measure for this system would involve replacing the boiler with an AWHP. Opportunities to retrofit existing systems to WAHPs are also possible. However, as noted above, all water source equipment requires an additional piece of equipment such as a cooling tower and/or AWHP to form a complete system. Since any WAHP measure opportunity involves other equipment, we're discussing these ideas in a different section, "C10: ASHP + WSHP."

C3.2 WATER TO WATER HEAT PUMPS (WWHP)

Water to water heat pumps (WWHP) are functionally very similar equipment to water source heat recovery chillers (discussed in

C2.2: Water Source Heat Recovery Chillers). A product described as a "heat recovery chiller" implies a cooling-dominated use case, whereas a "water to water heat pump" implies a heating-dominated use case. But the equipment itself is very similar. A 2013 Johnson Controls, Inc. slide deck discusses the differences in technology, with a key slide shown in Figure 8. The important aspect to note is the controlled setpoint, which is the chilled water setpoint for heat recovery chillers and the hot water supply temperature setpoint for WWHPs.

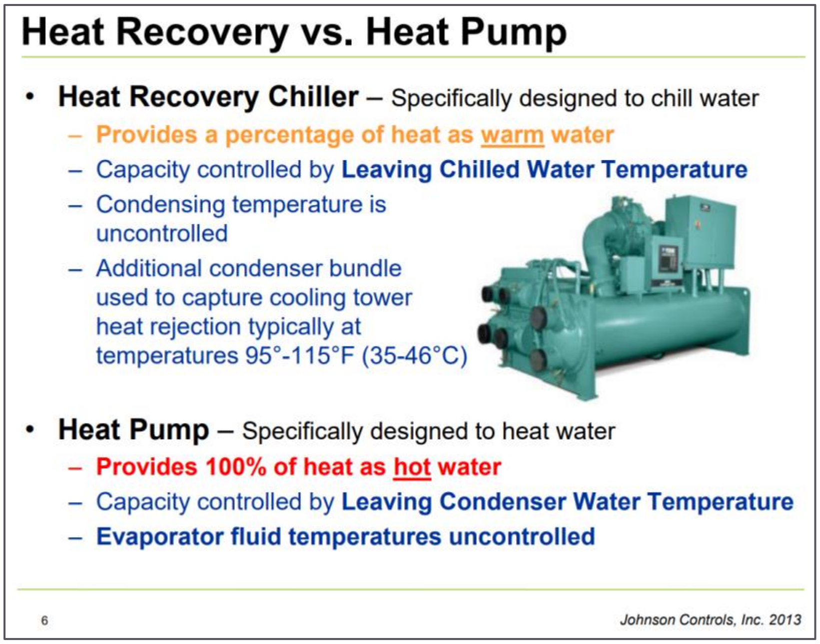

Figure 8: Hydronic Heat Recovery vs. Heat Pump technology

Source: Johnson Controls, Inc.

As with other WSHP equipment types, this unit would require additional components to form a complete system and is identified in "C10: ASHP + WSHP."

C3.3 WATER SOURCE VRF (WS-VRF)

Water-source VRF equipment (WS-VRF) is popular in large buildings where roof space is insufficient for all of the necessary air source VRF equipment. A WS-VRF system is installed within the building, and then the resulting water loop is connected to a cooling tower and boiler elsewhere in the building. A WS-VRF system can include or exclude heat recovery capabilities. Similar to WAHPs, the system could be all-electric if an AWHP were used instead of a boiler. As with other subcategories in this section, a full system is captured in "C10: ASHP + WSHP."

C4: Ground Source Heat Pumps (GSHP)

The commercial application of GSHPs is similar to what was described for its residential counterpart described in R4.

In addition to offering high efficiency and low maintenance costs, GSHPs also take up less space. In large buildings, they use smaller central system ducts, because the central air handling system only provides ventilation air rather than also being responsible for distribution of heating and cooling [OGT (1999)]. The Washington State University conducted a study on the operation and the maintenance of commercial GSHPs installed in the state of Washington since 1950s. They performed interviews and concluded that these GSHPs offered a high level of reliability over periods exceeding 25 to 30 years and a very high level of owner satisfaction [WSU].

Despite their popularity and being a mature technology, the commercial GSHPs penetration into the California market has been low [CaliforniaGeo (2023)]. Some of the barriers to the uptake of GSHPs in California include the first initial cost, high drilling costs due to the rocky soil in California and significant installation costs of ground heat exchangers. Commercial GSHP applications are an interesting choice as a component to a larger all-electric system configuration, which may include ASHPs to offset the unbalanced loads if present.

C5: Thermal Energy Storage (TES)

Thermal energy storage (TES) is an emerging technology in the all-electric HVAC space. TES is a component technology that can be paired with other elements (such as ASHPs and/or HR chillers) to achieve complete electrification of space heating.

The technology is mature in HVAC applications such as campuses (where chilled water storage is prevalent) and ice storage for peak cooling load shifting, and water heating applications such as hot water storage for domestic hot water usage. TES for space heating has been identified as a promising technology to pair with heat recovery (especially mechanical heat recovery), it can almost be thought of as an extension of the heat recovery function. This is because a heat recovery unit can only provide utility to the building when there are simultaneous cooling and heating loads present. The addition of TES makes that requirement disappear, since heat rejection from a cooling load can be stored for later usage in space heating. This feature vastly improves the usefulness of mechanical heat recovery, potentially making TES + mechanical heat recovery a complete all-electric space heating solution for sites with sufficient cooling loads and TES capacity (i.e., a commercial building may be able to fully electrify without any ASHPs).

TES without heat recovery provides much more limited value to the building and would be unlikely to become a major all-electric space heating option. The TES would have to be set to hot water temperatures, and the system would require a good amount of ASHP capacity. A TES+ASHP system with the storage at hot water temperatures could benefit the building by allowing for peak heating load shifting and peak heating electric load reductions (via the ability for the ASHPs to "trickle charge" the HW TES tank throughout the day, and then discharge it during morning warm-up), but if the building elects for a TES tank, then it's a major missed opportunity to not also include mechanical heat recovery to allow for the recapture of building cooling waste heat, making this theoretical combination not worthy of further investigation.

H_2O-based TES can be designed around several temperature bands: hot water (e.g., 110 – 140 °F), condenser water (e.g., 40 – 90 °F), chilled water (e.g., 32 – 65 °F), or ice/water (e.g., 25 – 45 °F). Each option has pros and cons, summarized in Table 14.

