HVAC Fuel Substitution Measure Opportunities in California

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ABSTRACT

The California Electronic Technical Reference Manual (eTRM), the repository for deemed measure package (MP) information, currently includes three heating, ventilation, and air-conditioning (HVAC) fuel substitution (FS) MPs. A 2023 research effort focused on identifying incremental viable all-electric space heating technology options for future inclusion in the eTRM for residential and commercial buildings in California. That report researched currently available and emerging all-electric space heating technologies and system configurations, summarized ongoing California incentive programs for decarbonized space heating, and summarized relevant energy end-use benchmarking datasets that helped quantify the top opportunities.

That research effort identified eight residential and 15 commercial space heating electrification options. The options were then categorized based on shared characteristics and prioritized based on savings potential, market readiness, and regulatory feasibility. After the report was completed, our team presented the opportunities to the California Technical Forum (Cal TF) whose members are experts in the domain of deemed measure packages. The Cal TF members voted on their preferred measures for immediate inclusion in the eTRM based on their professional experience and judgment. For this paper, we sought to align the report with the U.S. Department of Energy (DOE) concept of "Market Readiness Levels" (MRLs) to further guide prioritization.

The results from the prioritization exercise and the Cal TF member scoring yielded clear trends. A top measure opportunity is commercial mechanical heat recovery, which is highly cost-effective using California metrics such as total system benefit and total resource cost. Solutions that leverage thermal energy storage for space heating are on the horizon and deserve promotion.

Introduction

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 (EE) performance in the measure case is achieved. FS is the process through which a baseline system containing natural gas-fired equipment (boilers, furnaces, or unit heaters) providing space heating undergoes a retrofit to an electric-powered alternative.

As of 2024, there are currently three HVAC FS MPs active in the eTRM. These measures cover the core HP offerings currently available in the market:

- SWHC044: Residential ductless HPs
- SWHC045: Residential central ducted HPs
- SWHC046: Commercial unitary air-to-air HPs

This is a good starting point, however, there are numerous other types of electric space heating options that could be investigated for potential additional MPs. Our research identified HVAC decarbonization (through gas-to-electric FS) technologies and prioritized them using quantitative and qualitative methods. Other adjacent measure ideas are discussed in passing (such as EE measures to support the actual space heating electrification) and should be the

subject of future investigation. Overall, there are three main categories of electric space heating, namely HPs, HR, and electric resistance that are discussed in this paper. The sections below are divided into residential and commercial measure opportunities. Each section begins with a table of the measures analyzed followed by a brief narrative explaining the measures. Certain measures that were not further analyzed have been omitted from this paper for brevity, the full report contains a narrative on every measure identified (Boyce et al 2023a). The report focused on insights from research for the California statewide electric emerging technology program (branded as "CalNEXT"), California codes and standards program research, review of major HVAC manufacturers' product offerings, other HVAC fuel substitution literature reviews, and day-to-day program implementation work of the authors' firms. Savings estimates and market impact potential estimates were heavily informed by California benchmarking studies including the Residential Appliance Saturation Survey (RASS) and the Commercial End-use Survey (CEUS) as well as California Energy Commission building stock floor area estimates.

HPs are an integral part of CA's decarbonization roadmap with the state setting a goal to install 6 million HPs by 2030. However, for commercial buildings, our research points to HR as being a critical component to all-electric systems and may surpass HPs as the first consideration in the "loading order" as market familiarity increases. In large buildings with internal zones that rarely encounter much if any space heating loads, electric resistance could be a compelling option in targeted applications to cost-effectively electrify space heating. This option would not only cost less than the HP equipment but would also avoid expensive piping in the building and avoid the need to leverage refrigerants which can contribute significantly to GHG emissions.

It is important to emphasize that complementary EE measures such as controls upgrades are a critical component of cost-effective space heating FS for both residential and commercial sectors. The scope of this project was to examine potential FS opportunities for the eTRM, which led the team down a path focused on "widgets" and equipment. But an essential precursor to any widget-based FS activity is to shrink the space heating load through building envelope and complementary EE measures first. If the identified measures are developed in the California eTRM, our strong recommendation would be to include requirements in the measure packages that ensure some level of EE and/or space heating load reduction has been accomplished prior to any incentivization of all-electric space heating equipment.

Residential Measures

The residential sector is further along than commercial when considering technological development and market readiness. Table 1 shows the full list of residential technologies that were investigated.

