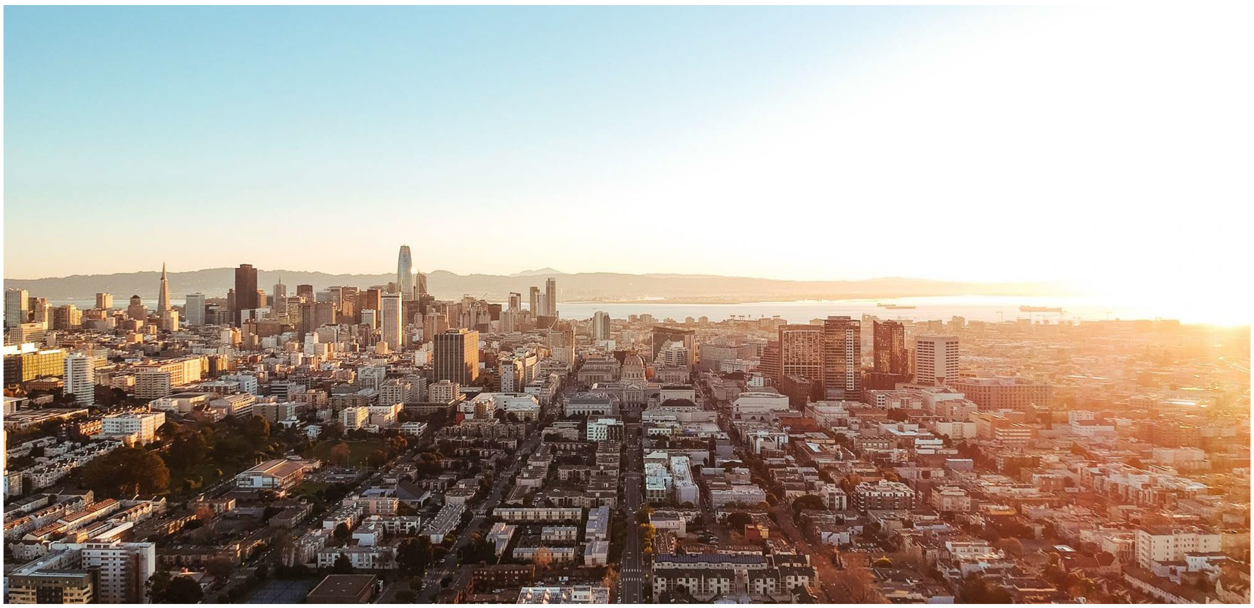
# Propane (R-290) Air-to-Water Heat Pump (AWHP) Market Study
# Final Report

**ET23SWE0041**



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## Disclaimer

# Executive Summary

Heat pumps are pivotal in decarbonizing buildings and phasing out fossil fuel-based heating systems. However, their widespread adoption has unintended environmental consequences from the release of fluorinated refrigerant gases (HFCs, HFOs) into the atmosphere. These substances have high- and mid-GWP (Global Warming Potential) values and are associated with forming per- and polyfluoroalkyl substances (PFAS), which persist as harmful environmental pollutants. Eliminating emissions from fluorinated refrigerants is a critical aspect of climate action, with phasedowns implemented at national, regional, and international levels over the last decade. During that time, the use of natural PFAS-free refrigerants has expanded in the HVAC and refrigeration sector, with propane-based (R-290) heat pumps emerging as the lead single-family residential market option. R-290 stands out due to its low GWP compared to other refrigerants and its exceptional efficiency and cost-effectiveness.

Despite being readily available in European and Asian markets, R-290 heat pumps face restrictions in America due to flammability concerns, and current US standards and building codes have created a confusing web of obstacles related to R-290 adoption.

This market study investigates these challenges, and seeks to demonstrate the market potential and suitability of R-290 heat pumps—specifically monobloc air-to-water heat pump (AWHP) designs— as an end-to-end decarbonization solution for domestic heating, cooling, and hot water needs across California's single-family residential market. It also illustrates how the speedy adoption of R-290 AWHP as a replacement option for central and window air conditioning and fossil fuel heating systems is likely the fastest means of achieving California's HFC reduction target of 7.5 million metric tons of carbon dioxide equivalent ($MTCO_2e$) by 2030.

To support these facts, this Report details key technical background considerations and analysis activities alongside pertinent secondary research findings on AWHP technology, market trends and barriers, and relevant policies. These insights provide a clear set of steps for policymakers to address current regulatory and code confusion and a technology roadmap that utilities, manufacturers and other key players can leverage to bolster product availability and improve awareness and knowledge on R-290 AWHP design and installation best practices across California.

Secondary research was conducted to learn the specifications of currently available R-290 AWHP products and their best application to the California HVAC market, followed by an analysis of technology adoption's potential energy and greenhouse gas emissions impacts. R-290 AWHPs are available and popular in other countries, so research was conducted to understand what considerations influence market uptake internationally. Finally, relevant regulations, standards, and codes were reviewed to understand the market's barriers to R-290 AWHPs in the US.

Research and analysis revealed a tremendous opportunity to promote R-290 AWHPs in single-family homes, and that the technology yields significantly more energy and greenhouse gas emissions savings compared to competing heat pump designs. International trends also illuminated several potential steps that California could take to remove existing regulatory barriers to R-290 AWHPs being an immediate decarbonization solution for the residential market. Recommendations include working with aligned partners to update California's code requirements to reference International Electrochemical Commission (IEC) standards for R-290 equipment. Authorities Having Jurisdiction

(AHJs), including municipal agencies, and specific government officials are also called out as critical players, given their legal power to enforce codes, standards, or require specific above-code regulations and mandates within a jurisdiction. Manufacturers are encouraged to leverage Nationally Recognized Testing Laboratories (NRTLs) to obtain certification of R-290 products for installation in California.

Further research is also recommended in the form of field demonstrations of R-290 AWHPs, a market study on commercial-sector R-290 AWHP technology, and regional market and sales impact assessments. Research collaboration among energy efficiency organizations is also recommended by introducing an alliance or joint public report effort to promote ultra-low GWP AWHP technology.

## Abbreviations and Acronyms

| Acronym | Meaning |
|---|---|
| AC | Air Conditioning |
| AHJ | Authority Having Jurisdiction |
| AIM | American Innovation and Manufacturing |
| ANSI | American National Standards Institute |
| ASHP | Air Source Heat Pump |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| ASTM | American Society for Testing and Materials |
| AWHP | Air-to-Water Heat Pump |
| CARB | California Air Resource Board |
| CEC | California Energy Commission |
| CPUC | California Public Utilities Commission |
| DAC | Disadvantaged Community |
| DOE | Department of Energy |
| DHW | Domestic Hot Water |
| EN | European Standards |
| EPA | Environmental Protection Agency |
| GHG | Greenhouse Gas |
| GWP | Global Warming Potential |
| HFC | Hydrofluorocarbons |
| HFO | Hydrofluroolefin |
| HPHWH | Heat Pump Hot Water Heater |

| Acronym | Meaning |
| --- | --- |
| HTR | Hard To Reach |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IEC | International Electrotechnical Commission |
| IOU | Investor-Owned Utility |
| IPCC | Intergovernmental Panel on Climate Change |
| LADWP | Los Angeles Department of Water and Power |
| kWh | Kilowatt-hours |
| $MTCO_2e$ | Metric Tons of Carbon Dioxide Equivalent |
| MWh | Megawatt-hours |
| NREL | National Renewable Energy Laboratory |
| OEM | Original Equipment Manufacturer |
| PFAS | Per- and Polyfluoroalkyl Substances |
| RMP | Refrigerant Management Program |
| SMUD | Sacramento Municipal Utility District |
| SNAP | Significant New Alternatives Policy |
| TSB | Total System Benefit |
| UL | Underwriters Laboratories |
| VRF | Variable Refrigerant Flow |

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# Introduction

California is decarbonizing space heating and domestic water heating in buildings across the state. Air-to-water heat pumps (AWHPs) are an excellent decarbonization technology due to their ability to convey heating or cooling while supplying domestic hot water and their potential to provide thermal storage to shift energy use away from peak demand time periods. In building applications that are a good fit for an AWHP—such as replacing traditional gas or oil boilers and furnaces—the global warming potential (GWP) of the system's refrigerant must also be included in the climate impact analysis.

Due to pressure generated by the US American Innovation in Manufacturing (AIM) Act, domestic manufacturers are transitioning to mid-GWP working fluids by using slightly flammable synthetic refrigerants such as R-32 or R-454B in new heat pump products. However, while these mid-GWP refrigerants can reduce greenhouse gas (GHG) emissions from previous high levels, an ultra-low GWP natural refrigerant can eliminate those emissions. As California looks towards a low-carbon future, natural refrigerant heating, ventilation, and air conditioning (HVAC) systems are a critical investment. They are future-proof against new regulatory restrictions on refrigerant GWP and against future legislation to control poly-fluoroalkyl substances (PFAS) and should be prioritized above synthetic refrigerants wherever possible.

Propane[1] (R-290) is one ultra-low-GWP natural refrigerant poised to impact the US heat pump market significantly. Its superior energy efficiencies, economic efficiencies, and environmental characteristics have already been documented in international markets, where AWHPs dominate, and R-290 heat pump products have gained significant traction. Several manufacturers plan to bring these products to the US, however, confusion over perceived regulatory and building code obstacles alongside clarity around installation and maintenance requirements has created uncertainty, making it difficult for utilities to incentivize.

The objectives of this market study were to review the regulatory and market foundation for the adoption of AWHP in the residential sector in California and to elevate the selection of R-290 AWHPs as a long-term one-step decarbonization solution. This Report details key technical background considerations and analysis activities alongside pertinent secondary research findings on AWHP market trends and the advancements of R-290 AWHP from both US and non-US-based studies. These insights provide a clear set of steps for policymakers to address current regulatory and code confusion and a technology roadmap that utilities can leverage to bolster product availability and improve awareness and knowledge of AWHP design and installation best practices among California's HVAC technicians.

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[1] Fuel-grade propane is sometimes used to provide a combustion heat source for an "absorption" type heat pump (USEPA 2023c), which is not a relevant technology for the purposes of this study nor a beneficial one with respect to climate emissions as compared to conventional AWHPs. In this report, VEIC will discuss propane exclusively as a refrigerant in closed vapor compression cycle HVAC technologies, and will only refer to AWHPs that use propane (R-290) as the thermodynamic working fluid. Also, in some international markets, AWHPs are referred to as "air-source heat pumps" or ASHPs, while in domestic markets, the term ASHP can refer to HPs that perform air-to-air rather than air-to-water heat transfer. Therefore, the primary technology in question will be discussed using the term air-to-water heat pump or AWHP.

# Background

## Overview of Air-to-Water Heat Pumps

### AWHP Configuration

Heat pumps use the mechanical vapor compression cycle and the phase change properties of a working fluid, or "refrigerant," to transfer energy. AWHPs work similarly to air-to-air heat pumps, but heat transfer occurs between refrigerant and water instead of refrigerant and air.

The main elements of an AWHP system include a heat pump unit, an indoor distribution system, and heating or cooling emitters such as fan coils, panel radiators, or floor radiant piping. The heat pump unit includes an outdoor fan with a coil heat exchanger, a compressor, and a refrigerant circuit connected to the refrigerant-to-water heat exchanger.

AWHP systems are arranged in either a split system configuration or as a packaged monobloc system. Split systems are configured with a refrigerant line set connecting the outdoor unit (which contains the compressor and fan) to the indoor unit where the refrigerant-to-water heat exchange occurs. Monobloc AWHPs have a factory-charged and sealed refrigeration circuit contained in a single compact unit installed outside the building. The refrigerant-to-water heat exchanger is located in the monobloc unit. Insulated water or water-glycol piping connects the heat exchanger directly to the interior distribution system or a secondary heat exchanger. Glycol may be added to water lines to prevent freezing in the hydronic pipelines. When an AWHP is installed, it is also considered best practice to integrate thermal storage with sensors and control point connections into the system.

A monobloc AWHP is illustrated in Figure 1 below. Monobloc configurations are generally more common in AWHPs than split system arrangements and monobloc equipment presents an opportunity to overcome the barrier of using R-290 as a refrigerant by containing the entire refrigerant charge in a factory-sealed outdoor unit.