Table 14: Comparison of H_2O TES Strategies

Type	Advantages	Disadvantages
Hot	Avoids need for cascading system, enables peak heating load shifting, commonly applied to DHW systems.	Large tank requirement (because of low operating temperature range), requires high lift chiller (less efficient), challenging in cold climates, low HWSTs
Condenser	Highest efficiency. Orients all chillers (WCC, HR chillers, AWHP) into low-lift envelopes. Smallest tank volume requirements of sensible TES options.	Limited peak shifting capabilities, relatively tall tank requirement to enable thermocline (though can double as fire water storage)
Chilled	Common technology on campuses, enables peak cooling load shifting	Large tank requirement (because of low operating temperature range), relatively inefficient TES option
Ice	Low equipment volume requirements, enables peak cooling load shifting	Requires a high lift heat recovery chiller (less efficient, cannot achieve high HWSTs), requires glycol (equipment lifetime impacts)

Although it is early days for TES, our early assessment is that condenser water TES and ice TES are the two more promising strategies for TES applied to all-electric space heating. Each option provides unique advantages relative to the less compelling options. Condenser water TES is attractive mainly because of the system efficiency that results from using all of the chillers in low-lift configurations. Ice TES is attractive due to the lowest amount of building real estate needed. Hot water and chilled water TES may find some niche applications, but at this point, they seem to combine some of the least attractive characteristics of condenser TES and ice TES without providing many benefits (other than industry familiarity and peak load shifting ability).

Phase-change material (PCM) options are also available, though we understand them to be significantly more expensive relative to H_2O-based TES and therefore we did not focus on this type in our research.

C6: Electric Resistance (ER) heating (wire-to-air only)

Although long derided as the poster child for inefficient space heating, research indicates that there is likely some place for ER heating in targeted applications in the future. A snapshot of this measure opportunity is shown in Table 15.

Table 15: Snapshot of Wire-to-Air ER Heating Opportunity

Measure Aspect	Description
Base case	Boiler
Measure case	Wire-to-air ER heating in the zone VAV box (i.e., not an electric boiler or an ER heating coil in a central AHU)
Building types	Large buildings with interior zones that rarely experience space heating loads, buildings in mild climate zones, highly efficient buildings (e.g., those with an efficient envelope or well performing HVAC controls).
C&S information	ER heating is prescriptively banned by Title 24 Part 6 at section 140.4(g). ER heating can be leveraged if the performance compliance approach is used.
Other information of note	There is an active CASE proposal for Title 24-2025 to loosen the prescriptive ban on wire-to-air ER heating when other EE measures are leveraged.

It is unlikely that a full ER heating system is ever going to become a widespread option for commercial buildings due to the inherent benefits that ASHPs (with COPs on the order of 3.0) and heat recovery ("free heating") provide. However, ER heating provides some benefits relative to these other options as well. For example, despite the attractive COPs, heat pumps also contain refrigerant, which can leak into the atmosphere and cause far greater GHG emissions per pound than the equivalent amount of carbon dioxide (as expressed by the global warming potential or GWP rating). Today's commonly used refrigerants such as R-134a and R-410A have GWPs on the order of 2,000. Upcoming CARB and EPA regulations are driving vapor-compression-based systems to use lower GWP refrigerant options, but still, these up-and-coming refrigerants still have GWPs on the order of 500-750. "Lower GWP" refrigerants are also more likely to be classified by ASHRAE 15 as being "mildly-flammable" (i.e., rated A2L), providing some challenges to building occupant safety. ER heating comes with none of these complications since they have no refrigerant.

The obvious rebuttal to the refrigerant discussion is that ER heating still comes with an upper limit of efficiency of 100% (i.e., a 1.0 COP), which is inherently lower than heat pump COPs which can range from 2 (for ASHPs at heating design conditions) to as high as 8+ COP if thermal energy storage and/or heat recovery are included and conditions are mild. However, the high heat pump COPs are partially degraded by the reality that the refrigerant or hydronic piping throughout the building experiences thermal and pumping energy penalties. This is not the case for wire-to-air ER heating (ER boilers with hydronic distribution are the worst of both worlds, since they have a 1.0 COP and distribution losses. We would strenuously argue against their inclusion in any measure package design).

On the upfront cost side of the equation, ER heating is a clear winner due to the elimination of expensive ASHP equipment and a refrigerant or hydronic distribution network in the building. It is less clear if a full ER heating system would provide lifecycle cost benefits to the building owner, but it might be possible in some situations.

The clear penalty to ER heating is that it compares unfavorably to heat pump & heat recovery options. The research team screened out "full ER heating" as a measure opportunity due to this expected downside. However, as elaborated in a subsequent measure discussion, ER heating when paired with "other measures" is attractive to our team (due to the targeted benefits of ER heating noted above). When deployed in a zone with very low space heating loads (either due to climate, zone placement within the building, or other EE measures such as envelope and HVAC controls), the energy penalty of ER heating is going to be limited and the benefits could be substantial. ER heating should be a consideration as a component to all-electric commercial buildings.

C7: Waste fluid heat recovery

The category of "waste fluid heat recovery" consists of two different applications of the same idea: some form of waste energy contained in a fluid is departing the building that can be used to preheat (or precool) another fluid stream. The subcategories include ventilation air heat recovery and wastewater heat recovery. This form of heat recovery is important to distinguish from the earlier category of "mechanical heat recovery" because waste fluid heat recovery does not include a compressor pumping heat from a source to a sink. This is a comparatively more "passive" form of heat transfer, essentially a single heat exchanger. Mechanical heat recovery takes advantage of the fact that the vapor-compression cycle can generate a robust temperature gradient in two heat exchangers and can deliver 6 or more units of useful energy per unit of power input (i.e., its COP). Waste fluid heat recovery, by contrast, cannot exceed 100%.

Despite being less appealing than mechanical heat recovery, waste fluid heat recovery technologies should definitely be explored for inclusion in buildings if cost effective, because they can improve the overall efficiency of the building. Mechanical heat recovery and waste fluid heat recovery can complement each other. For example, a wastewater heat recovery system can preheat an intermediate water loop that then offloads a water-to-water heat pump (a.k.a. a heat recovery chiller) to supply hot water to VAV boxes.