Table 1: Residential HVAC FS Options

No.	Measure Name	In eTRM?	Included in Projection
R1	Combination DHW + Space Heating HPs	No	Yes
R2	120V HPs	No	Yes
R3	Air to Water HPs (AWHP)	No	Yes
R4	Ground Source HPs (GSHP)	No	Yes
R5	Ductless HPs (SWHC044)	Yes	No
R6	Central Ducted HPs (SWHC045)	Yes	No

R7	Electric resistance (ER) heating	No	No
R8	Dual fuel HPs	No	No

R1. Combination DHW + space heating HPs

Combination HPs or "multi-function HPs" provide space heating and water heating with a single product. The basic design revolves around using a domestic hot water tank to store the heat needed for both space heating and domestic hot water. The technology is in a nascent stage in California relative to other global regions. One key barrier that could preclude a MP is that multifunction HPs lack a standardized test method and the existing performance ratings (UEF for water heating and HSPF2 for HPs) 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.

R2. Micro HPs (120V HPs)

The term Micro HP captures any 120V plug in HP such as window units, through the wall, portable HPs, etc. Plug-in systems enable a customer to electrify their space heating without the need for a contractor or a panel upgrade (Jenkins 2022). These systems have the potential to address decarbonization needs for the millions of gas-fired heating appliances in multi-family buildings across California. Such units offer several features such as compatibility with standard wall outlets, potential operation down to -13°F without backup electric resistance, and options for venting through the bottom of a window opening (CEE 2022).

R3. Air to water HPs (AWHP)

AWHPs can provide space heating and space cooling and are the most promising option for electrifying hydronic systems such as boilers. 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 (CEC 2021). This is due to a variety of factors including the widespread market acceptance of conventional central forced air HVAC systems and limited contractor familiarity with AWHPs. AWHPs, with a seasonal coefficient of performance (COP) of 1.7 – 3.0, can offer energy savings up to 47% over a typical gas condensing boiler (ENERGY STAR 2019-20). Overall, residential AWHPs are a promising FS technology but are unlikely to be heavily adopted in California since most of the single-family building stock is currently served by forced air furnace systems.

R4. Ground Source HPs (GSHP)

A GSHP consists of a HP connected to a series of buried pipes. There are four basic types of ground loop systems (DOE 2023). Three of these are closed-loop systems, namely horizontal, vertical, and pond/lake (immersed in pond water), while the fourth type is the open-loop, where water is circulated through the heat exchangers. After researching residential GSHPs, we conclude that 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 pursuing a full MP.

R5. Ductless HPs & R6. Central Ducted HPs

Residential ductless HPs (R5) are active in the eTRM (SWHC044) and are becoming very familiar to the market. This measure is applicable to older residential buildings that currently do not have a ducted central system and may not have air conditioning. A central HP (R6) distributes cooled and heated air throughout the home through ductwork. This measure is an excellent option for replacing existing central air conditioner + gas furnace combinations. These measures are compelling options for much of the residential built environment in California and have seen adoption in recent years though initiatives including Comfortably CA and TECH Clean California. A gap in these MPs that could be addressed in the short term is the lack of dedicated offerings for variable capacity heat pumps (VCHPs).

Commercial Measures

Commercial FS technologies are grouped together whenever there are similarities in the equipment's technical configuration or if efficiency performance is expected to be roughly similar. The ideal application of a commercial unitary HP 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/MP specifications may need to be tailored for each subcategory. However, for the purposes of this broad survey of all FS options, grouping the specific measure ideas by broad efficiency and technology patterns simplified the process of estimating energy savings and GHG impacts.

Partial FS is a type of measure where the existing natural gas equipment is partially offloaded but not entirely decommissioned. Our team is interested in pursuing these opportunities for commercial buildings as a stepping-stone to total electrification. Consider a building using a central plant with a water-cooled chiller (WCC) at the end of its effective useful life (EUL) but the boiler has some remaining years of EUL. The WCC system would be replaced by a HR chiller or combined WCC + HR chiller system, but the boiler would remain intact and operated at a reduced firing rate. Then later, the boiler could be replaced by an appropriate amount of AWHP equipment. Current CPUC FS 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 FS in one retrofit may not be financially feasible even with incentives. Table 2 details the full list of commercial technologies that were investigated and are then subsequently described in the follow up sections.