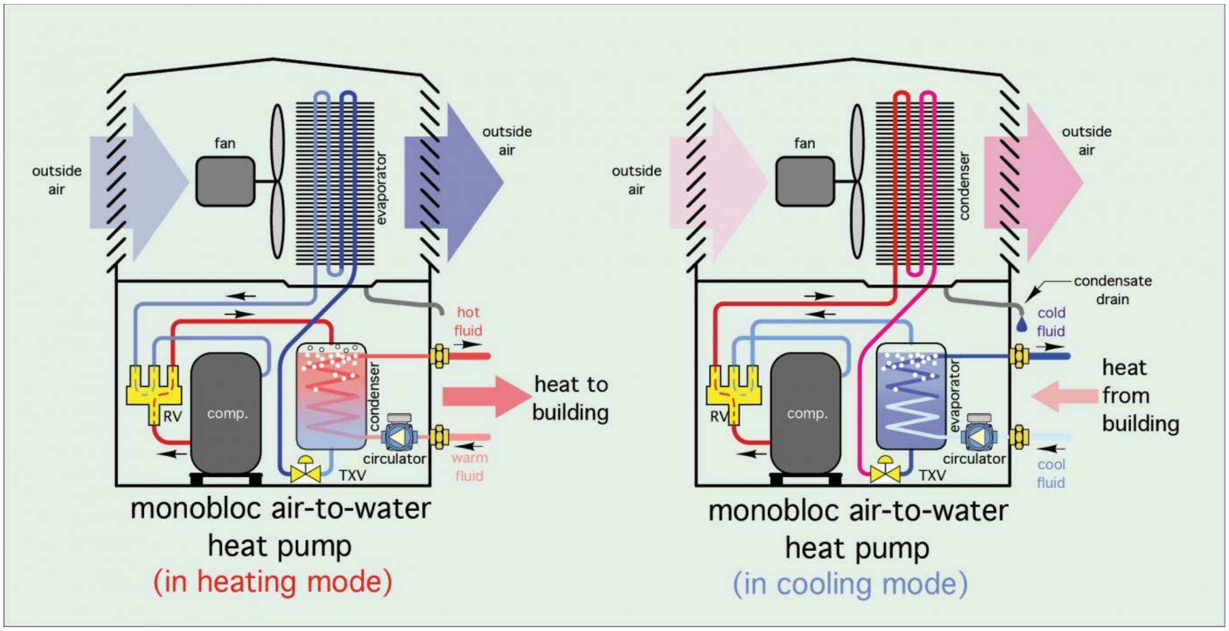


**Figure 1: Simplified diagram of an AWHP monobloc outdoor unit configuration connected via hydronic lines to an indoor space.**

Source: (Idronics 2020)

While this report focuses on displacing fossil fuel combustion using AWHP hydronic heating, a significant benefit of AWHP systems is their ability to provide heating and cooling efficiently. As such, this technology also provides a valuable alternative and displacement option for central air conditioning or window air conditioning (AC). An AWHP can cool and dehumidify using the reversing valve in the refrigerant cycle supply line.

## R-290 AWHP Configuration

Currently available R-290 AWHP products contain all refrigerant in an outdoor packaged unit that is charged and sealed at the factory and designed to operate in a monobloc configuration. Appropriately trained professional technicians must install all heat pumps, but monobloc systems designs do not require refrigerant-certified professionals because there are no in-field refrigerant connections. This is an essential feature for the installation of R-290 AWHPs. The monobloc design alleviates concerns about R-290's flammability by eliminating the risks associated with a refrigerant leak from a field flare or brazing connection on a refrigerant line-set. Also, it opens up the potential to add capacity to the clean energy workforce (detailed later in this report).

## Climate Benefits of AWHPs

Demand for electrification of HVAC systems is increasing across California, guided by the Electric Program Investment Charge Program (2021-25) and driven by multiple policies, including SB 350 and AB 3232, alongside California Energy Commission (CEC) funding directed at accelerating and expanding the use of efficient heat pump installations to meet building heating, cooling, and domestic hot water (DHW) needs.

In 2020, a California Public Utilities Commission (CPUC) study found that air-source heat pumps (ASHPs) comprised 4 percent of existing residential space heating systems and approximately 20 percent of the state's new heating and cooling installations. More recent studies show this growth in ASHP adoption but do not identify AWHPs (CPUC 2022). As an emerging technology type, the AWHP market is still tiny (Frontier Energy 2021). However, AWHPs present a variety of energy-saving options for a home's heating, cooling, and hot water system. They can simultaneously electrify and decarbonize a residential space, making them a crucial and effective tool for rapid decarbonization (Billimoria et al., 2018).

### Grid Benefits of AWHPs

While accelerated market adoption of heat pumps can help cities meet their decarbonization goals through practical building electrification, it does not address the broader decarbonization goals of the grid. When the electrical grid is not powered using 100 percent renewable sources, a switch from an oil furnace or gas boiler to an ASHP merely shifts the use of fossil fuels from the building upstream to the power plant. It also adds additional demand strain to the grid.

California has already made significant progress towards a cleaner energy grid. Per SB 100, approximately 60 percent of the state's electricity mix comes from carbon-free sources. However, this is still far from the state's aggressive goal of carbon-free by 2045. California is also looking to double its current levels of demand flexibility to 7000 megawatts (MW) by 2030 and to power up to seven million homes without adding any new power plants (SB 846).

Investing in flexible load-shifting measures as a form of demand response will be a crucial strategy in these efforts. Flexible load shifting moves electricity consumption to periods that make the most sense for the customer and for the grid by rebalancing the current mismatch between times of peak solar generation and electricity demand and by reducing the carbon emissions of energy produced by moving from high- to low-demand periods (Billimoria et al. 2018).

As a technology, AWHPs have more potential than air-to-air equipment for load-shifting capabilities when systems include thermal energy storage (TES), as is a recommended best practice (J. Siegenthaler 2022b). TES decouples heat pump electric demand from the building load. This presents a massive opportunity for further decarbonization by shifting the time-of-use (TOU) of the system's energy demand to when electricity is cheaper and has a lower carbon intensity. It can provide a meaningful longer-term grid forecast benefit.

A recent modeling assessment prepared for the U.S. Department of Energy's Building Technologies Office showed that the combination of AWHPs with TES could be highly effective at moving cooling energy use to non-peak hours, with over half of non-storage cooling energy usage shifted from on-peak to off-peak, even in scenarios with short, 3-hour on-peak peak periods (Becker, Hoeschele and German 2023). A field study evaluation of residential AWHP serving space heating loads and domestic hot water loads with TES is currently being conducted under ET23SWE0050.

## R-290 AWHP - Advantages

### Climate Advantages

To drive down GHG emissions, natural refrigerants such as R-290 are the long-term solution versus synthetic refrigerants for all types of HVAC systems, including AWHPs. This is true relative to both legacy Hydrofluorocarbons (HFCs) with "high" GWP values and the mid-GWP synthetic substances being proposed as AWHP solutions by US manufacturers, which have GWP values hundreds of times higher than carbon dioxide (ASHRAE 2022c). R-290's GWP was recently reclassified by the Intergovernmental Panel on Climate Change (IPCC) AR6 report to have an even lower GWP than previously calculated—an overall 100-year GWP of 0.02 (IPCC 2021)—making it a future-proof refrigerant option against any required GWP limits in the near or far future.

While there are Hydrofluroolefin (HFO) refrigerants with low GWP values, such as HFO-1234yf, these substances degrade in the atmosphere into trifluoroacetic acid (TFA), which is a PFAS, also commonly known as a "forever chemical" due to its inability to break down naturally. Low-GWP HFOs are not available in ASHP or AWHP products at this time. Still, even if they were, they accumulate in the environment and the bodies of people and animals, as has been proven by international scientists. Natural refrigerants such as R-290 do not create harmful PFAS and are future-proof against regulations banning fluorinated PFAS precursor substances such as HFOs. Due to the PFAS accumulation in the environment, the European Chemicals Agency recently announced the intent to ban HFOs and most other fluorinated refrigerants beginning in 2025 (ECHA 2023)

R-290 also has favorable thermodynamic properties for heat transfer that can lead to energy savings. Its relatively high latent heat of vaporization makes it a more efficient working fluid than the most common synthetic refrigerant types on a mass flow basis (ASHRAE 2022d). This characteristic results in higher volumetric capacity, meaning that for identical component sizes, the heating or cooling capacity of an R-290 system is significantly larger (Nawaz et al., 2022). Research has shown that R-290 can yield better overall performance and energy savings in HVAC&R applications over comparable systems that use other refrigerants (NASRC 2022, Purohit et al. 2022; Cipres 2020, Hwang, Jin, and Radermacher 2005, Elbel, Visek and Hrnjak 2016, Palm 2008, Nawaz, et al. 2022, Capanelli 2021). This fact was first highlighted by AHRI's Low-GWP Alternative Refrigerants Evaluation Program (AREP) in 2015 (Stöben et al, 2016) and further documented by a database study that compared R-290 AWHP performance efficiency to other mid-to-low GWP AWHP systems already installed across the EU (Cao & Hwang, 2022).

Further, it has been generally acknowledged that additional cost and embodied carbon could be saved if an R-290 AWHP replaced the heating appliance in an existing hydronic distribution system because R-290 AWHP systems can supply hot water up to 160°F. This feature makes them more compatible as a replacement for a fossil fuel boiler compared to competing technologies with synthetic-refrigerant-based AWHPs or ground-source heat pumps, as these cannot supply water hotter than 140°F (Energy Star 2019; Mitsubishi Electric 2023; Idronics 2020; J. Siegenthaler 2022a).

## Installation Advantages

For California to meet its 2045 zero carbon emissions goal, it must replace every home's fossil fuel-based furnace and gas water heater with heat pump-based systems. This is a significant challenge, made more challenging when dealing with homes built before the 1980s limited by 100- or 125-amp electrical services which cannot support the installation of multiple air-to-air heat pumps and a heat pump water heater, let alone electric cooking appliances without significant investments in upgrading electrical services (Frontier Energy 2021).

An advantage of any AWHP technology is its ability to reuse the existing heating or cooling distribution infrastructure, such as radiant floor, baseboard or panel radiators or ductwork. This retrofit strategy saves costs on distribution equipment and labor, and it also saves significant money and disruption for the homeowner. A single AWHP unit reusing a Central AC system's distribution circuit also does not need to upgrade electrical services as may be required for an air-to-air heat pump plus heat pump hot water heater (HPHWH) design.

California homes with central AC and furnaces will have existing ductwork to deliver heating and cooling to the interior space (NREL 2023). AWHPs can be integrated into systems with ductwork distribution. This is done with either a new air handling unit or the addition of a hydronic coil in an existing furnace. It can sometimes be corrected when existing ductwork is determined to be undersized to meet space setpoints. AWHPs also provide an opportunity for additional emitters, such as towel warmers and panel radiators for heating only or fan coil units for heating and cooling. In systems where a boiler provides hot water to hydronic distribution, the existing emitters can continue to be utilized at a lower supply water temperature. Additional emitters may be required to meet space set points.

Similarly, AWHP systems can include an integrated indirect domestic hot water heater and provide water heating year-round. Water thermal storage and buffer tanks, and other emerging thermal storage such as phase-change materials can be integrated into AWHP systems to optimize the AWHP performance. This flexibility in system configuration is an advantage over mini- Variable Refrigerant Flow (VRF) or split air-to-air heat pumps.

The ease of installation and low pressures in hydronic distribution also presents a crucial advantage for AWHP installations, given that plumbers and mechanical technicians have the expertise to manage the hydronic distribution and emitters installation. Further, the refrigeration design of R-290 monobloc systems places all refrigerant outdoors, conveniently addressing nearly all possible American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 15 / Standard 34 occupant safety considerations. This also creates additional installation advantages. Technicians do not have to handle or adjust the factory-sealed refrigerant charge or receive special refrigerant training or the Environmental Protection Agency (EPA) Clean Air Act Section 608 certification, compared to electric heat pump technology types that rely on installing refrigerant line sets.

## Business Case

### CALIFORNIA AWHP OPPORTUNITY

As is detailed later in this report, AWHPs sales are seeing exponential growth globally. Even though current residential AWHP installation numbers are small, their adoption rate is expected to grow, driven largely by California's electrification goals and the adoption of all-electric reach codes (Frontier Energy, 2022). In addition, emerging regulations throughout California that will enforce prohibitions on fossil fuel-based heating and domestic hot water systems, and CARB's commitment to developing zero-emission GHG standards will elevate demand for new space and water heaters sold in the state (CARB, 2022). These new and upcoming regulations present a substantial market opportunity for all types of heat pumps to fill the gap left by fossil fuel-based heating and domestic hot water systems.

#### R-290 AWHP OPPORTUNITY

In response to EPA AIM Act federal rulemakings and CARB's HFC phasedown requirements, many market players have chosen to promote HVAC products that use mid-GWP HFCs such as R-32 or HFC/HFO blends such as R454B to comply with the upcoming 2024-2029 phasedown period (USEPA 2022b, ASHRAE 2022b). Others have made R-290 their next-generation PFAS-free refrigerant of choice to leapfrog these temporary synthetic refrigerant solutions and meet all future phasedown requirements of the AIM Act.

R-290 is already regulated for safe use in HVAC equipment outside the US, and R-290 AWHPs have been commercially available for application in single-family homes for almost a decade (Santos 2023a, 2023b, 2023c, Viessman 2023; Panasonic 2023b; Haroldsen 2023; Williams and McLaughlin 2019). In prior work, VEIC has also had conversations with manufacturer representatives who have expressed interest in bringing their R-290 AWHPs to the US market; others indicated that they would "love to shift to propane [R-290]." If California could transition HVAC equipment straight to the lowest GWP technology option—skipping over intermediate mid-GWP refrigerants—they could immediately meet their long and short-term GHG emissions goals by eliminating all direct GHG emissions, netting time and economic investments.

Part of the purpose of this study, as discussed in the Objectives section, is to identify and explain regulatory and code barriers to R-290 AWHP adoption in California. These findings are presented in later sections of this report.

## R-290 AWHP – Barriers to Implementation

Outside of current code and perceived regulatory barriers, R-290 AWHP adoption is also challenged by flammability concerns and critical skilled labor shortages across the HVAC industry.

### Flammability

The primary concern about R-290 as a refrigerant is its flammability. R-290 is rated as "A3," or non-toxic and highly flammable, by ASHRAE, while the most common legacy synthetic refrigerants are categorized as non-toxic and non-flammable, or "A1." Many newer synthetic refrigerants are classified as "A2L," which indicates that they are slightly flammable, as shown in Figure 2 (ASHRAE 2022c).