As is the case with mechanical heat recovery, waste fluid heat recovery technologies are generally a "partial" electrification measure, in that they would only offset a fraction of the building's gas energy usage for space heating. Waste fluid heat recovery can be combined with other technologies to form a complete system (see C12: ASHP + Waste Fluid Heat Recovery for some more discussion).

C7.1 EXHAUST AIR HEAT RECOVERY (EAHR)

EAHR is a technique whereby the airstream exhausted from the building is connected to an air-to-air heat exchanger with incoming fresh air and energy is either transferred between the two airstreams depending on whether the building needs heating or cooling. The technique is most effective in more extreme climates. For instance, when it's very warm outside and the building is in cooling mode, the air leaving the building would be roughly 75 °F, whereas ambient air could be 90 °F or greater. In this condition, the leaving exhaust air would precool the incoming fresh air. In the reverse situation, when it's cold outside and the building is in heating mode, exhaust air would preheat the incoming fresh air. This technology is clearly less useful in mild climates, where the temperature of the incoming and outgoing airstreams are generally fairly close, making the driving thermal difference small.

In 2022, the Title 24 CASE Team successfully proposed a measure requiring EAHR in some scenarios, depending on the hours of operation, climate zone, design airflow rate, and percent outside air. Any program inclusion for EAHR could be based on this Title 24 requirement but with improved enthalpy recovery ratios (ERRs) or with fan performance criteria. In addition to the Title 24 requirement, the DOE direct expansion dedicated outdoor air system (DX-DOAS) standard includes product categories for equipment with "ventilation energy recovery systems" (VERS) which have higher efficiency requirements than the categories without VERS. Program requirements could use the DOE metric (integrated sensible moisture removal efficiency, ISMRE2) as the basis for program qualification. Since many of the technologies described throughout this report are "decoupled" (i.e., ventilation and sensible conditioning systems are separate), then ventilation systems are separate but include their own efficiency opportunities, including EAHR and fan system efficiency improvement measures.

C7.2 WASTEWATER HEAT RECOVERY

It is a similar concept to EAHR, except instead of waste air, the wastewater stream is leveraged as a heat source or sink depending on if the building requires heating or cooling. Wastewater temperatures vary (e.g., wastewater from showers or dishwashing would be warmer than toilet wastewater), so the exact heat flow diagram could take different forms depending on the specific configuration. But the general idea is that the wastewater stream can offset a portion of the building's space heating or cooling loads by receiving or rejecting heat back into the building before being sent to the sewer.

Some manufacturers of this technology include Sharc Energy and Kemco Systems.

C8: Single Zone Wall Mounted Equipment

We use the term "single zone wall-mounted equipment" to encompass two major categories of unitary HVAC equipment: package terminal air conditioners and heat pumps (PTAC/PTHP) and single package vertical air conditioners and heat pumps (SPVAC/SPVHP). From a technical standpoint, the two categories are very similar, but they are considered separately because of their unique form factors and applications. The two subcategories are similar in that they are both promising candidates for new deemed fuel substitution measures.

Table 16: SZ Wall-Mounted Equipment Snapshot

Measure Aspect	Description
Base case	SZ wall-mounted AC equipment + gas heating
Measure case	SZ wall-mounted HP equipment
Building types	PTHP: hotel/motel, multifamily buildings (e.g., dormitories, condominiums, apartment buildings), education SPVHP: relocatable classroom, multifamily buildings
C&S information	Both PTHP and SPVHP are federally regulated products. The industry standard test procedure for PTHP is AHRI 310/380 and SPVHP's is AHRI 390, both of which are referenced by DOE. Both PTHPs and SPVHPs are rated using EER for cooling-mode and COP[47] for heating-mode.
Other information of note	DOE is currently in the process of re-analyzing these products (homepages for PTHP and SPVHP) which may result in changes to the equipment rating and/or energy conservation standard levels.

C8.1: PACKAGE TERMINAL HEAT PUMPS (PTHP)

A **packaged terminal air conditioner or heat pump** (**PTAC/PTHP**) is a self-contained commercial grade HVAC unit commonly found in hotels, motels, senior housing facilities, hospitals, condominiums, apartment buildings, add-on rooms and sunrooms. PTACs are often "unitary" systems, meaning the single heat pump unit can provide both heating and cooling. They include a prime source of refrigeration, separable outdoor louvers, forced ventilation, and heating availability by builder's choice of hot water, steam, or electricity and mostly go through a window or a wall, having vents and heat sinks both inside and outside. There is no "indoor unit" and "outdoor unit;" instead, it is just the single through-the-wall model that blends into the exterior façade. Examples of this equipment are shown in Figure 9.

		
Source: Islandaire PTAC EZ Series 42	Source: Friedrich PDH09K3SGR3	Source: Ice Air PTAC RSXC09
Quieter, cooling only or heat pump with back up electric heat	R32 Unit with 9.4 kBTU EER=12.1	Claimed to be world's first cold climate Heat Pump- heating down to -5 °F

Figure 9: Examples of PTHP Equipment

All residential and most commercial Units come with 208/240 volt and in different dimensions including 42×16 inches (1067 x 406 mm), 36x15 inches, and 40x15 inches. They are not, however, easy to install and can be noisy. Many modern Units offer inverter technology allowing compressor to vary speed resulting in higher efficiency and better comfort.

Although PTHPs heat or cool a single living space using only electricity (with resistive and/or heat pump heating), there are cooling only PTACs with external heating through a hydronic heating coil or natural gas heating. Typical PTAC heating and cooling capacity values range from 1.5 to 7 kW (5,000–24,000 BTU/h) nominal. One characteristic of PTACs is that condensate drain piping is not required because the condensate water extracted from the air by the evaporator coil is drawn by the condenser fan onto the condenser coil surface where it evaporates.

A cooling only PTAC with gas heat provided either from the PTAC itself or another source is the ideal candidate for retrofit with a PTHP. Our initial research indicates that most PTAC systems have electric resistance heat, so most PTAC to PTHP replacements will not be fuel substitution projects, limiting the potential reach of PTHPs as a fuel substitution measure.

In some cases, there is no difference in price between a PTAC and a PTHP of the same size so incentivizing PTHPs through NR pathways may be difficult without requiring efficiency improvements in addition to fuel substitution. However, fuel substitution incentives could be provided without efficiency improvements for AR projects as the full measure cost would be used as the basis for the first baseline.