Table 2: Commercial HVAC FS Options

No.	Measure Name	In eTRM?	Solution Type	Included in Projection	Notes
C1	Air Source HPs (ASHP) • C1.1: Air to air HPs • C1.2: Air to water HPs (AWHP) • C1.3: Air source VRF HPs w/o HR	Yes (C1.1 only)	Partial or Full	Yes	C1.1 currently covered by SWHC046; we propose adding offerings for variable speed equipment.
C2	Mechanical HR (Mech HR) • C2.1: Air source HR chillers • C2.2: Water source HR chillers	No	Partial (usually) or Full	Yes	HR using the vapor-compression cycle.

	• C2.3: VRF with HR				
C3	Water Source HPs (WSHP) • C3.1 Water to air HPs • C3.2 Water to water HPs • C3.3 Water source 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 HP (GSHP)	No	Full	No	Presence of ground loop makes this a complete system, in contrast to C3.
C5	Thermal Energy Storage (TES)	No	Partial	No	
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 HR • C7.1: Exhaust air HR • C7.2: Wastewater HR	No	Partial	No	
C8	Single zone wall-mounted equipment • C8.1: Package Terminal HP (PTHP) • C8.2: Single Package Vertical HP (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	C1 + C2
C10	ASHP + WSHP	No	Full	Yes	C1 + C3
C11	ASHP + Mech HR + TES	No	Full	Yes	C1 + C2 + C5
C12	ASHP + Waste fluid HR	No	Full	No (future research)	C1 + C6
C13	Electric Resistance bundled with additional measures (envelope improvement, HVAC controls upgrade, solar PV, battery)	No	Full	No (future research)	C6 + additional measures
C14	ASHP + Mech HR + TES in exterior zones and ER for interior zones	No	Full	No (future research)	C1 + C2 + C5 + C6
C15	EE/DG measures • Lower hot water supply temperature (HWST) • HVAC controls measures (e.g., VAV box minimum airflows) • Building envelope improvement • PV + Battery Storage • Solar thermal assisted hot water	No	N/A	No (future research)	Shrinking space heating loads through EE is an important aspect of HVAC decarbonization. Adding distributed generation to offset the electric load addition of HPs/HR/resistance equipment will be important as well.

C1: Air Source HP (ASHP)

ASHP is an umbrella term for any equipment that draws or rejects heat to the ambient environment. ASHPs are an important component to a fully electrified space heating system but are typically best deployed only after EE and HR opportunities have been maximally leveraged. Included within this umbrella category are three subcategories based on the distribution network type:

C1.1 Commercial Unitary HP (CUHP)

Commercial unitary HPs (CUHP) or HP 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 paired with a warm air furnace is a candidate for an all-electric CUHP system. CUHPs are currently the only technology covered by an active eTRM MP (SWHC046). Similar to the residential ducted and ductless HP MPs in the eTRM, SWHC046 should be expanded to capture VCHPs. Dual fan dual duct and variable volume and temperature heat pumps are subcategories of this equipment and could be added as new offerings within SWHC046 or as standalone MPs.

C1.2 Air to Water HP (AWHP)

AWHPs are a subset of ASHPs and are physically similar to HP water heater (HPWH) equipment, though the term AWHP is typically applied to space heating whereas HPWH is typically applied to domestic hot water heating. AWHPs are significantly more expensive and occupy significantly more space than a gas boiler serving an equivalent load. However, due to the ubiquity of gas boiler hydronic reheat systems in California and the pace of innovation by manufacturers in this area, this technology is a promising candidate for a MP if the distribution system can be reconfigured for the lower hot water supply temperature (HWST) that AWHPs deliver relative to boilers. The 2025 edition of Title 24 Part 6 is expected to include a mandatory 130 °F limit to HWSTs including retrofits. This measure was found to be cost-effective by the Statewide CASE Team (Boyce et al 2023b).

C1.3 Variable Refrigerant Flow (VRF) HP

Air-source VRF HPs without HR are a frequently installed all-electric space heating option in commercial buildings. 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 HR capabilities. Air-source VRFs are better suited for small and medium buildings (e.g., below 50,000 ft^2), while water-source VRFs are more common in large buildings. Any deemed measure must consider factors such as the potential for refrigerant emissions and updated equipment testing requirements per the updated AHRI 1230-2021 standard. The CPUC refrigerant avoided cost calculator (RACC) will be a critical tool for properly accounting for the increased volume of refrigerant that is necessitated by VRF system layouts. If the RACC analysis indicates that the GHG emissions from refrigerant leakage in VRFs is not offset by the GHG reduction and EE, then a measure package will not be pursued.