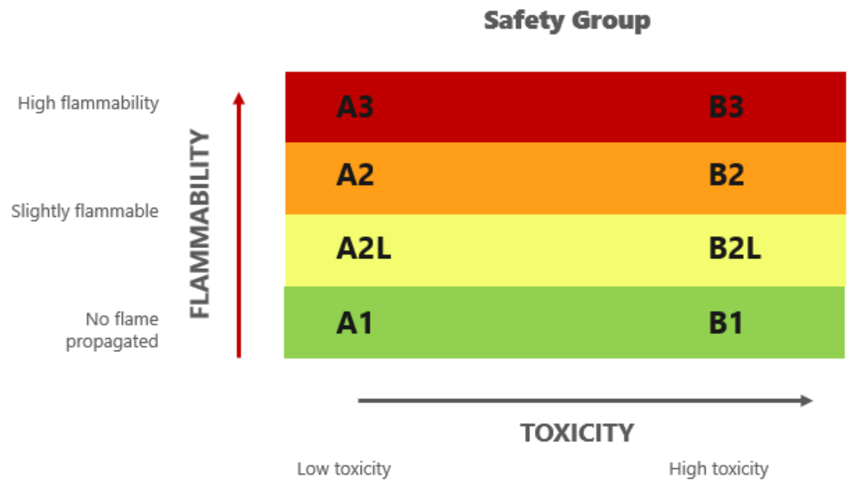


**Figure 2. ASHRAE refrigerant safety classification system.**

EPA approved R-290 in late 2011 for use in the commercial refrigeration sector, where it has been growing in popularity because it is more efficient and environmentally friendly. System designs are factory sealed and charged, reducing maintenance costs and risks of leaks.

Common, non-refrigerant uses of propane, such as barbeque grills and patio heaters, have created a public perception that propane always combusts when used in equipment. This has created an assumption that R-290 cannot be used safely as a refrigerant, which is not valid, as evidenced by the successful deployment of R-290 in the US in commercial refrigeration, and abroad in various HVAC and refrigeration technologies.

### Workforce Training

Labor shortages have been a challenge for the HVAC industry for decades, and companies across the US are struggling to recruit skilled electricians, technicians, and engineers to support heat pump installations. The market adoption of AWHPs can alleviate this some by providing an opportunity to engage and train other trades, such as plumbers and pipefitters, on AWHP system installation best practices.

The AIM Act will require the widespread introduction of A2Ls in the coming 2-5 years and this will necessitate an upgrade of basic refrigerant training for the workforce, including clear education on the flammability issues, leak detection, and ventilation systems required for A2Ls alongside tool upgrades to ensure compatibility with flammable refrigerants. The transition away from A1s presents an immediate opportunity to introduce A3 refrigerants as a topic in technician training and the use of non-sparking tools, as well.

## Objectives

The objectives of this study are to conduct a technology-specific energy and climate emissions savings analysis and to provide informed recommendations that will help promote the adoption of R-290 AWHP technology to drive down GHG emissions and energy use in California.

### Understand the Decarbonization Opportunity

The secondary research and savings analyses performed in the initial study phase aimed to understand the potential impacts of adopting R-290 AWHP technology in California. To that end, research was needed to learn what products are currently available and what types of buildings and systems they are best applied to. Based on that information, an evaluation of potential impacts was conducted.

### Evaluate Internationally Available Technology

The project team reviewed existing literature, market publications, and publicly available product specifications to evaluate and report on global technology trends and the adoption of R-290 AWHPs.

### Identify Barriers to R-290 AWHP Adoption

Regulatory, safety code, and other barriers to U.S. and California adoption of R-290 AWHP technology were reviewed, and findings were summarized. The project team aimed to identify significant challenges that limit or stop the widespread adoption of these ultra-low-GWP, energy-efficient heat pumps rather than comparable boiler-based systems.

### Deliver Actionable Recommendations

The overall objective of this study is to provide recommendations for utilities and other partners to build confidence in R-290 AWHP technology. Increased R-290 AWHP adoption would speed the phasedown of synthetic refrigerants in the HVAC sector and dramatically drive down GHG emissions alongside the benefits of electrification.

These recommendations could be leveraged to inform the following actions:

- Statewide coordination on activities to advance code revisions, including updates or clarifications about safe and effective installation standards for R-290 AWHPs nearby or in buildings,
- Technician workforce training to empower California contractor businesses in the HVAC clean technology transition.
- Utility awareness of this technology's market potential and impact, including which specific market segments will benefit from adopting this technology, what building types and use cases are appropriate to target, and the associated energy and emissions savings estimates from increased market adoption.
- Generation of a list of key market players, including manufacturers, distributors, and others who may have a vested interest in the future market and availability of R-290 AWHP.

While not a direct focus of this effort, these recommendations may also be helpful to other market actors (manufacturers, distributors, etc.) as they navigate future opportunities. California makers of relevant policies and regulations would also benefit from a clear understanding of how their activities could promote rapid adoption of this beneficial technology.

Further, while the scope of this market study is preliminary to any later Hard to Reach (HTR) or Disadvantaged Community (DAC) engagement, the recommendations and market insights that come out of this project should help utilities interested in pursuing additional research about how R-290 AWHPs could reduce overall energy burden for customers, as well as support utility-funded workforce development initiatives.

# Methodology & Approach

Overall, the project team's approach includes secondary research, technical evaluation, and emissions and energy savings analysis components. Relevant information will be synthesized, and informed recommendations will be made.

## Technology Evaluation and Application Identification

The project team conducted a literature review to evaluate and characterize R-290 AWHP products' current state and relevance to California HVAC market segments. International R-290 AWHP product characteristics and technical reports from other countries were gathered and assessed.

To analyze potential energy and GHG emissions savings from adopting R-290 AWHP in California, National Renewable Energy Laboratory (NREL) ResStock data was used to determine critical characteristics of relevant building types and create a savings baseline. NREL ResStock was developed to support the U.S. Department of Energy and offers real-time data visualization of an immense range of market factors and information. NREL ResStock provides granularity in modeling diverse housing stock and distributional impacts of building technologies across different communities through multiple public and private data sources, statistical sampling, sub-hourly building simulations, and high-performance computing (NREL 2023). US Census data for the state of California, California Air Resources Board (CARB) GWP and GHG emissions data, and manufacturer specifications for AWHP equipment were also used in the analysis.

Findings from this effort include a narrative summary, qualitative and quantitative data assessments, and recommendations for future research efforts.

## Regulation and Safety Code Review

Federal regulations and codes related to R-290 AWHP technologies were reviewed, characterized, and summarized alongside relevant state building codes and rules. Existing barriers to R-290 AWHP technology adoption were summarized and discussed in the Findings section of this report and informed recommendations on changes that could support the safe use of R-290 AWHP systems in California.

## International Technology Investigation

The project team reviewed existing literature, market and manufacturer publications, and product specifications to evaluate and report on global technology trends of R-290 AWHPs. The team sought to understand what forces or entities help promote or inhibit technology adoption worldwide, including relevant regulations and codes.

### Identification of Primary Research Opportunities

The project team identified gaps in current knowledge that present future research needs and critical questions for manufacturers, distributors, HVAC installation/service companies, and other key industry players.

# Findings

Findings from secondary research and impact analyses are described in the following sections.

First, findings are summarized from research into the best potential applications of R-290 AWHPs in California, including the case for natural refrigerants in California AWHPs, the case for R-290 as the AWHP refrigerant of choice in single-family homes, and identification of the California market for R-290 AWHPs as single-family residential buildings.

Then, an analysis of the potential impacts of R-290 AWHP technology adoption in the state is detailed, and findings are displayed in tables and figures.

Research findings on international considerations related to R-290 AWHPs are reported after the analysis findings, followed by a review and discussion of relevant regulations and codes.

## R-290 AWHPs in California

### The Case for Natural Refrigerants in California AWHPs

The need to decarbonize versus simply electrify buildings and the Total System Benefit (TSB) metric for California utility energy efficiency programs require consideration of the refrigerant GWP impacts of any heat pump technology. The market adoption of centralized AWHPs represents a step toward true decarbonization vs. isolated electrification by reducing refrigerant charge and any associated GHG emissions when adopting natural refrigerants.

As detailed in this report, AWHPs can be flexibly integrated into existing distribution systems, minimizing the cost and barrier to electrifying single-family residences with fossil fuel systems relative to retrofitting with ASHP plus HPHWH designs. Even to the extent that current high-GWP R-410A units are sold and as mid-GWP A2L units become required by CARB regulation (CARB 2020), the total GHG impact of utilizing an AWHP still clearly reduces the total refrigerant charge of the system by eliminating the need for multiple heat pumps, and if a monobloc design is installed, eliminating any points of lineset failure and associated refrigerant leaks.

While real-world leak rate data for factory-sealed heat pump systems such as AWHP monobloc installations is not currently available, it is still essential to recognize the environmental impact of refrigerant leaks that may occur during equipment servicing and, more specifically, end-of-life handling and eventual disposal. At this point, the adverse climate effects of high-GWP refrigerant leaks necessitate adopting natural refrigerants. This fact is supported by CARB rulemakings and the

US AIM Act, both of which will ban R-410A in new non-VRF equipment beginning in 2025 through GWP ceilings of 750 and 700, respectively (CARB 2020, USEPA 2023a, 2022b).

Further, simple analysis shows that recovering even half of the high-GWP refrigerants from existing Central AC systems (containing over 40 million pounds) and replacing them with R-290 central AWHP systems would eliminate approximately three times the CO2 equivalent of GHG emissions CARB has committed to reduce as directed by SB 1383 (2020 Scoping Plan for Achieving Carbon Neutrality, p. 43). As detailed later in this report, such R-290 AWHPs are sold and installed in the UK, Europe, and China today, and several manufacturers have expressed interest in selling them in the North American market.

## The Case for R-290 AWHPs in Single-Family Residential Buildings

### R-290 VS. OTHER NATURAL REFRIGERANT OPTIONS

Research was conducted to evaluate what types of buildings were best-fit applications for AWHP technology that uses propane versus ammonia and carbon dioxide. Other natural refrigerants such as butane or other hydrocarbons were not evaluated since there are no widely available HVAC products in applications comparable to single-family residential AWHPs. Findings are summarized in the following sections.

### AMMONIA (R-717)

Ammonia (R-717), a thermodynamically efficient option often used in industrial or large commercial refrigeration systems (Cefaly and Blocker 2023), is classified as a B2L refrigerant, which is both moderately flammable and highly toxic. It must be managed continuously to ensure human health and safety (ASHRAE 2022b). Industrial and commercial facilities can handle these requirements using on-site technical staff, but R-717's toxicity would present a significant hazard to residents. R-717 chiller systems are widespread in the industrial sector, but there are no known available ammonia AWHP products for residential applications.

### CARBON DIOXIDE (R-744)

Energy-efficient carbon dioxide (R-744) AWHP systems are an emerging technology that is becoming available in commercial or large multi-family residential buildings (Cefaly and Blocker 2023) and can be an excellent option for decarbonizing the domestic hot water supply.

In small-to-medium residential HVAC applications, R-290 systems are more energy efficient than comparable R-744 equipment due to the complex operational challenges of R-744, including the high operating pressures required for R-744 systems, which can reach 1000 psi or more (Hwang, Jin and Radermacher 2005, Elbel, Visek and Hrnjak 2016). While R-744 systems can deliver high hot water temperatures, they also have high operating pressure requirements that lead to relatively high installation and maintenance costs and precise operational needs due to strict return water temperature requirements (Cefaly and Blocker 2023, Elbel, Visek and Hrnjak 2016). Due to these limitations, R-744 systems do not yet reliably provide space heating and cooling in small-to-medium-scale residential applications. However, it is essential to note that research and development are happening in this space, with the potential for new products coming onto the market (RenewaBoiler 2023).

### PROPANE (R-290)

While other natural refrigerants such as carbon dioxide (R-744) and ammonia (R-717) present opportunities in multifamily, commercial, or industrial settings, R-290 is currently the best natural refrigerant choice for single-family residential HVAC. R-290 systems allow efficient operation with a range of acceptable return temperatures, operate at pressures that HVAC technicians are accustomed to, do not cause a human toxicity concern, and can provide both heating and cooling within appropriate ranges for single-family residences (Cefaly and Blocker 2023, NASRC 2022, Elbel, Visek and Hrnjak 2016). As previously discussed, the main design challenge for using R-290 versus other ultra-low-GWP refrigerants is its flammability.

Available international products show a capacity range consistent with single-family residential applications. While larger equipment for multifamily residential applications of R-290 AWHPs is expected in Europe in the coming years and may become a viable market option, they are not yet available (Economist 2023).

Research at the Fraunhofer Institute in Germany implies that R-290 AWHPs could be applied in European multifamily buildings as retrofits for gas boiler systems as soon as the next few years (Economist 2023). However, this is not yet an available option. Multifamily buildings could hypothetically use R-290 AWHPs modularly per housing unit, but this is not common practice.

Primary market segments for current natural refrigerant heating and/or cooling HVAC systems are shown in Table 1, along with a summary of the chief design challenges for each refrigerant type.

**Table 1: Natural Refrigerant AWHP Primary HVAC Market Segments and Design Challenges**

| Natural Refrigerant | AWHP Primary HVAC Market Segment | Challenges |
|---|---|---|
| Propane (R-290) | Single Family Residential | Flammable |
| Carbon Dioxide (R-744) | Multifamily Residential, Commercial | High operating pressures (1000 psi or more), low return temperatures required |
| Ammonia (R-717) | Industrial | Toxic and slightly flammable |

### R-290 AWHPS IN BOTH RETROFITS AND NEW SYSTEMS

R-290 AWHPs can supply hot water at greater than 160°F, as shown in Table 1 and also reported in other manufacturers' marketing materials, e.g., (Haroldsen 2023). This indicates that R-290 AWHPs are potentially compatible with existing high-temperature hydronic distribution systems initially designed to operate with a boiler and a possible replacement for forced air furnace systems through fan coils and air handlers. It is also possible to add to existing hydronic distribution systems to allow AWHPs to heat at much lower, leaving water temperatures in the range of 95°F to 120°F to improve operating efficiency (Williams, 2023).