C8.2: SINGLE PACKAGE VERTICAL HEAT PUMPS (SPVHP)

SPVHP systems are similar to PTHPs and other through-wall systems with the main difference being the vertical orientation of components with the condenser and evaporator coils are stacked vertically instead of horizontally There are two major types of SPVHPs, interior and exterior wall mounts. While both types of systems are mounted to a wall, interior wall mount systems have the components in the building interior and are generally used in multifamily applications. Exterior wall mount systems are mounted to the outside of the building and are generally used in portable buildings such as classrooms. Systems range between 0.5-5 tons with exterior wall mount systems generally being larger. SPVHPs can be an attractive fuel substitution option for buildings that use SPVAC systems with gas heat or for applications that require vertical packaged systems such as portable classrooms. With multi-stage and variable speed models becoming more prevalent on the market due to increasingly stringent standards, the installation of an efficient SPVHP can lead to energy efficiency impacts in addition to decarbonization impacts through fuel substitution. Examples of this product are shown in Figure 10.

	
Source: GE Zoneline	Source: Eubank
Interior mount SPVHP used in multifamily applications.	Exterior mount SPVHP used in portable buildings

Figure 10: Examples of SPVHP Equipment

C9: ASHP + Mech HR

Combining mechanical heat recovery with air source heat pumps is an increasingly popular option for nonresidential buildings pursuing all-electric space heating. The two elements combine well and can constitute a complete all-electric system. Figure 11 is a schematic that shows the direction of heat transfer and major equipment elements of a hydronic ASHP + mechanical heat recovery system. The umbrella term of "ASHP + mechanical heat recovery" could also be applied to a VRF-based system, the underlying concept is the same. The benefit of this system configuration is that when leveraged appropriately, a portion of the mechanical heating and/or cooling equipment can be downsized and/or experience fewer runtime hours when the heat recovery equipment is included. The advantages of mechanical heat recovery are detailed in section C2: Mechanical Heat Recovery. The main difference between that discussion and this is that in this case, the balance of heating capacity is provided by an ASHP, which of course, is an electric piece of equipment. This is what enables ASHP + mechanical heat recovery to constitute a complete all-electric system.

The primary issue with this configuration is the fact that cooling and heating loads must "overlap" in order for the heat recovery equipment to be used effectively. This aspect is not something that the HVAC system has any control over because it's a result of the building location, end-uses, and occupancy patterns. This means that not every building is necessarily a great candidate for an ASHP + mechanical heat recovery system. The best sites are going to be those that encounter very steady process loads, either on the cooling or heating sides. Building types such as hospitals, data centers, and mixed-use buildings (including process heating loads such as commercial kitchens or laundromats in some areas and then space cooling loads in other areas) come to mind as good candidates for this type of configuration.

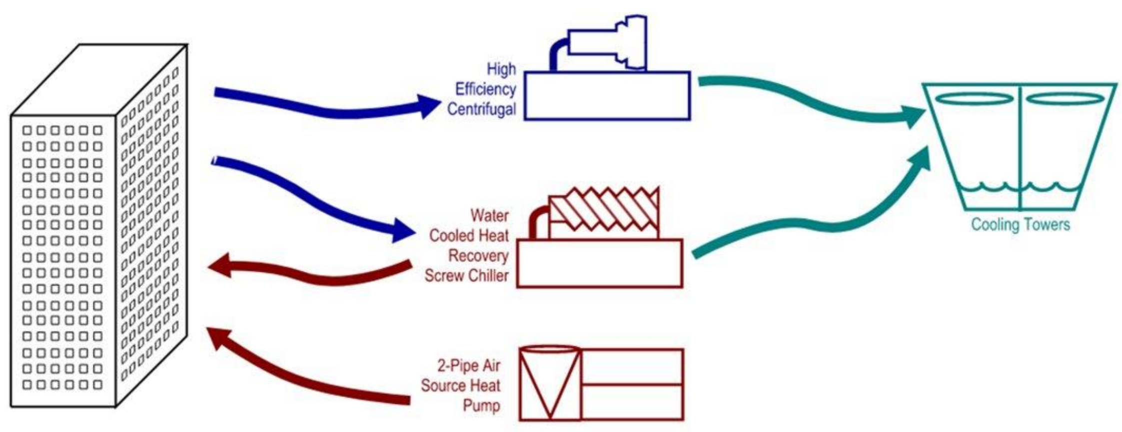

Figure 11: Schematic Showing ASHP + Mechanical Heat Recovery

Source: Brandon Gill, Taylor Engineers

As stated above, this system choice is very appealing for sites with significant annual overlapping cooling and heating loads. The individual pieces of equipment (i.e., ASHPs, heat recovery chillers/HR VRFs, water cooled chillers, cooling towers) are all mature and widely available commercially.

If a measure were to be designed around this system configuration, challenges would include 1) ensuring the building types being targeted are actually good candidates for this system, 2) overcoming up-front costs, and 3) considerations with the measure application type (i.e., if only a subset of the existing WCC + boiler system is at the end of its useful life, how would the measure be analyzed? Would it be accelerated replacement, normal replacement, or both?). These considerations cause the research team to determine that the "custom" delivery type is the most appropriate path for this system configuration in the short term. As more of a track record of retrofits is up, then perhaps patterns can be identified, and the measure can be "deemified" in the future.

C10: ASHP + WSHP

There are many existing "water-source heat pump" (more specifically, water to air heat pump) systems in the field. These systems rely on a water loop that runs throughout the building, with a number of WAHPs spread throughout the interior. The water loop is also connected to a trim heating source (historically a boiler) and heat rejection device (typically a cooling tower). The trim gas boiler can be straightforwardly retrofitted to be an air to water heat pump (AWHP) instead.

There are other configurations of ASHPs and WSHPs that can be envisioned beyond the example of an AWHP+WAHP system. Configurations that mix-and-match AWHPs, WWHPs, WS-VRFs, WAHPs, etc. based on specific building needs. These types of flexible systems should be encouraged through the custom incentive programs over a period of time and then some of the more frequently occurring designs can be considered for deemed measure packages. The AWHP+WAHP configuration, however, should be considered for deemed in the near term, since there is a clear base case and measure case, the savings can be accurately quantified using BEM, and incremental costs can be quantified.