C2: Mechanical HR

The term “mechanical HR” refers 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 allows HVAC systems to achieve very high COPs because the energy transferred across the evaporator as well as the condenser are counted 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. Mechanical HR is classified in this report as a partial FS solution as it can only be leveraged when both heating and cooling end loads are present. In a scenario with unbalanced cooling and heating loads, some dedicated cooling or heating solution may still be required. In a scenario with very low space heating loads and very high process cooling loadsa such as a data center located in a very mild climate, a HR chiller could fully satisfy the building space heating loads. Mechanical HR is a critical piece of the puzzle for commercial building FS, 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."

C2.1: Air Source HR Chillers

Air source HR chillers, sometimes referred to as 4-pipe ASHPs, are systems that include an air-to-refrigerant heat exchanger and use two supply pipes and two return pipes. The equipment can be configured to supply hot water using either ambient air or the waste heat from a chilled water loop as the heat source. An example product would be the Multistack ARA line. Systems that combine 2-pipe and 4-pipe AWHPs are an appealing electrification option for large buildings.

C2.2: Water Source HR Chillers

Water source HR chillers are a well-established product in the market. Historically, the equipment was primarily marketed as a water-cooled chiller with HR capabilities, implying that the cooling function takes priority over heating. A HR chiller can recover condenser waste heat by being in the condenser loop or 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 reducing the return water temperature before it enters the cooling only WCC equipment. Generally, HR chillers are most effective when they are first in the loading order, which ensures that the HR is maximized throughout the year.

C2.3: VRF with HR

VRF with HR 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 HR" applied to refrigerant-based multi-split systems. VRF with HR, however, comes with several major disadvantages, namely: large pressure losses due to long refrigerant lines throughout the building, thermal losses throughout the VRF distribution system, and the reality that VRF HR compressors are typically always going to be configured for high "lift" (since it must produce both ~40 °F and ~120 °F refrigerant to provide space cooling and space heating, respectively), limiting the opportunity for reset when portions of the building are in part-load. Furthermore, the efficiency metric for VRF HR, simultaneous cooling and heating efficiency (SCHE), is premised on the unrealistic assumption that half of the system is in cooling and the other half is in heating, which implies ultra-high COPs that are rarely ever achieved in the field.

C3: Water Source HP (WSHP)

This category is quite mature and encompasses any equipment with a water-to-refrigerant heat exchanger 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. WSHPs tend to be more complex than ASHPs and offer FS opportunities in large buildings for cascading systems that leverage a combination of ASHPs and WSHPs.

C3.1 Water to Air HP (WAHP)

Water-to-air HPs (WAHPs) are an established technology that exist in various capacities (Carrier's Aquazone line- up to 20 tons, Daikin's Large Capacity WSHP line and Trane's Axiom line go up to 25 tons) and have been installed throughout California for decades. Since any WAHP requires other equipment such as a cooling tower and/or AWHP to form a complete system, opportunities are discussed in section "C10: ASHP + WSHP."

C3.2 Water to Water HP (WWHP)

Water-to-water HPs are functionally very similar equipment to water source HR chillers (discussed in C2.2: Water Source HR Chillers). A product described as a "HR chiller" implies a cooling-dominated use case, whereas a "water to water HP" implies a balanced or heating-dominated use case. WWHPs 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 is popular in large buildings where roof space is insufficient for air source VRF equipment. Like WAHPs, the system could be all-electric if an AWHP were used instead of a boiler for reheat. As with the other subcategories in this section, opportunities for full systems are discussed in "C10: ASHP + WSHP."

C5: Thermal Energy Storage (TES)

Thermal energy storage (TES) with HVAC is an emerging technology and can be paired with other elements such as ASHPs and/or HR chillers to achieve complete electrification of space heating. TES for space heating has been identified as a promising technology to pair with HR because a HR unit can only provide utility to the building when simultaneous cooling and heating loads are present. The addition of TES diminishes that need, since heat rejection from a cooling load can be stored for later usage in space heating. This feature vastly improves the usefulness of mechanical HR, potentially making TES + mechanical HR 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). Water/ice-based TES can be designed around several temperature bands, summarized in Table 3.