As detailed earlier in this report, hydronic piping network installation and maintenance does not require special refrigerant training or EPA Clean Air Act Section 608 certification, nor do they expose technicians to the flammability of R-290. The skills and training needed for AWHP system installations are more similar to conventional HVAC than comparable electric heat pump technology types that rely on installing refrigerant line sets. This is true whether a system is new or part of a retrofit.

Due to the higher supply water delivery temperatures compared to synthetic refrigerant AWHPs, R-290 AWHPs present new electrification retrofit possibilities for replacing fossil fuel boilers in heating systems. If the quality and condition of an existing boiler system's hydronic distribution is good, then it may be reusable for an R-290 AWHP system. Some components may need upgrades, but unlike copper refrigerant line sets, every part of the prior system is not generally required to be torn out or abandoned (J. Siegenthaler 2022b, Idronics 2020, Capanelli 2021). Since R-290 AWHPs are an emerging technology, no peer-reviewed data appears on how often or well retrofits work as partial or complete fossil fuel boiler replacement retrofits. However, recent Economist and PV Magazine articles argue that the retrofit market, especially for older buildings, is primed for this application (Economist 2023; Santos 2023b). Domestic pilot studies would be helpful to advance retrofits as a decarbonization opportunity.

Whether in new construction or retrofits, AWHP installations provide an opportunity for existing plumbers, pipefitters, and boiler-focused mechanical contractors to transition into a new, climate-friendly technology market since they are already trained in handling the types of low-pressure piping used in boiler systems' hydronic distribution, such as polypropylene (PP) or cross-linked polyethylene (PEX) (Idronics 2020, J. Siegenthaler 2021). This could significantly lower the barrier to workforce entry to support the adoption of R-290 AWHPs. Also, hydronic piping materials are generally less expensive than the higher-pressure copper piping used in refrigerant line sets, which can lower the overall system installation cost (J. Siegenthaler, 2022b).

### California Market for R-290 AWHPs

Previous research has identified fossil fuel boiler and furnace systems as candidates for retrofits to heat pump technologies for effective decarbonization (Billimoria et al. 2018). An analysis of the HVAC systems in residential buildings can further help estimate the potential total energy and GHG impact of AWHP retrofit and future new installations' potential impacts.

The following assessment of California residential buildings was performed to understand the characteristics of buildings where R-290 AWHP technology could be used. According to the US Census Bureau, California has over 14.5 million residential homes. Of those 14.5 million, single-family homes[2] comprise approximately 65 percent of the market, followed by multifamily homes at approximately 31 percent (NREL 2023). Further characteristics of residential building types in California are shown in Figure 3.

Single-family residential buildings were identified as the potential California market for R-290 AWHP systems based on products currently available in international markets, as discussed in previous sections (see Table 1). While multifamily buildings can use R-290 AWHPs modularly on a per-

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[2]Single family housing is defined by the US Census Bureau as single-family structures including fully detached, semi-detached, row houses, duplexes, quadruplexes and townhouses with individual heating systems, meters and separated by a ground to roof wall.

housing-unit basis, this is not reported as a common practice and was therefore disregarded in this analysis.

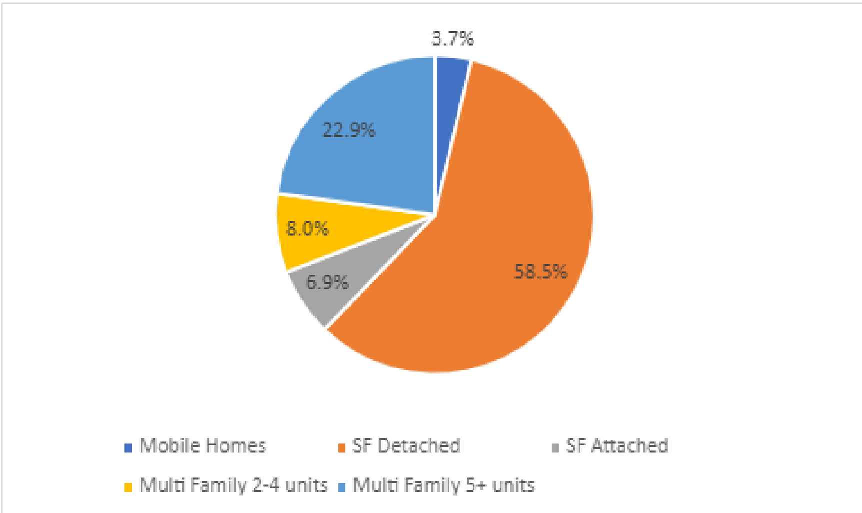


**Figure 3: Distribution of residential building types in California.**

Source: (NREL 2023)

The cooling system type used most across all residential building types is central air conditioning (AC), followed by room-scale (unitary) ACs and air-to-air heat pumps. Most residential buildings use furnaces as the heating appliance for building heating, followed by air-to-air heat pumps, electric baseboards, and fossil fuel boilers. This information about residential buildings in California is shown in the tables below. The data shown in the following two tables were used to calculate the estimated impacts of AWHP adoption in the state.

**Table 2: HVAC Cooling System Types Are Found in Residential Buildings in California**

| Building Type | Central AC | Heat Pump | Room AC | None |
|---|---|---|---|---|
| Mobile Homes | 1.3% | 0.1% | 0.7% | 1.7% |
| SF Detached | 29.6% | 1.5% | 6.9% | 20.5% |
| SF Attached | 3.3% | 0.2% | 0.7% | 2.7% |
| Multi Family 2-4 units | 3.0% | 0.3% | 1.0% | 3.7% |
| Multi Family 5+ units | 9.1% | 1.4% | 2.9% | 9.3% |

Table 3: HVAC Heating System Types Found in Residential Homes in California

| Heating Type | Single Family Detached | Single Family Attached | Multi Family 2-4 units | Multi Family 5+ units | Mobile Home |
|---|---|---|---|---|---|
| Air Source HP | 5.8% | 0.6% | 0.7% | 2.7% | 1.3% |
| Electric Baseboard | 4.4% | 0.4% | 0.7% | 1.7% | 0.5% |
| Boiler | 5.4% | 0.5% | 0.5% | 0.5% | 0.2% |
| Furnace | 38.4% | 3.6% | 3.8% | 7.8% | 3.8% |
| Shared Heating | - | 0.2% | 1.7% | 4.7% | - |
| Wall or Floor Furnace | 5.4% | 0.5% | 0.5% | 0.5% | 0.3% |
| None | 2.2% | 0.0% | 0.0% | 0.3% | 0.2% |

The number of new construction single-family homes in California has continually increased yearly (CBIA 2023). There was a slight decrease in the number of new homes built during the early pandemic years of 2020-2021, but growth has rebounded to the previous new construction rate in California. The graph below illustrates the number of homes being built per year. The orange portion of the line represents a projected growth rate based on the California Building Industry Association data. New construction presents a massive opportunity for GHG savings by installing AWHPs rather than boilers or furnaces with conventional AC systems in the coming years, with additional GHG savings possible from R-290 use rather than R-32 or R454B as the equipment's working fluid[3].

[3] Starting in 2025, new residential HVAC systems will no longer be allowed to use R410A according to both CARB and the AIM Act. As such, the future impact of refrigerant-associated emissions for all new construction from 2025 onward should be estimated based on comparison of R-290 to R-32 and R-454B, which are the two primary mid-GWP synthetic refrigerant options that have been recommended by the EPA as replacements for R-410A and announced by major HVAC manufacturers in new products.

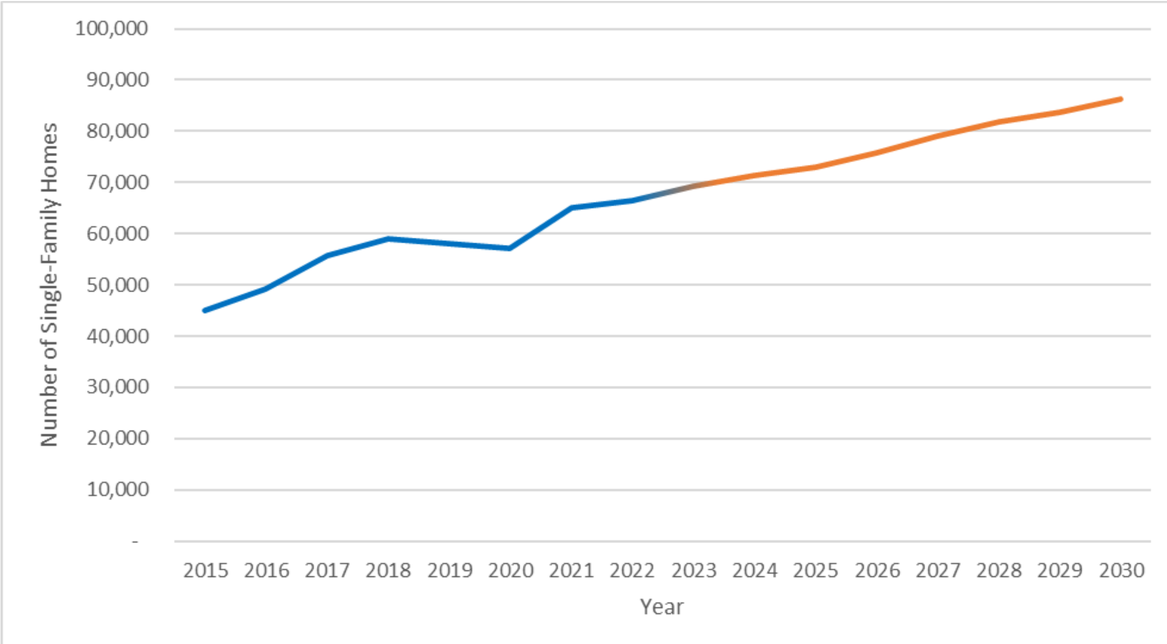


**Figure 4: Number of single-family new construction homes built each year in California. The blue line represents historic construction rates, and the orange line represents projected growth rates through 2030.**

Source: CBIA, 2023

## Potential Climate Impacts of Technology Adoption

### Impact of Electrification of Heating and Cooling

The baseline for this analysis is current single-family homes with fossil fuel boilers or furnaces and conventional air-conditioning (AC) systems. For analysis, the attached and detached single-family homes in California with boilers or furnaces were assigned a cooling system distribution based on the state's distribution (see Tables 2 and 3 in the prior section). Average capacity and efficiency data for HVAC equipment in California homes from NREL's ResStock data and R-290 AWHP equipment specifications were used to calculate overall savings.

As shown in Table 2, most homes in California have Central AC, followed by no AC at all, and then by Room AC. This energy consumption analysis disregards the small percentage of homes with ASHP AC systems since AWHP systems have similar energy efficiency to ASHPs. Since many California homes currently have boilers but no cooling systems, retrofitting an AWHP system will create an associated cooling energy penalty. Nevertheless, if attached and detached single-family homes in California were retrofitted with AWHP systems as described earlier in the report and used for heating and cooling in all those homes, the energy and GHG emissions saved would be significant, as shown in the Net Savings values in the following tables and figures. If the retrofitted AWHP systems were not used for cooling in homes with no AC systems, the savings realized by the utility would reflect the larger Gross Savings values.

Even a one percent conversion of these existing building types would result in net energy savings of over 268,000 megawatt-hours (MWh), shown in Table 4, with about 47,000 metric tons of carbon dioxide equivalent (MT $CO_2e$) associated GHG savings, shown in Table 5.