C11: ASHP + Mech HR + TES

As stated earlier in Section C1, Air source heat pumps are an important component to a fully electrified space heating system but are typically best deployed with a combination of water-to-water heat pumps (a.k.a. heat recovery chillers) and thermal energy storage tanks. As detailed in the ASHRAE Journal article, Solving the Large Building All-Electric Heating Problem (Gill, 2021), large nonresidential buildings have unique challenges regarding all-electric space heating. The most common space heating option today is a natural gas boiler system with hydronic distribution. This option is space-efficient (i.e., it doesn't occupy a large fraction of the building's floor area) and has a low upfront cost, but comes with the penalty of on-site GHG emissions. All-electric space heating options that could work for smaller buildings tend to carry more significant drawbacks when being considered for large buildings. For example, an air-source VRF system may work fine for a 50,000 ft^2 building, but there may simply not be enough roof space for the necessary amount of condenser equipment at the 500,000 ft^2 building footprint level.

This conundrum of ever-increasing space needs for air-to-refrigerant or air-to-water heat exchangers to satisfy building space heating loads as the size of the building increases can be resolved by the use of heat recovery and thermal energy storage. That way, the building is capturing its waste heat from space cooling end-uses and then repursuing that energy for space heating.

<u>Time Independent Heat Recovery (TIER) (Taylor Engineers)</u>

TIER is a novel system concept developed by Taylor Engineers that leverages TES + HR. The result is a cascading all-electric system that ensures all chillers are used in low-lift conditions. A schematic of the heat flows for a condenser water TIER system is shown in Figure 12.

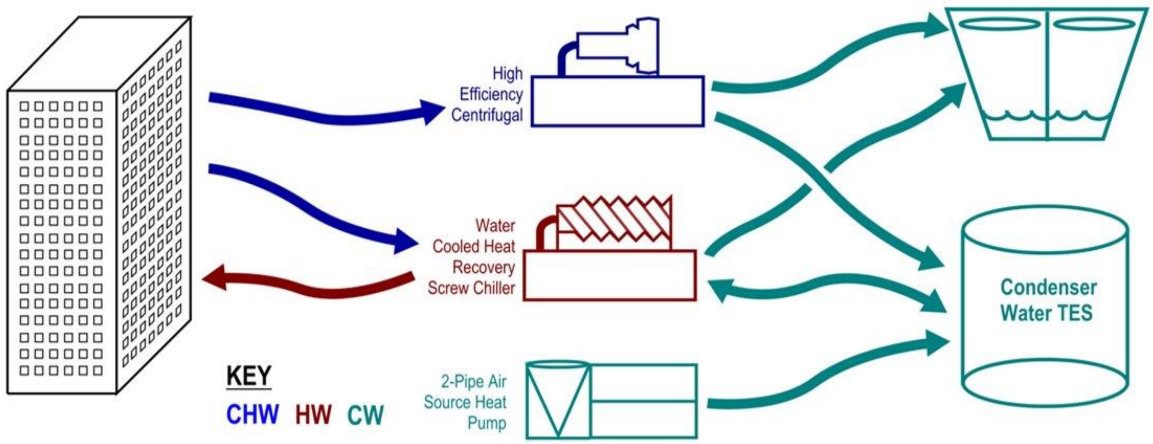

Figure 12: Schematic showing direction of heat transfer for a condenser water TIER system

Source: Brandon Gill, Taylor Engineers

The TIER design is a space saver due to its load shifting mechanism and thereby reducing ASHP capacity dramatically. A traditional TES tank is used for cooling peak shifting, not for heat recovery, and is typically sized to either ride through the utility peak period without running chillers or trim some fraction of chiller capacity throughout that period. A TIER TES tank is sized to ensure that on a design heating day, heating loads can be met during all hours of the day using the available heat recovered from the building(s) and trim heat source energy added to the tank.

The cooling chillers and heat recovery chillers are placed in a cascade configuration: the cooling chillers have a lift envelope of 40 °F chilled water supply temperature to 80 °F condenser water leaving temperature, while the heat recovery chillers have a lift envelope of 60 °F evaporator supply temperature to the active hot water supply temperature setpoint, typically 110 °F to 140 °F for all-electric designs. In California's mild climate zones, the energy recovered from cooling loads alone can satisfy heating loads.

The load shifting allows the TIER design to save space, improve efficiency and reduce cost as well as ASHP capacity dramatically. The tank capacity should be maximized since it generally reduces overall project costs and improves plant efficiency.

Storage Source Heat Pump (SSHP) (Trane)

SSHP is a twist on the long-standing ice TES application of cooling peak load shifting. In an all-electric configuration, the ice TES is "charged" (i.e., melted) during winter afternoons (when many nonresidential buildings are in fact cooling dominated in California and nationwide) and then "discharged" (i.e., frozen) during winter morning warm-up using a high-lift (i.e., ice to hot water) heat recovery chiller system. A schematic of this system is shown in Figure 13.