Table 3: Comparison of Water-based TES Strategies

Type	Range (°F)	Advantages	Disadvantages
Hot	110-140	Avoids need for cascading system, enables peak heating load shifting, commonly applied to DHW systems.	Large tank requirement (because of low temperature delta), requires high lift chiller (less efficient), challenging in cold climates, low HWSTs
Condenser	40-90	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	32-65	Common technology on campuses, enables peak cooling load shifting	Large tank requirement (because of low temperature delta), relatively inefficient TES option
Ice	25-40	Low equipment volume requirements, enables peak cooling load shifting	Requires a high lift HR chiller (less efficient, cannot achieve high HWSTs), requires glycol (equipment lifetime impacts)

C6: Electric Resistance (ER) Heating

ER heating is much less efficient than HP and HR, and hence the research team did not research full ER heating as a measure opportunity. However, ER may offer advantages in targeted applications with minimal heating loads due to its affordability.

C7: Waste Fluid HR

The category consists of waste energy contained in a fluid departing the building that can be used to preheat or precool another fluid stream. Like mechanical HR, waste fluid HR technologies are a partial electrification measure, in that they would only offset a portion of a building's space conditioning needs. This type of heat recovery does not require the use of the vapor compression cycle to operate.

C7.1 Exhaust Air HR (EAHR)

EAHR transfers energy between building supply and exhaust air. This technology is most effective in extreme climates. In 2022, the Title 24 CASE Team proposed a measure requiring EAHR in some scenarios, depending on the hours of operation, climate zone, design airflow rate, and outside air requirements. Any measure for EAHR could be based on this Title 24 requirement but also include considerations such as improved enthalpy recovery ratios and fan performance criteria.

C7.2 Wastewater HR

Wastewater HR is a similar concept to EAHR, except instead of waste air, the wastewater stream is leveraged as a heat source or sink depending on building space conditioning needs. Wastewater temperatures vary (e.g., wastewater from showers or dishwashing may be warmer than sewage), so the exact heat flow diagram will vary depending on site conditions. Some manufacturers of this technology include Sharc Energy and Kemco Systems.

C8: Single Zone Wall Mounted Equipment

Single zone wall-mounted equipment encompasses two major categories of unitary HVAC equipment: package terminal air HPs (PTHP) and single package vertical HPs (SPVHP).

C8.1: Packaged Terminal HP (PTHP)

A PTHP is a self-contained commercial HVAC unit commonly found in hotels, motels, senior housing facilities, hospitals, condominiums, apartment buildings, add-on rooms and sunrooms. 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 FS measure.

C8.2: Single Package Vertical HP (SPVHP)

SPVHP systems are like PTHPs and other through-wall systems with the main difference being the orientation of components with the condenser and evaporator coils are stacked

vertically instead of horizontally. SPVHPs can be an attractive FS option for buildings that use SPVAC systems with gas heat or for applications that require vertical packaged systems such as portable classrooms.

C9: ASHP + Mech HR

Combining mechanical HR with air source HPs is an increasingly popular option for nonresidential buildings pursuing all-electric space heating as the two elements can combine to constitute a complete all-electric system. The benefit of this system configuration is that when leveraged appropriately, the mechanical space conditioning equipment can be downsized and/or experience fewer runtime hours when HR is present. The primary downside to this configuration is that cooling and heating loads must overlap for the HR equipment to be used effectively. This measure is most suited to buildings with constant process loads such as hospitals, data centers, and mixed-use buildings.

C10: ASHP + WSHP

There are many existing water to air heat pump systems currently installed, many of which require a gas boiler to supply hot water. Replacing the boiler with an AWHP would constitute a complete all-electric system. System configurations may include AWHPs, WWHPs, WS-VRFs, and WAHPs depending on specific building needs.

C11: ASHP + Mech HR + TES

As stated earlier in Section C1, ASHPs are an important component to a fully electrified space heating system but are typically best deployed with a combination of HR and TES. Following are the two novel concepts that address these barriers:

- Taylor Engineers have developed a novel system, Time Independent Energy Recovery (TIER), that leverages TES + HR, resulting in an all-electric system that operates all chillers in low-lift conditions. The cooling chillers have a lift envelope of 40°F chilled water supply temperature to 80°F condenser water leaving temperature, while the HR chillers have a lift envelope of 60°F evaporator supply temperature to the active HWST 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 for most of the year.
- Trane's Storage Source HP (SSHP) is a variation of ice TES. In an all-electric configuration, ice is melted during winter afternoons when many nonresidential buildings are in cooling dominated in California and nationwide and created during winter morning warm-up using a high-lift HR chiller system. Ice storage is an appealing option relative to other types of TES in at least two situations: very limited space requirements and very cold climates where maximizing storage capacity is a priority.