**Table 4: Annual Energy Savings from the Use of AWHP Systems Rather Than Boilers or Furnaces and Conventional AC Systems in Attached and Detached Single Family Homes in California**

| Percent Fossil Fuel Boilers and Furnaces Replaced by AWHPs | Gross Energy Savings (MWh) | Cooling Energy Penalty (MWh) | Net Energy Savings (MWh) |
|---|---|---|---|
| 100% | 35,334,593 | (8,516,048) | 26,818,545 |
| 10% | 3,533,459 | (851,605) | 2,681,855 |
| 5% | 1,766,730 | (425,802) | 1,340,927 |
| 2% | 706,692 | (170,321) | 536,371 |
| 1% | 353,346 | (85,160) | 268,185 |

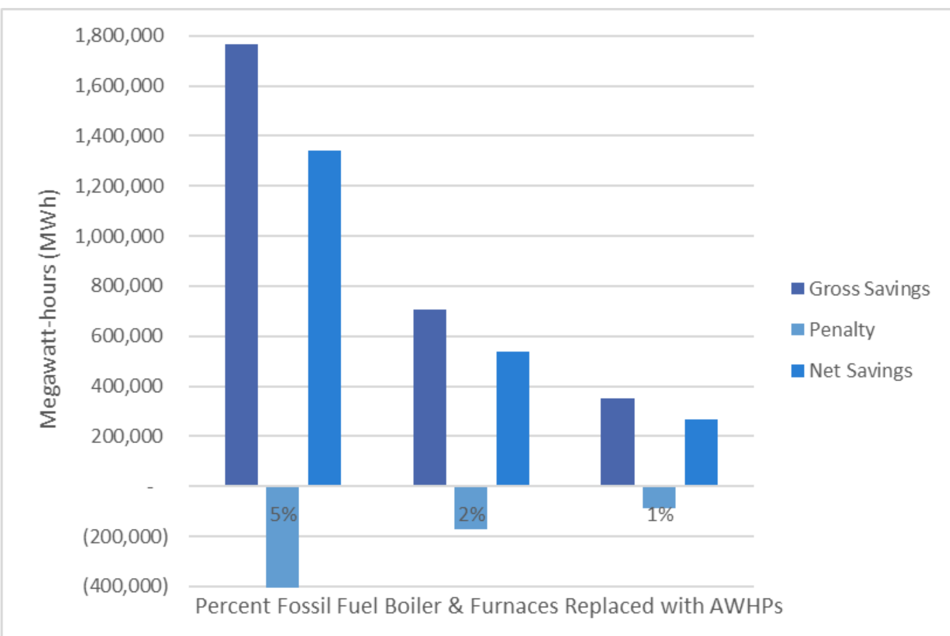


**Figure 5: Annual energy savings in MWh from the use of AWHP systems rather than fossil fuel boilers or furnaces and conventional AC systems in attached and detached single-family homes in California.**

**Table 5: Annual Energy-Associated GHG Savings from the Use of AWHP Systems Rather Than Boilers or Furnaces and Conventional AC Systems in Attached and Detached Single Family Homes in California**

| Percent Fossil Fuel Boilers and Furnaces Replaced by AWHPs | Gross GHG Savings (MT CO2e) | Cooling GHG Penalty (MT CO2e) | Net GHG Savings (MT CO2e) |
|---|---|---|---|
| 100% | 6,458,138 | (1,793,893) | 4,664,245 |
| 10% | 645,814 | (179,389) | 466,424 |
| 5% | 322,907 | (89,695) | 233,212 |
| 2% | 129,163 | (35,878) | 93,285 |
| 1% | 64,581 | (17,939) | 46,642 |

Source: CARB, 2023a; NREL, 2023; Panasonic, 2023; United States Census Bureau, 2023.

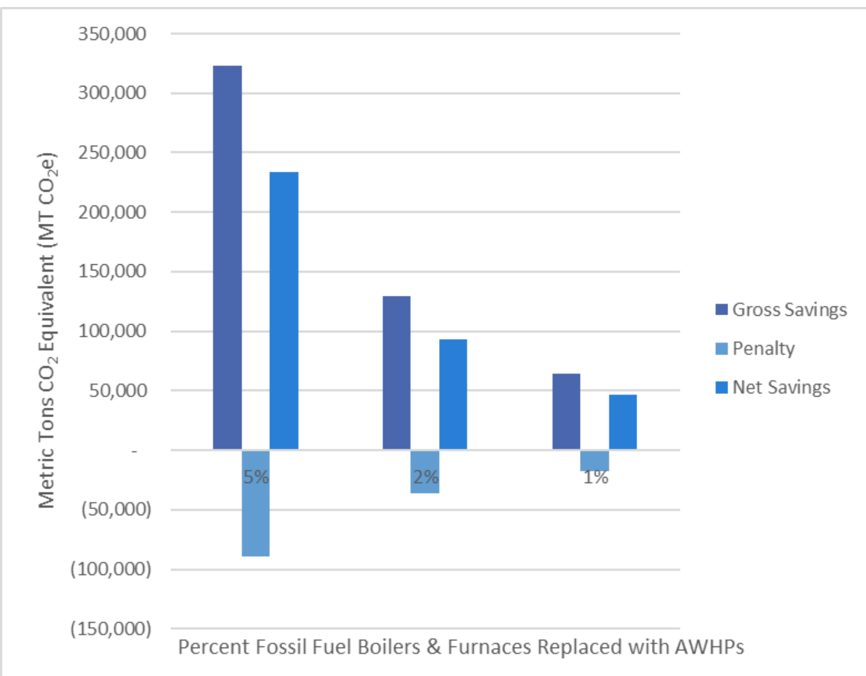


**Figure 6: Annual energy-associated GHG savings from the use of AWHP systems rather than fossil fuel boilers or furnaces and conventional AC systems in attached and detached single-family homes in California.**

Additional energy cost and GHG emissions benefits can also be expected from AWHPs during the cooling season, given the technology's potential to provide thermal storage and load-shifting capabilities (Becker, Hoeschele, and German, 2023). Potential grid-emissions impacts of TES are highlighted later in this report.

## Impact of Refrigerant Choice

The baseline configurations for calculating the GHG refrigerant emissions below are single-family homes with fossil fuel boilers or furnaces retrofitting to an AWHP that uses synthetic refrigerant or R-290. While most installed AWHPs use the refrigerant R-410A, it has a GWP value of over 2,000 and will be phased out across all new HVAC&R equipment beginning in 2024 at both state and federal levels. In response, manufacturers are increasingly advertising and communicating that they are shifting their product lines to the synthetic refrigerants R-32 and R-454B. The 100-year GWP values calculated in the 2007 IPCC AR4 report are currently used in California's Refrigerant Management Program (RMP) regulations. They are shown in 6 below for refrigerants used in commercially available AWHP equipment. The 100-year GWP value of R-290 has been updated in more recent IPCC reports as less than 0.02 (near zero) (Stausholm, 2022). However, the value of 4 from the 2007 IPCC report was used in this analysis to be consistent with the RMP regulations.

**Table 6: IPCC AR4 (2007) 100-year GWP of AWHP refrigerants.**

| Refrigerant | GWP |
|---|---|
| R-290 | 4 |
| R-454B | 467 |
| R-32 | 677 |
| R-410A | 2088 |

Source: CARB, 2023b.

Using these GWP values, the potential future climate impact of leaks from AWHP systems based on refrigerant choice was estimated as follows.

A (low) system leak rate of two percent was used based on the 2022 California Public Utilities Commission Refrigerant Avoided Cost Calculator value for factory-packaged HVAC since AWHP contain the refrigerant loop within a factory-sealed outdoor unit. The average AWHP system charge size was estimated at 2 pounds per ton of capacity based on product system charge specification data multiplied by the average HVAC system cooling capacity in tons for all single-family attached and detached homes in California (Chiltrix, 2023; NREL 2023; Spacepak, 2023; Stiebel Eltron, 2023).

Table 7 below illustrates the annual refrigerant-leak-related emissions impact of retrofitting a percentage of the California single-family fossil fuel boiler and furnace residential market with an AWHP by refrigerant type. R-410A is included because new residential R-410A systems will continue to be installed and serviced until they are legally prohibited. The most recent HFC rulemaking released by CARB sets a GWP ceiling of 750 that will take effect on January 1, 2025, for AWHPs, eliminating R-410A from the new equipment market (CARB, 2020). This coincides with the U.S. EPA AIM Act's 700-GWP ceiling deadline for new equipment (USEPA, 2022b). Both the AIM Act and CARB HFC phasedown rulemaking will be discussed in more detail later in this report.

Figure 7 following Table 7 provides a data visualization, highlighting the overwhelming GHG benefit of selecting a natural refrigerant over a synthetic refrigerant, even in systems such as AWHPs with low expected leak rates.

**Table 7: Annual Estimated GHG Emissions from AWHP Refrigerant Leaks from Systems Replacing Fossil Fuel Boilers or Furnaces and Conventional AC Equipment in Single-Family homes in California.**

| Percent Fossil Fuel Boilers or Furnaces Replaced by AWHPs | R-290 Emissions, MT $CO_2e$ | R-454B Emissions, MT $CO_2e$ | R-32 Emissions, MT $CO_2e$ | R-410A Emissions, MT $CO_2e$ |
|---|---|---|---|---|
| 100% | 368 | 42968 | 62290 | 192113 |
| 10% | 37 | 4297 | 6229 | 19211 |
| 5% | 18 | 2148 | 3114 | 9606 |
| 2% | 7 | 859 | 1246 | 3842 |
| 1% | 4 | 430 | 623 | 1921 |

Source: (NREL 2023, United States Census Bureau 2023, USEPA 2023b, CPUC 2022b).

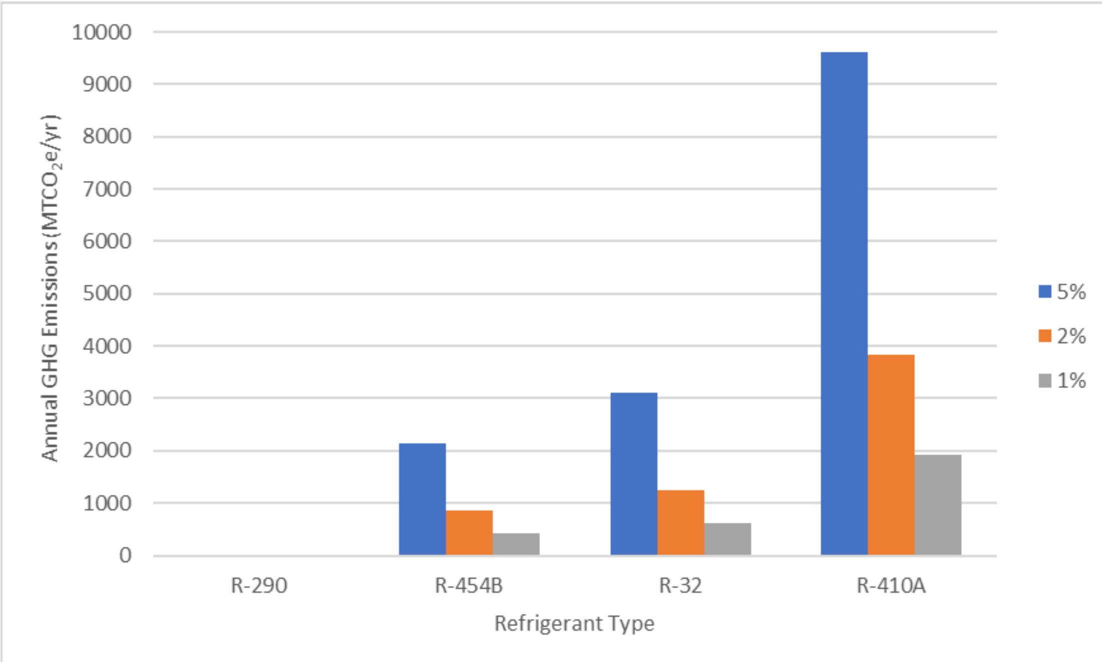


**Figure 7: Annual California GHG emissions from AWHP refrigerant leaks by the percentage of fossil fuel boiler or furnace replaced with AWHP systems in single-family homes according to refrigerant type, in metric tons of $CO_2$ equivalent.**

The net GHG impact of adopting R-290 AWHP replacement under this baseline consideration could provide a significant percentage of the state's 7.5 Metric Tons of Carbon Dioxide Equivalent ($MMTCO_2e$) goal even if only partial market adoption is achieved.

## Impact of AWHP Thermal Energy Storage (TES) on the Grid

California has set an aggressive statewide grid decarbonization goal to become carbon-free by 2045 (SB100). This means 100 percent of electricity will always come from renewable or zero-carbon sources. In order to meet this goal, the CEC, CPUC, and CARB determined that California will need to triple its current electricity grid capacity through the development of additional renewable energy and storage resources (CEC, 2021). How buildings are heated and cooled is critical in increasing capacity and storage resources through available demand flexibility. The 2021 SB100 Joint Agency support summary states: "The state is working to increase the ability of the grid to shift the timing of electricity use to sunny and windy parts of the day when most renewable energy is produced. This load flexibility is critical to maintaining a reliable power supply at a low cost" (CEC, 2021). Accordingly, the CEC is revaluing energy efficiency in this regard. Starting in 2024, the Total System Benefit metric is to be applied to utility efficiency programs as well, requiring the hourly analysis of the effect of any measure as the primary driver of that measure's value to the grid.

As discussed earlier in this report, air-to-air heat pump systems have limited ability to shift their load without significant customer discomfort. Further, as noted by ASHRAE's Task Force for Building Decarbonization in 2023, electrification focused on ASHPs will likely end up having a higher upstream carbon grid impact than burning natural gas for heating, AWHPs, on the other hand, when integrated with TES, can decouple building heating and cooling load from heat pump operation, providing an opportunity to shift HVAC electric load with minimal to no impact on the customer's comfort[4]. Many customers leverage TOU plans to save money by shifting their usage to off-peak lower price periods. For utilities, load shifting is also a critical strategy for grid decarbonization efforts, as the temporal variation of the grid's carbon intensity can be significant. New initiatives such as the CalFlex Hub are working to shift energy management to a more automated and dynamic platform, making participation more accessible and the impact of load management greater (CalFlexHub, 2023).

As illustrated in Figure 8 through Figure 10 below, even though California's grid is powered by approximately 60 percent renewable electricity, the carbon intensity profile of operating the grid changes rapidly by generation source-mix, time of day and time of year. The carbon intensity of the grid will also vary by region across the state, although analysis of this breakdown was not conducted for this report.

Figure 8 illustrates the carbon intensity of the California Independent System Operator (CA ISO) on April 30th, 2022. This date was intentionally selected to demonstrate that the carbon intensity of the grid can vary by more than a factor of three within a day based on the availability of certain resources like solar and wind. As seen in this image, as the fuel mix changes so does the carbon intensity of the grid, and fluctuations like this present significant opportunities and benefits to shifting energy use to lower carbon-intense periods.