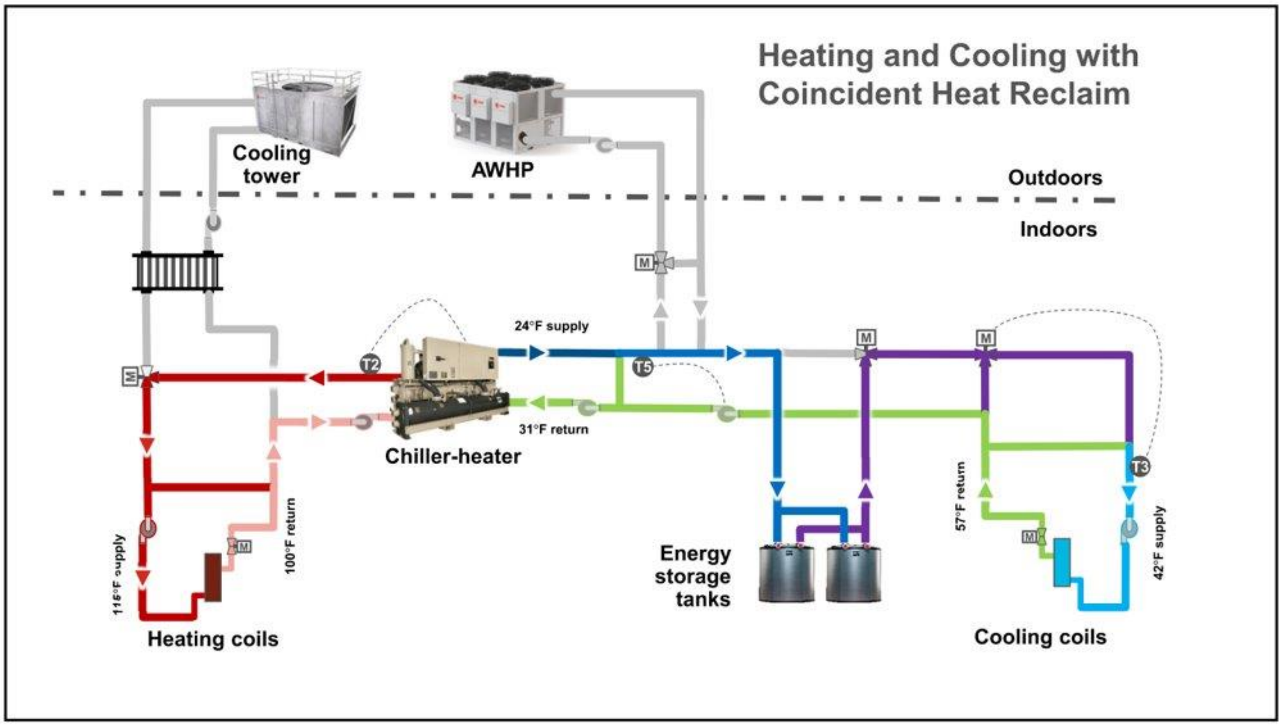

Figure 13: Storage Source Heat Pump (SSHP) Schematic

Source: Trane

Since this system uses ice storage, the heat recovery chiller is permanently in a "high lift" mode, which means that it must move heat across a large temperature gradient (which makes the compressor work harder and uses more energy). The benefit of ice storage is the space efficiency per unit of capacity, so this makes ice storage an appealing option in two situations: very limited space requirements (i.e., dense urban environments) and very cold climates (where maximizing storage capacity is a priority). There are some areas of California that fit both of these conditions, and an ice-storage based all-electric system may therefore be an appealing choice.

C12: ASHP + Waste Fluid Heat Recovery

This system configuration would consist of an ASHP (recall, these include CUHPs, AWHPs, and AS VRFs) alongside some form of waste fluid heat recovery. This measure could be appealing in very extreme climates, such as CZ15 or CZ16. This system combination could be envisioned as an offering as part of a broader AWHP or VRF measure package.

A variation on this system configuration could include mechanical heat recovery as well, but as noted elsewhere, it is not practical to separately itemize every possible system configuration in this report.

C13: ER Heating + other measures (EE Improvements, PV, Solar Thermal, Battery)

For existing sites with boiler systems, a cost-effective electrification option could involve envelope upgrades, HVAC controls, PV, battery storage, and ER heating. This combined system would eliminate the need for hydronic or refrigerant piping and refrigerant-bearing equipment from the heating system.

Although counterintuitive, it could be possible to reduce GHG emissions by converting an existing natural gas boiler to air-to-wire electric resistance system, if appropriate additional EE and/or DG steps are taken. EE steps would involve a focus on the building's envelope and HVAC controls enhancements. DG steps would include site-PV and battery storage to further reduce the peak electric load impacts of using ER heating. If all efficiency opportunities are leveraged to reduce space heating loads, ER heating can be an appealing fuel substitution option.

C14: Hybrid of ASHP + Mech HR + TES and ER Heating

This configuration is a potentially very efficient solution that combines the best qualities of heat pump + HR/TES systems with ER heating for very low load zones. Systems that include this configuration should be pursued as part of custom measures and perhaps ET studies to better understand the tradeoffs between ER heating and other more efficient (but more costly) heat pump and/or heat recovery-based designs.

C15: EE/DG measures

Energy efficiency (EE) and distributed generation (DG) measures pair extremely well with space heating fuel substitution efforts. This is because electric space heating typically includes some amount of heat pumps, and heat pumps remain expensive relative to gas equipment. The most impactful way to reduce the need for space heating equipment capacity is by pairing the fuel substitution retrofit with energy efficiency measures that shrink the peak heating loads. EE measures include building envelope improvements, HVAC controls retrofits, reducing the hot water supply temperature (HWST) to reduce thermal losses. DG measures include on-site solar PV, battery storage, and solar thermal assisted hot water). DG measures are particularly interesting for sites that pursue ER heating, since the battery storage could discharge to offset the peak heating loads. Although it may be excessive to require some amount of EE and/or DG measures to access FS incentives, these pairings should be strongly encouraged whenever possible. These opportunities can be further defined and quantified for potential measure package modification/development.

6. Scoring Methodology and Results

Deemed measure proposals were scored using the following criteria, with higher scores indicating better feasibility for a measure package. A maximum of 100 points is possible. Detailed explanations for the ratings can be found in the rating spreadsheet.

Energy Savings Potential (20 points): The percentage of energy savings of the measure technology compared to the baseline technology. The percentage is computed using the savings assumptions listed in the rating spreadsheet and then multiplied by the full points value to obtain the energy savings score. Note that this field is normalized to the least efficient all-electric option included in the scoring framework, so a low score is not indicative of a low efficiency technology. Technologies that made it to the scoring exercise were all considered to be average to above-average efficiency all-electric systems.

Product Maturity (10 points): The measure technology is assessed on the maturity of the technology with regard to market availability and points are assigned based on the following classifications:

- None (0) = Emerging Technology/no commercial production
- Low (2) = Starting commercial production
- Medium (6) = Limited commercial production
- High = (10) Widespread commercial production

CA Market Size (30 points): The percentage of statewide square footage or dwelling units that the measure has the potential to be installed in. Square footage and dwelling unit counts are obtained from 2026 Existing Building Stock estimates provided by the CEC. The percentage is divided by the percentage of the highest scoring residential or commercial value and multiplied by the maximum points value to obtain a normalized score.

Regulatory Barriers (20): Any regulatory barriers such as upcoming code changes, presence of technology in federal/state codes, or CPUC resolutions that would prevent the measure from being offered in a deemed program or negatively impact program success. A higher rating indicates fewer barriers.

Deemed Feasibility (20): The feasibility of the measure being deployed in deemed incentive programs and the amount of work necessary to create a measure package. Factors considered in determining the amount of work necessary include the need for market research and energy modelling. Higher ratings indicate better feasibility for deemed programs and/or reduced effort in creating a measure package.