Scoring Methodology and Overall Results

The primary focus of this work was to identify the pool of potential HVAC FS measures that could be added to the CA deemed portfolio in the coming years. Ideally, all of the identified measures would be added, but due to limited bandwidth, it is necessary to prioritize the measures so that they can be added in phases. Deemed measure proposals were scored using the following criteria, with higher scores indicating better feasibility for a MP.

1. Source energy Savings Potential (20 points): The percentage of energy savings of the measure technology compared to the baseline technology. 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. The least efficient technology that was scored was an air source heat pump without heat recovery, which is typically the code minimum type of heat pump in the market.
2. Market Readiness Level (30 points): The MRL, as determined by the team's judgment and understanding of the current status of the measure in the marketplace and level of standardization. The MRL is reset to 1-6 and then multiplied by five for the purposes of scoring the measures.
3. Regulatory Barriers (20 points): 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. For example, VRF is currently still subject to a CPUC disposition from 2017 which required 15% above-code EER levels, which is currently not capable of being met by sufficient equipment in the market to justify a measure package. On the other hand, a regulatory boost for VRF will occur when it becomes one of few prescriptive multizone options when Title 24-2025 takes effect, so VRF will likely become more familiar by HVAC stakeholders as a result.
4. CA Market Size (30 points): The percentage of statewide square footage or dwelling units that the measure could be installed in, which 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.

A maximum of 100 points is possible, with the relative weighting of each category informed primarily by our professional judgment based on our experience with developing deemed measure packages (and the various aspects that could derail or slow down these efforts). The qualitative scoring values were strongly influenced by the team's MRL estimate for each measure. San Diego Gas and Electric (SDG&E) is the California statewide HVAC program implementation lead. The statewide HVAC lead role gives the team significant expertise and insight into HVAC measure readiness and potential barriers. Energy Solutions has been developing HVAC MPs in California for over 20 years and implements HVAC programs in 14 states as of 2024. The original report has a supporting workbook with additional details on the quantitative aspects of the scoring (Boyce et al 2023a).

Market Readiness Levels (MRLs)

DOE has adapted the concept of Technology Readiness Levels (TRLs) ranging from 1 – 9 to apply to energy systems and measures (DOE 2011). The categories span the most nascent early stage of a new technology to a mature product that is ready to enter the market. DOE has extended the concept of TRL to MRL, with 6 categories ranging from MRL 10 – 15. The only documentation the authors could find on this framework is located at: https://www.energy.gov/eere/buildings/technology-market. We expanded upon this graphic by describing the characteristics and intervention tactics of each MRL, a summary of which is shown in Table 4.

Table 4: Energy Solutions Elaboration of DOE MRL Framework

MRL	Description	Tactics	Market Share Range[a]
10	The technology is proven but unknown to the market.	Additional demonstrations, White Papers, Case Studies, plan initial test procedure scope.	0-3%
11	Public sector (including regulated utilities) promotes the technology on a site-specific basis	Custom or NMEC incentive programs, ENERGY STAR Spec development, development of code performance compliance pathways	3-6%
12	Scaled deployments of technology. Large institutional procurements.	Scaled deployments, focused Pilots, Large institutional procurement	6-13%
13	Market accepts technology, financial barriers prevent universal adoption	Traditional EE programs to target Key Market Actors (Midstream, Retail distribution, new construction, sector-specific programs-SEM)	13-25%
14	Technology is financially competitive with its predecessor	Voluntary C&S: ENERGY STAR, Reach Codes, Procurement standards, Benchmarking	25-50%
15	Technology is required by government regulation	Prescriptive and Mandatory C&S: Codes, Standards, BPS	50-100%

[a] the market share relative to the upper limit of what is achievable given the technology's characteristics and constraints.

Any attempt at categorizing a given measure with a label such as MRL is going to inherently come with some judgment, but the effort is worthwhile in the sense that it helps clarify which types of program interventions are appropriate and also what levels of standardization are expected of the measure relative to its market share. Our team considered a range of factors when assigning the MRL to each measure, including the number of vendors that can produce the technology, the measure's level of standardization (such as test procedure and energy conservation standard development, rulesets in code compliance software, and the existence of any other performance specifications), our understanding of the incremental measure cost compared to the existing incumbent technology, and our understanding of the market share. We also factored in California history such as incentive programs and CPUC resolutions.