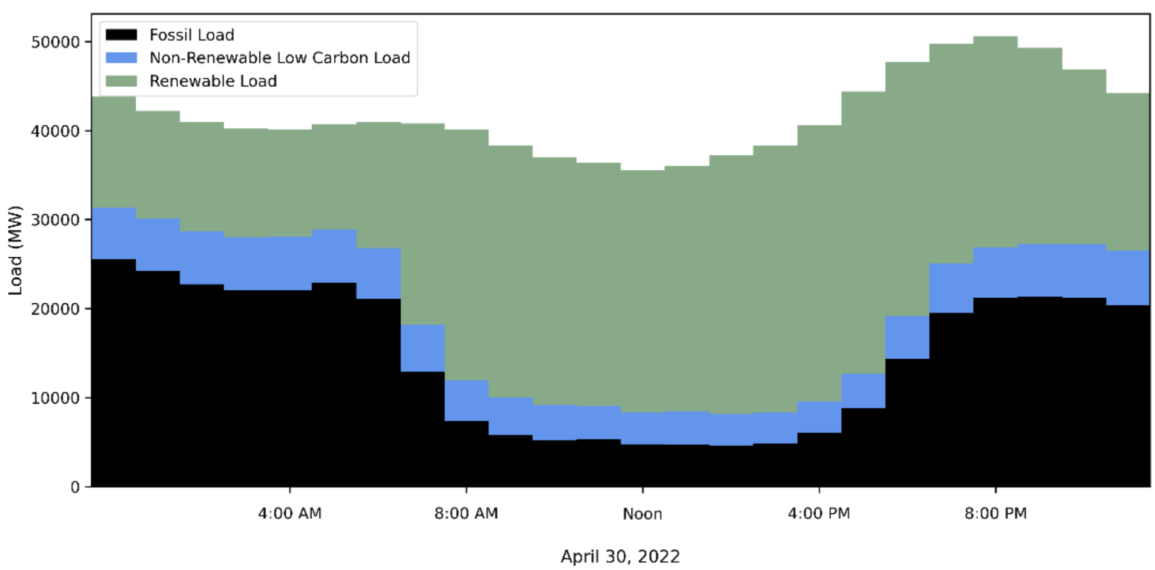


**Figure 8: The energy generation mix of CA ISO on April 30th, 2022.**

Figure 9 illustrates the same day (April 30th) and the carbon emissions impact on the grid of type of fuel mix. As noted in Figure 8, there is a marked drop in the use of fossil fuels to power the grid

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[4] This has been proven and is built into the design of many OEMs AWHP systems.

during the middle hours of the day. This results in grid carbon emissions of less than 150 gCO2/kWh compared with night hours, that exhibit emissions of over 230 CO2/kWh.

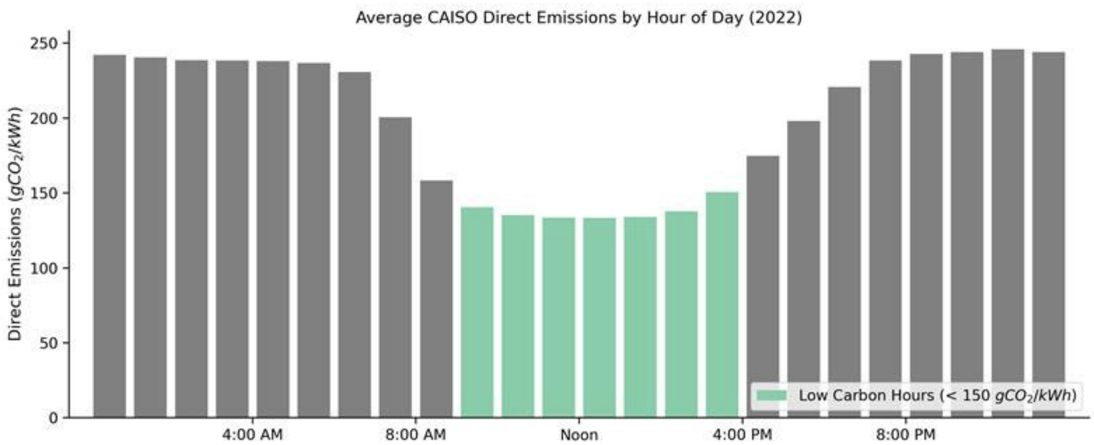


**Figure 9: Actual CAISO Electricity Fuel Mix for April 30, 2022.**

Further, Figure 10 illustrates the impact of seasonal change on the grid generation mix and how this impacts the carbon emissions over a year. As might be expected, and is highlighted mid-day April and May have the lowest impact on the grid and October-December at night have the worst.

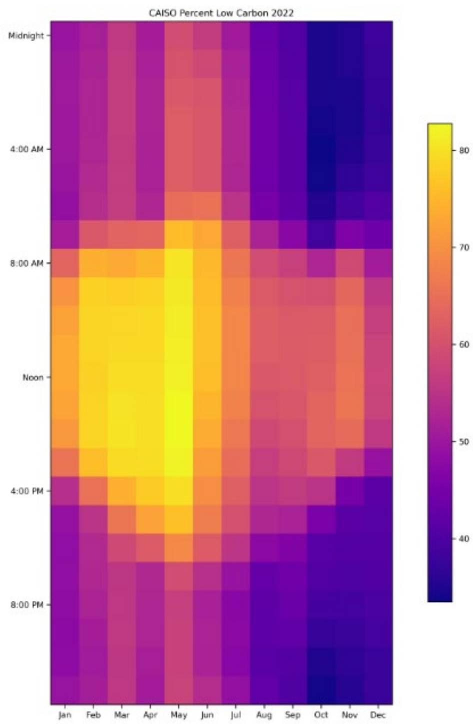


**Figure 10: Average direct carbon emissions by hour of day for the CAISO grid over 2022.**

## IMPACT ANALYSIS

The U.S. Department of Energy (DOE) BTO has already conducted several field studies in California and Arizona on the potential demand response benefits of AWHP with TES (provided by a slab) for off-peak cooling. These tests demonstrated up to 43 percent savings in seasonal cooling energy compared with a constant set point (DOE, 2023).

While conducting a similar field analysis is outside the scope of this Report[5], it is helpful to consider the potential impact of scaling AWHP with TES on CAISO's carbon intensity to inform further research needs and spark general consideration of this additional benefit. The following high-level exercise attempts to demonstrate this by modeling the possible effects of shifting heating and DHW load for a typical 2000-square-foot house, assuming the following parameters:

- All AWHP systems are installed with TES as is the recommended best practice.
- The installed TES can provide six hrs. of storage.
- The TES distribution system efficiencies are assumed to be 94 percent (similar to what was found in the DOE study).
- The baseline comparison of this analysis is the unshifted load for AWHP systems (without TES).
- Loadshape for unshifted heating scenario is adapted from ET 23SWE0050 insights[6].

[5] A field study evaluation of residential AWHP serving space heating loads and domestic hot water loads with TES is currently being conducted under ET23SWE0050.

[6] Loadshapes adopted from a Harvest Thermal presentation collected under ET23SWE0050.

Based on the temporal analysis of the carbon intensity of CA ISO above, the project team assumes that heating and domestic hot water production can be shifted into five non-peak "clean" hours a day, 365 days a year. Figure 11 illustrates this by comparing a typical home AWHP+TES shifted vs. typical non-shifted loadshape.

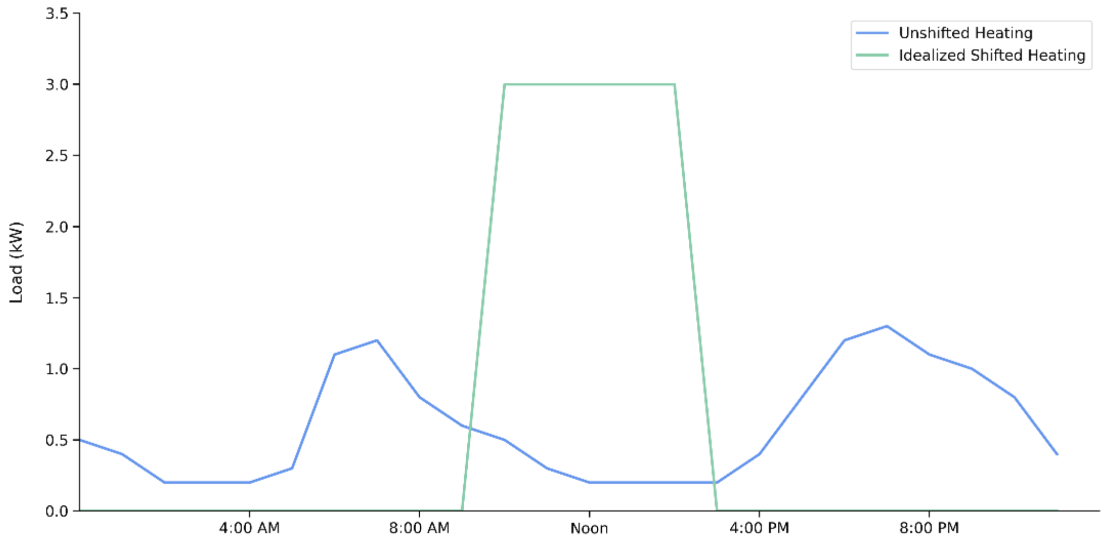


**Figure 11: Loadshapes for typical heating and domestic hot water with unshifted use and ideal shifted.**

As illustrated, the shifted loadshape demonstrates the ideal case in which all heating and hot water heat is heated for 55 hours in the middle hours of the day when CAISO's fuel mix is cleanest. By compressing the heating load into these hours, the total electrical demand also increased slightly to account for heating losses associated with storage vs. real-time energy use. This is represented by the area (electrical demand) under the ideal, shifted curve representing about 110 percent of the area under the unshifted curve.

The following analysis considered these profiles' upstream "grid" carbon intensity. Even though slightly more electricity (110 percent) is used in the "shifted" scenario, the total associated grid emissions as illustrated in Figure 12, are a third less than the "unshifted" scenario.

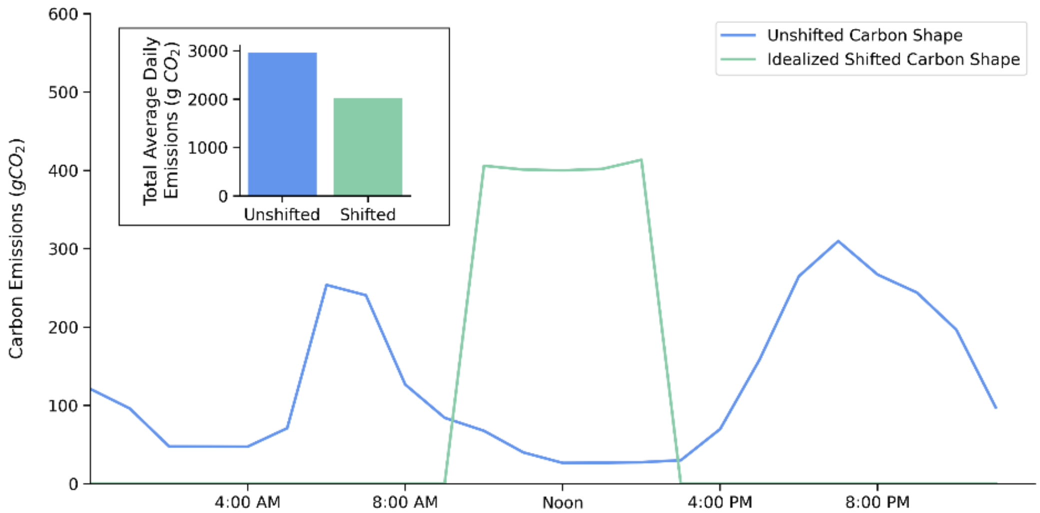


**Figure 12: "Carbon-intensity shapes" compare the carbon intensity of a typical profile of residential heating and hot water production with an ideal case "shifted" vs "unshifted" scenario.**

Next, assuming a market adoption rate of AWHP + TES of one, two, and five percent of California's total available retrofit market (Table 8), the project team calculated the estimated annual avoided grid emissions associated with deploying AWHP + TES shifted vs. non-shifted strategy.

**Table 8: Market Adoption of Air-to-Water Heat Pumps**

| Percent Market Adoption of AWHPs +TES | # Homes | Annual avoided emissions (metric tons of $CO_2e$ |
|---|---|---|
| 5% | 229,372 | 79,900 metric tons |
| 2% | 91,749 | 31,500 metric tons |
| 1% | 45,874 | 15,800 metric tons |

Starting January 1, 2024, investor-owned utilities (IOUs) will be required to demonstrate their portfolio performance in alignment with the TSB. This metric encourages programs to target efficiency measures that maximize longer-duration GHG reductions and deliver grid benefits. If California municipalities were positioned to support innovative natural refrigerant technology solutions such as R-290 AWHP+TES for residential single-family applications, they would have a single-end-to-end decarbonization strategy for their housing stock and ensure alignment in perpetuity with TBS metrics.

## International Considerations

### Global Decarbonization Trends

It is well established that the climate is changing due to human activities. Social attitudes and government policies worldwide are also changing to address this crisis by predominantly focusing on reducing carbon emissions. A majority of countries around the world—driven by the legally binding 2015 Paris Climate Accords—have set aspirational nationwide net neutrality goals for 2050[7] (COP26). Others have taken a step further and endorsed ambitious policies on energy efficiency in recognition of its central role in reducing energy-related carbon emissions (IEA, 2022). For all, the building sector is recognized as a critical area to address, as despite progressive shifts towards electrification and investments in efficiency, building-based fossil fuel use has still increased at an average growth rate of 0.5 percent since 2010; and as of 2022, accounted for 26 percent[8] of global energy-related emissions (IEA, 2022).