The results of the scoring exercise are presented in Table 17 and Table 18. As described above, some fields are more quantitative than others, but taken as a whole, we believe that the results directionally indicate which measures are a higher priority for pursuing eTRM measure packages. Our full set of recommended next steps is discussed in the Conclusion section.

Table 17: Scoring Results for Residential Measures

Measure Number/Name	Energy Savings (20)[a]	Product Maturity (10)	CA Market Size (30)	Regulatory Barriers (20)	Deemed Feasibility (20)	Total Score (100)
R1/Combi HP	20	2	30	5	10	67
R2/120V HP	0	2	28	20	10	60
R4/GSHP	18	10	3	10	10	51
R3/AWHP	11	6	3	15	10	45

[a] Note that this field is normalized to the least efficient all-electric option included in the scoring framework, so a low score is not indicative of a low efficiency technology.

Table 18: Scoring Results for Commercial Measures

Measure Number/Name	Energy Savings (20)[a]	Product Maturity (10)	CA Market Size (30)	Regulatory Barriers (20)	Deemed Feasibility (20)	Total Score (100)
C1.2/AWHP	3	6	30	15	15	69
C1.3/AS-VRF	3	10	30	5	15	63
C2/Mech HR	12	6	16	10	10	54
C10/AWHP+WSHP	3	6	6	20	15	50
C9/ASHP+Mech HR	11	2	18	10	5	45
C8/PTHP/SPVHP	0	8	0	20	10	39
C11/ASHP+Mech HR+TES	20	2	6	5	5	38

[a] Note that this field is normalized to the least efficient all-electric option included in the scoring framework, so a low score is not indicative of a low efficiency technology.

7. Advice Letter Inputs

A preliminary set of statewide savings estimates and program performance parameters is shown in Table 19 and Table 20. The CET was run for CZ09 only. This is based on the preliminary per-unit savings estimates, impacts estimates, RACC estimates, and incremental cost estimates all developed as part of this analysis. The estimates are based on the assumption that all measures will be run as custom, since by definition no deemed measure packages exist for any proposed new measures. As measure packages are created for these measures and they are introduced to the deemed portfolio, over time, we expect that program throughput would increase substantially.

Table 19: Residential FS Measure Estimates

Measure No.	Measure Name	TRC	TSB ($)	kWh	therms	GHG (metric tons)	Source Energy (MMBtu)
R1	Combination DHW+Space Heating Heat Pumps	0.55	$3,354,960	(1,090,612)	186,111	13,968	239,204
R2	120V Heat Pumps	1.30	$842,672	(857,852)	73,196	4,610	78,360
R3	Air to Water Heat Pumps	0.67	$98,319	(65,292)	7,799	541	9,307
R4	Geothermal Heat Pumps	0.37	$160,146	(50,782)	7,799	581	9,838

Table 20: Commercial FS Measure Estimates

Measure No.	Measure Name	TRC	TSB ($)	kWh	therms	GHG (metric tons)	Source Energy (MMBtu)
C1.2	Air to water heat pumps (AWHP) w/o heat recovery	0.57	$1,371,056	(1,061,485)	135,856	13,210	226,200
C1.3	Variable refrigerant flow (VRF) heat pumps w/o heat recovery	0.92	$905,102	(906,529)	99,953	6,854	116,712
C2	Heat recovery chillers (excluding VRF HR)	2.02	$497,722	(11,654)	17,949	2,199	35,398
C8	Single Zone Wall-Mounted Equipment	2.05	$60,956	(39,096)	5,002	276	4,638
C9	ASHP + Mech HR (including AWHP and VRF with HR)	0.46	$822,783	(326,227)	62,611	6,475	111,235
C10	WSHP +ASHP	0.17	$36,812	(32,657)	4,179	311	5,071
C11	ASHP + Mech HR+TES	0.35	$196,018	(14,129)	8,005	1,134	15,404

It must be emphasized that these numbers are early draft estimates and are subject to change as the measure analysis progresses. Some underlying per unit savings estimates are based on isolated building type/climate zone pairings, which we felt to be representative of the state but still, the numbers could change significantly for any final measure package analysis. See the supporting spreadsheets and CET files for further detail regarding the source of the savings and cost inputs.

8. Next Steps

This report documents the outcome of comprehensive research on the measures that impact HVAC fuel substitution. The research identified the HVAC decarbonization (though gas to electric fuel substitution) technologies and prioritized them using quantitative and qualitative methods. Overall, three main technologies for electric space heating are identified that include the heat pumps, heat recovery and electric resistance heater.

As identified throughout this report, there are numerous upcoming fuel substitution opportunities for both the residential and commercial sectors which are not currently captured in the eTRM. We identified eight residential and 15 commercial technologies and systems (comprising a variety of individual technologies). Many more surely exist, particularly on the commercial side, since many components can be mixed and matched to suit the individual site's needs.

Our recommendations for residential measures can be found in Table 21. Our recommendations for commercial measures can be found in Table 22. As noted throughout the report, these 23 opportunities are certainly do not reflect the full range of HVAC FS opportunities. Future upcoming opportunities not described in this report include community heat recovery (i.e., sharing heat between buildings), further pairings of components into systems not discussed in this report, industrial HVAC FS opportunities, and others. These and others should be continuously monitored for potential measure development.

Table 21: Recommended Next Steps for Identified Residential Measures

Measure No.	Name	Next Steps
R1	Combination DHW + Space Heating Heat Pumps	Pursue measure package. Base and measure cases are clearly defined, savings opportunity is present, products are commercially available and could benefit from promotion.
R2	120V heat pumps	Pursue measure package. Base and measure cases are clearly defined, savings opportunity is present, products are commercially available and could benefit from promotion.
R3	Air to Water Heat Pumps (AWHP)	Pursue additional research to study market size. Possible candidate for future measure package.
R4	Ground Source Heat Pumps (GSHP)	Pursue additional research to study installation/drilling costs. Possible candidate for future measure package.
R5	Ductless Heat Pumps (DHP) (SWHC044)	Update current measure package to add new offerings for VS heat pumps.
R6	Central Ducted Heat Pumps (SWHC045)	Update current measure package to add new offerings for VS heat pumps.
R7	Electric resistance (ER) heating	Do not pursue further research. Better all-electric options exist and should be promoted instead of ER for residential.
R8	Dual fuel heat pumps	The recent CPUC Proposed Decision may preclude incentives for dual fuel equipment in the future. Monitor CPUC Viable Electric Alternatives working group outcomes to see if incentives will be allowed.