Our view is that by approximately MRL 12, the measure is typically a good candidate for a deemed measure package. In California, a deemed incentive program requires a measure package. The initial version of the measure package can include a limited number of offerings at first to capture the core use cases of the measure which can then be expanded over time. Creating the initial analysis for a measure package helps not only achieve its typically understood purpose of allowing incentive program operation (e.g., moving the measure from MRL 12 to MRL 13), but it also paves the way for a follow-on C&S measure (e.g., MRL 14 and 15). Creating a

deemed measure package with its C&S destination in mind helps ensure that the process of market transformation for the measure is accelerated as much as possible.

In some cases, the various factors identified above were not in alignment regarding the measure's estimated MRL. In these cases, the team used its judgment to estimate the MRL. For example, if a measure is mature in a region outside of CA, but has low market share in CA, then its level of standardization (due to other regions' needs) may be out of alignment with its market share in CA. When this occurred, the factor considered more important for the prioritization of deemed measure packages prevailed, which in this case would be the standardization (making the measure easier to "deemify"). In other contexts, the market share may be the more important factor.

Measure Prioritization and Cal TF Member Voting Results

In our view, nearly all of the identified opportunities (with a few exceptions, e.g., residential ER heating) should be added to the eTRM once the measure has achieved enough of a presence in the market and to justify a deemed MP. However, time and resources are limited, so we felt the need to devise methods to prioritize the measures. The two primary methods that we relied on to prioritize the measures was our own internal methodology and then we brought these measures to the Cal TF members where they voted on each measure individually based on their professional judgment. The results of our prioritization exercise are presented in Table 5 and Table 6. We believe that the results directionally indicate which measures are a higher priority for pursuing eTRM MPs.

Table 5: Scoring Results for Residential Measures

Measure Number/Name	MRL Estimate	Source Energy Savings (20)	MRL Points (30)	Regulatory Barriers (20)	CA Market Size (30)	Total Score (100)
R1/Combi HP	10	20	5	5	30	60
R2/120V HP	11	0	10	20	28	58
R4/GSHP	11	18	10	15	3	46
R3/AWHP	12	11	15	10	3	39

Table 6: Scoring Results for Commercial Measures

Measure Number/Name	MRL Estimate	Source Energy Savings (20)	MRL Points (30)	Regulatory Barriers (20)	CA Market Size (30)	Total Score (100)
C1.2/AWHP	11	3	10	15	30	58
C1.3/AS-VRF	13	3	20	5	30	58
C2/Mech HR	11	12	10	10	16	48
C9/ASHP+Mech HR	11	11	10	10	18	48
C10/AWHP+WSHP	13	11	20	20	6	46
C8/PTHP/SPVHP	11	0	10	20	0	41
C11/ASHP+Mech HR+TES	10	20	5	5	6	36

In addition to prioritizing the measures ourselves, the measures were presented at the November 2023 Cal TF meeting where members voted on how ready the measures were for

deemed measure packages.[1] The Cal TF describes itself on its homepage as: "a collaborative of experts who use independent professional judgment and a transparent, technically robust process to review and issue technical information related to California's integrated demand side management portfolio." The results of this activity can be found in Figure 1 and Figure 2. There were 15 participants in the voting exercise.

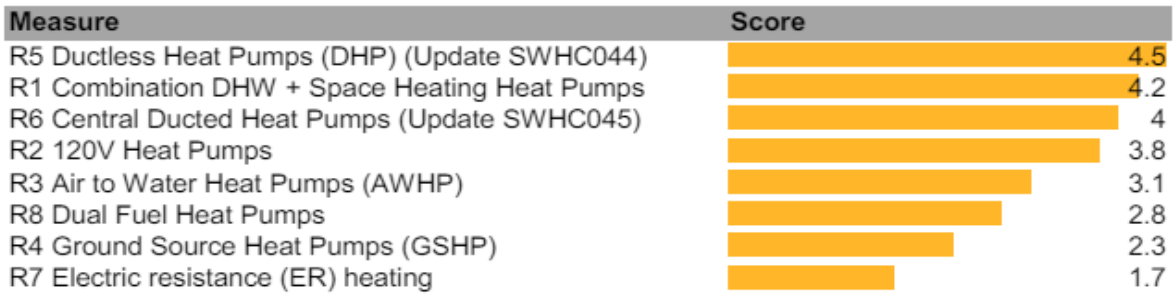

Figure 1: November 2023 Cal TF Residential Scoring Results

The residential voting results show that there is significant interest among the Cal TF members in updating the existing measure packages to include dedicated offerings for VCHPs as well as the more novel concepts of combined domestic hot water and space heating heat pump systems as well as 120V "micro" heat pumps. These results align with our team's rankings based on the methodology that we developed.