Decarbonizing the building sector requires significant investment in buildings' heating, cooling, and hot water systems, and based on 2021 electricity generation figures, more than 80 percent of global space and water heating demand can be met with heat pump technology. To date, more than 30 countries provide favorable financial incentives or subsidies to accelerate thermal electrification as a way to quickly move away from fossil fuels, with some offering higher subsidies for high-efficiency models or units operating with natural refrigerants, others choosing to ban gas in new buildings and boilers, or synthetic refrigerant "fluorinated gases" (known in Europe as "F-gases") in certain types of heat pump and AC systems.

### Global Heat Pump Market Trends

In 2021, heat pumps accounted for just ten percent of global heating equipment sales, compared to fossil fuel equipment that accounted for 45 percent (Heat pumps, 2023). That said, heat pump sales are gaining market share. In 2022 more heat pumps sold than fossil fuel-based systems in the US and France and investments in heat pump technologies rose globally by 25 percent (IEA, 2023).

According to market research firms, the current heat pump market is estimated at USD 81.58 billion. It is expected to grow annually at a rate of 9.3 percent over the next decade, reaching over USD 221 billion by 2032 (GVR 2023). Comparatively, according to JARN's database, the global AWHP market grew by almost 20 percent in 2021 and is expected to reach $113.5 billion by 2032. This represents more than 50 percent of the total heat pump market by that time (Global Market Insights, 2023).

This trend is visible in IEA's recent analysis of global heat pump sales (see Figure 13) that shows AWHPs outpacing air-to-air heat pump sales by 19 percent[9] (IEA, 2023), with the European and Japanese markets exhibiting the most significant growth rates. In Japan the AWHP market is driven by EcoCute, a leading water heating technology solution that has experienced steady growth over the last two decades (IEA, 2023). In Europe, accelerated heat pump sales are linked not only to the

[7] In 2021, 124 out of 137 signatories to COP 26, including the US set ambitious net-zero emissions goals by 2050 under the Glasgow Climate Pact.

[8] 8% coming from direct emissions and 18% coming from indirect emissions associated with the production of electricity and heat used in the buildings

[9] AWHP sales grew by 24% in 2022, whereas air-to-air heat pump sales grew by 5% globally.

European Union's focus on heat pumps adoption under REPowerEU as the most efficient and cost-effective lever to decarbonizing buildings, but also Europe's goal to reduce its heavy reliance on fossil fuel imports and supply risk associated with the Russia-Ukraine War.

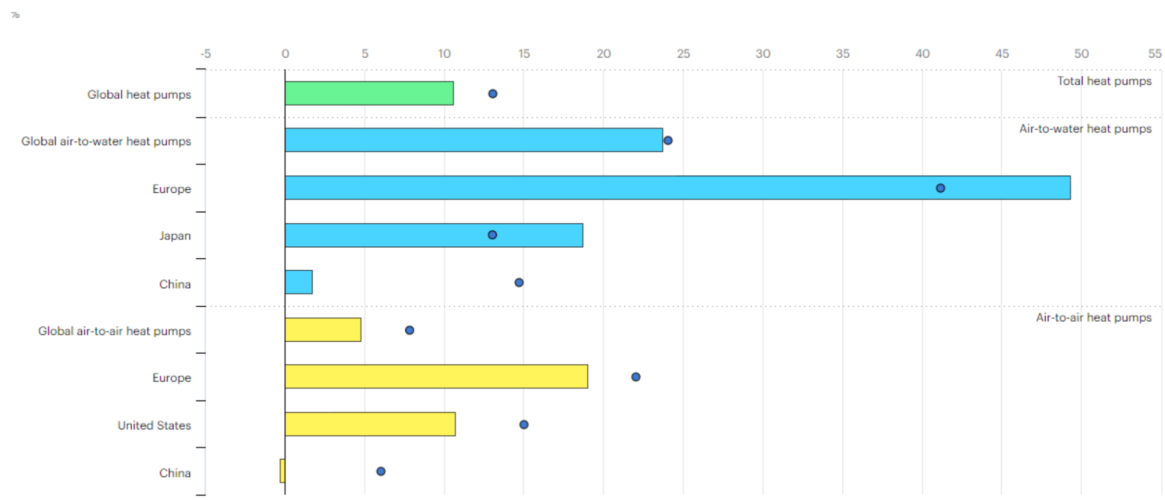


**Figure 13: Annual growth in sales of heat pumps in buildings worldwide and selected markets, illustrating 2021 (blue dot) and 2022 (bar) growth rates.**[10]

Source: IEA 2023

As detailed in the recent EU Heat Pump Accelerator, the EU plans to double heat pump deployment over the next five years to 60 million by 2030, specifically focusing on hydronic—including hybrid equipment (EHPA, 2023). Undoubtedly, this will drive additional technology advancements and expand regional production capacity investments in the AWHP market. Based on the recent analysis conducted by the British Heatpumps company, manufacturers are already said to be planning to invest around $4 billion in expanding heat pump production, with most of that investment centered in Europe, where AWHPs are favored. This trend is likely to continue and will also be supported by the EU's Emission Trading System that will put a price on carbon from heating fuels starting in 2027, revisions to the EU F-gas Regulations,[11] and member countries' plans to cut value-added tax (VAT) on heat pumps (European Commission 2023, Evans 2017)

[10] Per IEA's analysis, global AWHP heat pumps annual growth rate between 2021-22 was 24% whereas air-to-air was 5%.

[11] For many manufacturers R-290 has become the refrigerant of choice in preparation for the F-gas Regulation revisions that extend F-Gas measures and ban GWPs >150 starting in 2027.

## Heat Pump Trends

One hundred eighty million heat pump units were in operation in 2020, used mainly for heating purposes. While North America reportedly has the largest capacity of heat pumps installed today, this is driven predominantly by residential units with air-to-air models in ducted air systems. In contrast, the number of AWHPs installed for building heating and cooling is small compared to the European market, which has been widely used for over a decade, as illustrated in Figure 14 (EIA 2023; EHPA 2023).

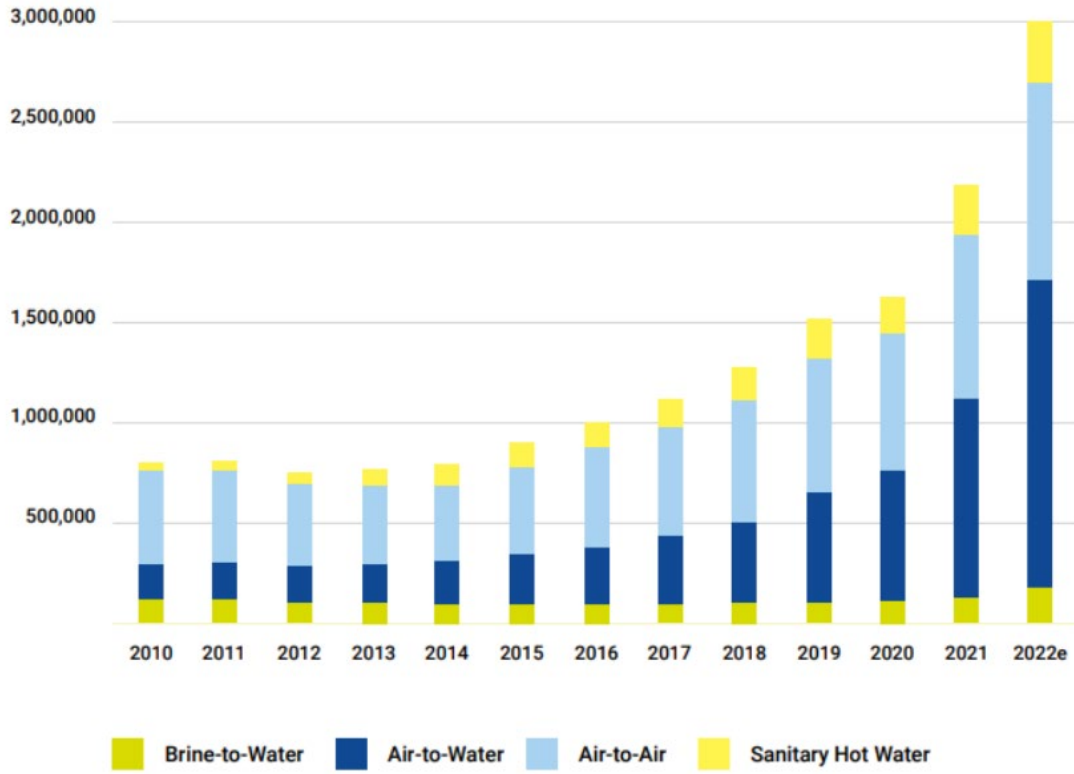


**Figure 14: Heat Pump Sales in 21 European Markets per type of technology**

Source: EPHA 2023

As noted above, Europe is one of the largest markets for AWHP and currently accounts for approximately 32 percent of global AWHP revenue (Global Market Insights, 2023). France has the most significant number of AWHPs, accounting for 35.5 percent of the market, followed by Italy and Germany; AWHPs are also growing in popularity across many other member countries, and the REPowerEU measure aims to have 30 million AWHP installed units by 2030—that represents 7/10 heating systems (ATMO 2023). Well-known manufacturers are positioning to take advantage of this trajectory as the most straightforward pathway for their businesses from fossil fuel-based to electric-based equipment (see Figure 15).

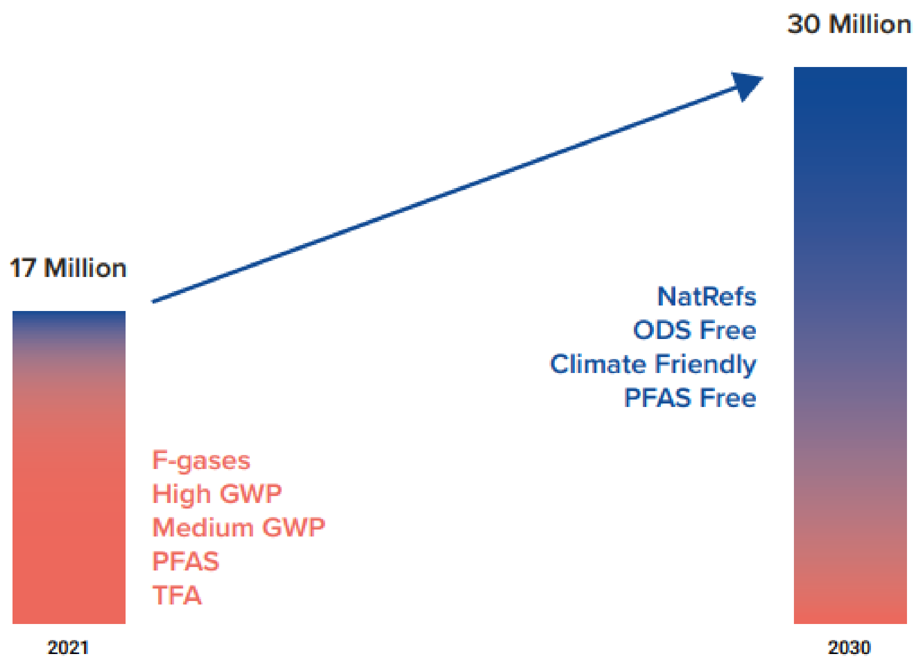


**Figure 15: AWHP installations in Europe and companies having natural refrigerant heat pumps in their portfolio, with characteristics shown of refrigerant types shown in red (fluorinated gases, high and medium Global Warming Potential, per- and poly-fluorinated substance byproducts, and tri-fluoroacetic acid byproducts) and blue (natural refrigerants, free of Ozone Depleting Substances , climate friendly, free of per- and poly-fluorinated substance).**

Source: Chasserot et al. 2023

For example, a major manufacturer has installed 1.2 million hydronic heat pumps in Europe since 2006 and plans to expand local production capacity and invest in new manufacturing sites and training centers (EMEA Startups, 2023). Also, another major manufacturer is promoting AWHP across Europe, noting the scale of the market, refrigerant regulations, and ability to utilize existing home heating systems as attractive characteristics (Jeong, 2022). In 2020, it saw a 100 percent increase in its Therma V AWHP. Similarly, AWHPs are cited as the most popular systems in Ireland—namely for their ease of installation, cost, and comparable efficiencies to GWHPs; in 2021, they represented 90 percent of installs (Irish Times, 2022).

Outside of Europe, AWHP is also increasingly popular in the UK, boosted mainly by the Energy Security Bill and Heat and Building Strategy,[12] which are expected to reduce the cost of AWHP by 25-50 percent by 2025 (GreenMatch, 2023). China and Japan are also significant markets for AWHP installations and serve as the main headquarters for 70 percent of the world's heat pump companies (IEA, 2023)

While most of the attention around AWHPs is being directed at the European market for now, past trends indicate that as significant economies, including the U.S., continue to increase their energy

[12] The UK Heat and Building Strategy outlines the implementation pathway for Britain to meet its goal to install an additional 27 million heat pumps by 2050.

performance requirements[13] for both new and existing buildings and align financial incentives to support these, many aspects of AWHP technology will migrate from these mature markets.