Table 22: Recommended Next Steps for Identified Commercial Measures

Measure No.	Name	Next Steps
C1	C1.1: Air to air heat pumps (a.k.a. commercial unitary heat pumps or CUHP) C1.2: Air to water heat pumps (AWHP) C1.3: Air source VRF heat pumps without heat recovery	C1.1: Update SWHC046 with offerings for VS CUHPs C1.2: Pursue measure package (in conjunction with C9.2 and the C10 'AWHP to WAHP' scenario) C1.3: Pursue measure package (in conjunction with C9.3)
C2	C2.1: Air source HR chillers C2.2: Water source HR chillers C2.3: VRF with HR	C2.1: Pursue measure package for partial FS. Clear base & measure case and savings opportunity. C2.2: Pursue measure package for partial FS. Clear base & measure case and savings opportunity. C2.3: Pursue with other offerings (i.e., C9.3)
C3	C3.1 Water to air heat pumps (WAHP) C3.2 Water to water heat pumps (WWHP) C3.3 Water source VRF (WS-VRF)	Since this is generally a 'component' technology, pursue all as part of other offerings (such as C10, a consolidated VRF offering, or other measure packages devised beyond the 15 identified in this list).
C4	Ground Source Heat Pump (GSHP)	Conduct additional research on installation/drilling costs. Explore for potential as a future 'component' or complete system technology for promotion.
C5	Thermal Energy Storage (TES)	Pursue as part of other offerings (e.g., C11).
C6	Electric Resistance (ER)	Pursue as part of other offerings (e.g., C13, C14).
C7	C7.1: Exhaust air heat recovery C7.2: Wastewater heat recovery	Consider as a standalone "partial" FS measure. Most likely pursue as offerings within another measure package (e.g., C12).
C8	C8.1: Package Terminal Heat Pump (PTHP) C8.2: Single Package Vertical Heat Pump (SPVHP)	Pursue additional research to quantify the nature of the heating side of current PTAC and SPVAC systems. Determine the prevalence of PTAC + gas furnace vs. PTAC + electric resistance. Perform analogous analysis for SPVACs. This will inform the magnitude of the FS opportunity.
C9	ASHP + Mech HR C9.1: CUHP + Mech HR C9.2: AWHP + Mech HR C9.3: VRF+ Mech HR	C9.1: Pursue some additional research to better quantify whether this system combination merits a measure package. Pursue with custom measures. C9.2: Pursue measure package (in conjunction with C1.2 and C10) C9.3: Pursue measure package (in conjunction with C1.3)

Measure No.	Name	Next Steps
C10	ASHP + WSHP	Pursue measure package, particularly for the condition with an AWHP replacing a gas boiler as part of a WAHP system. We recommend combining with a measure package (as additional offerings) drawing from C1.2 and C9.2. Research if additional combinations of ASHP + WSHP are appropriate for a measure package(s). Pursue with custom measures to gather data.
C11	ASHP + Mech HR + TES	Pursue with custom measures and perform additional research and data gathering activities that can lead to a future deemed measure package. This system configuration is a promising long-term all-electric solution for large buildings.
C12	ASHP + Waste fluid heat recovery	Pursue as offerings combined with other ASHP measure packages.
C13	Electric Resistance bundled with additional measures (envelope improvement, HVAC controls upgrade, solar PV, battery)	Pursue additional research into understanding the peak load impacts of ER heating and the savings impact of bundling ER with other measures.
C14	ASHP + Mech HR + TES in exterior zones and ER for interior zones	Pursue additional research into peak load impacts of ER heating, consider pursuing as a custom measure.
C15	EE/DG measures (Lower HWST, HVAC controls, building envelope improvement, PV+Storage, Solar Thermal assisted hot water)	Perform additional research into the interaction between EE/DG measures and space heating electrification.

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Appendix: Fields needed for CPUC Tools

Table 23: Fuel Substitution Test Fields

Parameter Name
Quantity (no of units)
EUL (years)
Install year
AStdWBkWh
AStdWBtherm
Baseline Desc
Measure Desc

Table 24: Refrigerant Avoided Cost Calculator (RACC) Fields

Parameter Name
Device Type
Device lifetime (yr)
Device installation year
Device retirement year
Active device refrigerant charge (lb)
Device refrigerant used
User-specified refrigerant GWP (applicable for user-specified refrigerant)

Table 25: Cost Effectiveness Test Fields

CET Field	Need to Gather
CEInputID	
PrgID	
ClaimYearQuarter	
Sector	Yes
DeliveryType	Yes
BldgType	Yes
E3ClimateZone	Yes
E3GasSavProfile	Yes
E3GasSector	Yes
E3MeaElecEndUseShape	Yes
E3TargetSector	Yes
MeasAppType	Yes
MeasCode	
MeasDescription	Yes
MeasImpactType	
MeasureID	
TechGroup	Yes
TechType	Yes
UseCategory	Yes
UseSubCategory	Yes
PreDesc	
StdDesc	
SourceDesc	
Version	
NormUnit	Yes
NumUnits	Yes
UnitkW1stBaseline	Yes
UnitkWh1stBaseline	Yes
UnitTherm1stBaseline	Yes
UnitkW2ndBaseline	
UnitkWh2ndBaseline	
UnitTherm2ndBaseline	
UnitMeaCost1stBaseline	Yes
UnitMeaCost2ndBaseline	
UnitDirectInstallLab	
UnitDirectInstallMat	

CET Field	Need to Gather
UnitEndUserRebate	
UnitIncentiveToOthers	
NTG_ID	Yes
NTGRkW	Yes
NTGRkWh	Yes
NTGRTherm	Yes
NTGRCost	Yes
EUL_ID	Yes
EUL_Yrs	Yes
RUL_ID	
RUL_Yrs	
GSIA_ID	
RealizationRatekW	
RealizationRatekWh	
RealizationRateTherm	
InstallationRatekW	
InstallationRatekWh	
InstallationRateTherm	
Residential_Flag	
Upstream_Flag	
PA	
UnitGasInfraBens	
UnitRefrigCosts	Yes
UnitRefrigBens	Yes
UnitMiscCosts	
MiscCostsDesc	
UnitMiscBens	
MiscBensDesc	
RateScheduleElec	
RateScheduleGas	
CombustionType	
MeasInflation	
Comments	