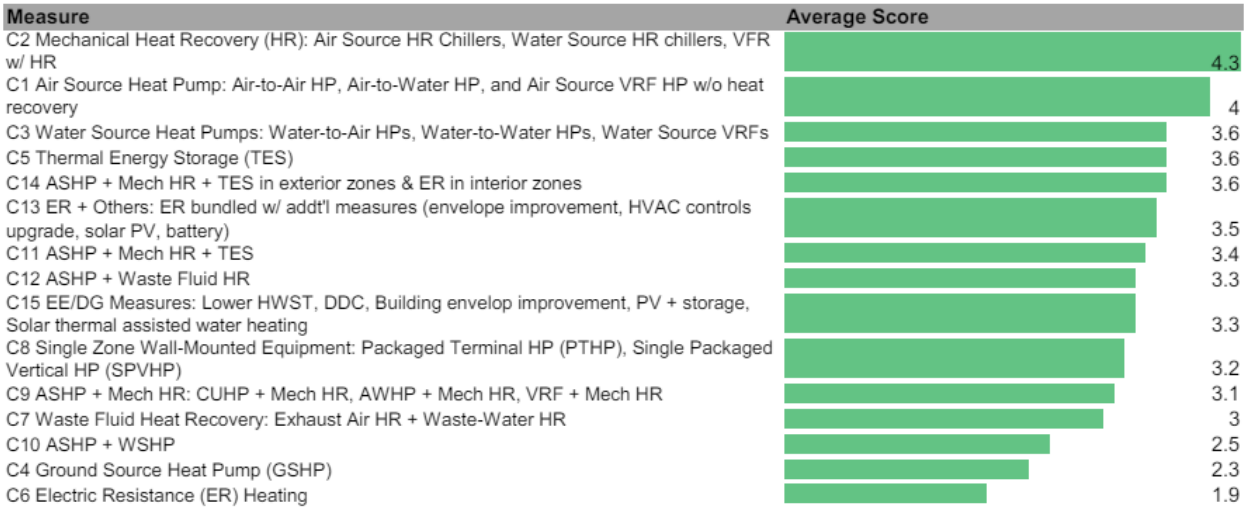

Figure 2: November 2023 Cal TF Commercial Scoring Results

The commercial voting results show the most interest from Cal TF members for measures that would cover mechanical HR and the various ASHP and WSHP options. When judging the results of this crowd-sourced approach with the team's rankings from our methodology, there are some clear trends, namely the preference for prioritizing mechanical HR and ASHP measures for addition to the eTRM.

[1] https://static1.squarespace.com/static/53c96e16e4b003bdba4f4fee/t/65579eb2eaa1b810b1b30d90/1700241074466/Cal+TF+Meeting_2023-11-16_Slido+Poll+Results.pdf.

Conclusion and Next Steps

This research identified HVAC FS technologies missing from the eTRM and prioritized them using quantitative and qualitative methods. This domain is rapidly evolving, and this work ultimately amounts to a snapshot in time. These opportunities range from emerging technologies to more mature commercially available technologies. There are numerous upcoming FS opportunities for both the residential and commercial sectors which are not currently captured in the eTRM. In our view, nearly all the measures that we identified should at some point be considered for inclusion in the eTRM, but due to limited resources, they should be added in phases. Table 7 shows this study's recommendations for top priority new HVAC FS MPs. This is a synthesis of our prioritization exercise, the Cal TF members' voting results, and our judgment of what constitutes the most significant gaps that can be closed in the eTRM. We recommend pursuing these MPs in the short term and conducting additional research on other opportunities for future MPs in the medium term.

Table 7: Recommendations for New HVAC FS Deemed MPs

No.	Measure Name	Code(s)
1	Add VCHP offerings to existing FS MPs (SWHC044, SWHC045, SWHC046)	R5, R6, C1.1
2	Air to Water HP (with and without Mechanical HR; with and without Exhaust Air HR, as a standalone system and as part of a Water Source HP retrofit)	C1.2, C9.2, C10, C7
3	Mechanical HR (e.g., HR Chillers)	C2.1, C2.2
4	Micro HPs (120V)	R2

The California emerging technologies program, CalNEXT, provides an appropriate vehicle for additional research on any measures that are not ready for immediate inclusion in the eTRM. As noted above, assigning the measure opportunity a MRL value and then tracking that opportunity's status over time will further assist in the decision-making process regarding "deemed readiness."

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