## AWHP Technology Trends

AWHP systems—monoblocs or splits—present various energy-saving options for a home's heating and hot water system. As discussed earlier in this report, the terms 'split' and 'monobloc' refer to the heat pump unit configuration, whether the refrigerant circuit is self-contained in a convenient and safe outdoor unit or split into an indoor and outdoor unit. The monobloc system's design, installation, and maintenance advantages have made it the preferred heat pump for existing residential buildings across the UK and Europe, given the older age and space-limited characteristics of Europe's building stock. In contrast, the split system is more often leveraged for more complex installations such as apartment buildings (WOLF, 2023). The monobloc's design also alleviates safety concerns and perceived risks associated with A3 refrigerants such as R-290.

## R290 AWHP Adoption and Market Trends

While the global R290 AWHP market is not yet mature, it has grown exponentially since 2016. Data collected on heat pumps installed in Germany under their market incentive program (MAP) clearly illustrates this trend (see Figure 16).

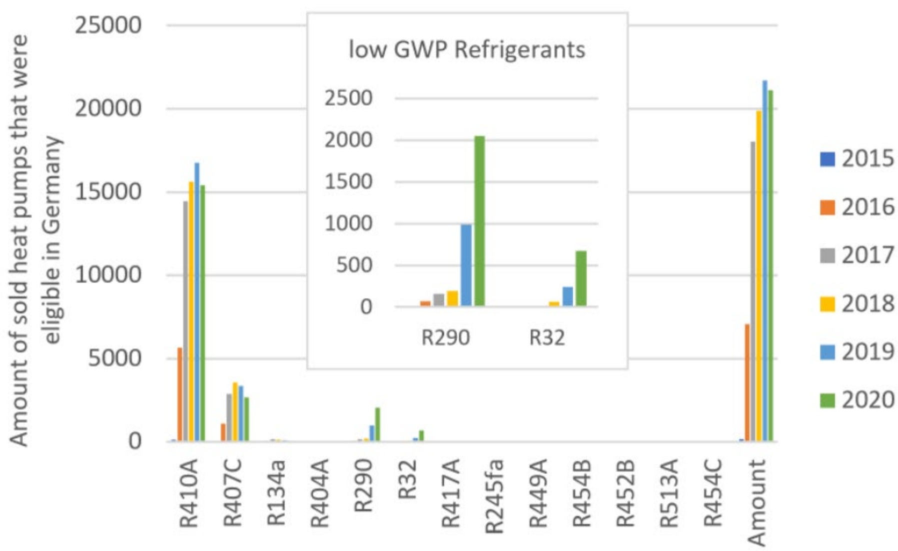


**Figure 16: Data collected on heat pumps installed in Germany under their market incentive program (MAP)**

Source: Market Incentive Program (MAP)-Antragsdaten, BMWK, 2022, as presented by Fraunhofer ISE on 10.10.2022

R-290 has become the refrigerant of many manufacturers in preparation for EU F-gas regulatory requirements[14]. Several manufacturers have actively promoted their commercially available R-290

[13] In the United States, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), published in 2023 zero net energy and zero net carbon standards for buildings operations.

[14] The EU F-Gas proposal bans systems with GWP >150 by 2027. This supports the market adoption of hydrocarbon-based appliances such as R-290 heat pumps.

products for years; others are just launching their lines[15]. All have witnessed record orders and interest in R-290 from customers across Europe. For example, a Chinese heat pump manufacturer, saw sales of its residential R290 AWHP quadruple in 2022 compared to 2021.

The soaring volume of orders aligns with the global trends noted above, and leading industry figures, such as Van Der Hoff, CEO of TripleAqua, expect this to continue. Based on data shared at the most recent ATMO Europe conference, Van Der Hoff stated he expects the natural refrigerant heat pump market to grow at an average rate of 9.5 percent from 2022 to 2027 (from $5.8 million to $9.8 million). He also spoke about the clear refrigerant performance efficiencies of R-290 over R32 units (Koegelenberg 2022), a fact that was first highlighted by AHRI's Low-GWP Alternative Refrigerants Evaluation Program (AREP) in 2015 (Stöben et al., 2016) and further documented by the Heat Pump Keymark database (Cao and Hwang 2022). Both identify and confirm that R290 AWHPs consistently show higher COP than f-gas equipment. The later research, which leveraged insights from the Keymark database,[16] also illustrated the number of R-290 AWHP models available on the market.

### R290 Safety Testing

R-290 is already used in many other types of commercial refrigeration around the globe and the US. An IEC safety standard already exists for R-290 in heat pumps and has been adopted by numerous countries and harmonized under EU safety standards. Validate safety testing of R-290 in residential HVAC use has also been completed. For example, publicly available reports highlight the successful testing of an R-290 AC in Thailand in 2020 (Everitt 2020; RAC NAMA 2020). The test process was carried out by the Thai Refrigeration and Air Conditioning National Appropriate Mitigation Action (RAC NAMA), a project commissioned by the German and British governments. The findings showed that R-290 is safe if applicable safety standards EN 378-2:2016 and IEC 60335-2-40 are met and if installation and services are conducted by trained technicians who adhere to the requirements of the standards. As a result of this test, the Thai Standard Institute (TISI) is now updating its national standard to reflect these findings and has asked the Thai government to review its building codes to ensure they reflect these changes as well.

### AWHP Training and Certification Requirements

Ensuring contractors are trained and able to comply with local regulations and codes will be essential for R-290 AWHP installation and maintenance. The skills, tools, and safety procedures needed to work with A3 refrigerants differ from those of conventional non-flammable A1 synthetic refrigerants. That said, A2L training and retooling functionally should do a great deal to bring HVAC technicians up to the preparation level of refrigeration technicians in handling A3 refrigerants.

Across the EU, training and certification courses on using flammable refrigerants in AC and heat pumps (A2L, A2, and A3) are already offered. Courses cover installation, testing, servicing, and maintenance best practices alongside specific requirements when using different refrigerant classifications in various applications, as outlined by safety standards EN 378.

[15] More than 40 companies exhibited R-290 based heat pumps at the March 2023 ISH International Trade Show in Germany

[16] The Keymark database is a voluntary independent European certification mark for all heat pumps sold.

Further, in response to the EU's stricter F-gas regulations that will ban refrigerants with GWPs over 150 in split systems in 2024, four European training providers and Italian HVAC equipment manufacturer Clivet have joined forces to offer R-290 focused training for split systems (Cooling Post 2022).

Training began in 2022 and is aimed at technicians who may already be F-gas certified but do not have experience handling more flammable refrigerants. This new training initiative aims to assist with reskilling the existing workforce to ensure the safe adoption of R-290 in split systems by 2024. The training will provide a certification already recognized in 20 countries globally and translated into 17 languages.

With a lack of trained technicians often cited among the main barriers to adopting HVAC in the US, replicating what the EU has done to provide proper training and adherence to necessary safety standards and guidelines can overcome such issues. Technicians are already going to have to retrain to handle A2Ls. This also presents an opportunity to introduce A3 and ready the market for when R-290 split systems are made available. In the meantime, as detailed throughout this report, the immediate market introduction of the R-290 monobloc system, requires no retraining, retooling, or certification, and presents an immediate opportunity to positively engage and position plumbers and pipe fitters in building decarbonization efforts, individuals that otherwise may feel disenfranchised by a focused effort to phase out fossil fuel systems.

## Review of Relevant International and US Regulations, Standards, and Codes

Across the US, there exists a lack of regulatory certainty and no clear policy consistent with international or European standards. The following section reviews the key bodies, current language, and actions that support the use of R-290 in a residential AWHP to highlight a pathway for adoption in the US that will support policymakers and manufacturers alike.

### Relevant International Standards

#### THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

The International Organization for Standardization (ISO) is a worldwide federation of national standard bodies that support the development of international standards through technical committees. It collaborates closely with the International Electrotechnical Commission (IEC) on all matters related to electrotechnical standardization. The current ISO standard 817:2014 (EN) establishes the system for assigning a safety classification to a refrigerant based on toxicity and flammability. It references the American National Standards Institute (ANSI)/ASHRAE Standard 34 and the American Society for Testing and Materials (ASTM) E681. It classifies R-290 as an A3 refrigerant but does not discuss charge limits, or limits associated with system design.

#### THE INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

The IEC develops global standards for electrical and electronic products often included or referenced in other mandatory standards, such as Underwriters Laboratories (UL) standards and European Standards (EN). IEC 60335-2-40 is the international safety standard for electric heat pumps, hot water heaters, air conditioners, and dehumidifiers. The standard is currently used as the basis for the design evaluation, testing, and certification of HVAC equipment using low-GWP refrigerants in places such as Europe. The IEC 60335-2-40 code allows up to a 4.9 kg charge size of A3 refrigerant in outdoor units, and recent revisions to this standard (seventh edition) permit a larger charge size of

R-290 (up to 988g / 2.18lbs of R290 from 150g) for a standard sized fixed air system[17] (Everitt, 2022a).

IEC compliance is voluntary, but IEC standards are often adopted in part (or full) by countries' legislators and technical committees. EN typically adopts IEC standards in total, but adoption is not default. The EU has encouraged member countries to adopt revisions to IEC 60335-2-40 into national legislation.

The US does not directly recognize IEC standards. However, they do recognize other standards like those developed by ANSI and ASTM. ASTM and ANSI may cooperate with the IEC to develop new ASTM and ANSI standards, referencing IEC standards. The US also recognizes UL standards, sometimes based on IEC standards.

Manufacturers should generally comply with IEC standards, especially for emerging technologies, as an IEC standard may be published before a corresponding EN or UL standard.

### INTERNATIONAL ENERGY CONSERVATION CODE (IECC)

The International Energy Conservation Code (IECC) establishes minimum energy-efficient building requirements using prescriptive and performance-related provisions. It was developed and published by the International Code Council (ICC) and addresses residential and commercial buildings. It is fully compatible with all other international codes.

The US Department of Energy has codified the IECC as the baseline Federal building standard in its existing energy efficiency standards. Alongside ANSI/ASHRAE/IEC 90.1, IECC is the main baseline energy conservation code. Most U.S. jurisdictions have adopted the 2012, 2015, 2018, and 2021 codes, ANSI/ASHRAE/IEC 90.1, or both.

Updates to the 2024 International Building, Fire, and Mechanical Code (IBC, IFC, and IMC) permit using A2L refrigerants for human comfort uses, consistent with industry standards, were made available in August 2022 (ICC 2022). To comply with these changes, states must amend their existing building, fire, and mechanical codes to ensure they are consistent and have been encouraged to work with the Code Council to help support adoption.

This presents an opportunity for California to consider early adoption of IEC standards, as noted above since they are already changing their building, fire, and mechanical codes to be consistent with the 2024 updates to the IBC, IFC, and IMC.

### EUROPEAN STANDARDS (EN)

EN are technical standards drafted and maintained by the European Committee for Standardization. The various committees create them and interested parties through a transparent and consensual process.

EN 378:2-2016 is a European standard for refrigerating systems and heat pumps that specifies the safety and environmental requirements. It is the most critical standard in adopting R-290 AWHP

[17] Split systems with less than 150g of R290 have been available in Europe for several years. Typically, the safety of these systems has been based on minimizing the charge size. This change will likely support a broader product range of R290 split-systems, many potentially suitable for renovating old apartment buildings.

technology related to product development and is generally harmonized with IEC 60335-2-40 (although the most recent revisions have not yet been included).

### TÜV SÜD

TÜV SÜD is a leading globally recognized testing and certification organization. It provides independent laboratory testing, electrical safety compliance certification, and targeted field labeling for three major world markets, including the United States (UL/ANSI), Canada (CSA), and Europe (EN/IEC).

It currently operates the most prominent independent European testing laboratory for refrigeration and air-conditioning technology in Olching near Munich, where the safety, reliability, and environmental compatibility of HVAC systems and equipment like heat pumps are tested. It also performs safety testing and certification across the U.S. and Canada. In California, TÜV SÜD has a nationally recognized testing laboratory in San Diego. This serves all of the West Coast of the USA and offers third-party compliance testing and certification services, which are recognized worldwide and by industry associations such as AHRI and AHAM.

Within the US, TÜV SÜD offers a unique program that authorizes a manufacturer's facility and staff to perform product safety testing themselves. Test results are reviewed and approved by TÜV SÜD engineers, allowing proper certification to be applied to the product. This process helps organizations drastically reduce their overall product compliance costs while simultaneously accelerating the compliance process by eliminating duplicate testing schemes.

To participate in the TÜV SÜD ACT program, a manufacturer must possess and maintain the capabilities to test their products to relevant safety standards. This is assessed by an on-site audit based on EN 45001 (General Criteria for the Operation of Testing Laboratories) and ISO/EN 17025 (Guide 25). Alternatively, approved internal programs from UL can demonstrate compliance.

American states, counties, and municipalities can introduce their own safety standards (see authority having jurisdiction (AHJ) commentary below). Assuming a manufacturer located in the US has demonstrated testing abilities based on UL requirements, it could theoretically also seek TÜV SÜD standard approval of its own R-290 AWHP product by using its testing facilities as an on-site TÜV SÜD facility.

### ELECTRICAL TESTING LABORATORIES (ETL)

Intertek Testing Services, a global testing, inspection, and certification company, administers the ETL certification mark. It is one of the Nationally Recognized Testing Laboratories (NRTLs) approved by the Occupational Safety and Health Administration (OSHA) in the United States. ETL certification covers various product categories and standards, including electrical and electronic devices, appliances, lighting, industrial equipment, and more. It indicates that a product complies with the safety standards required for market access in the United States and Canada.

Intertek Testing Services has thousands of labs worldwide and a testing facility in southern California. Like TÜV SÜD, an ETL certification is equivalent to a specific UL standard. As noted above, a US manufacturer could work with Intertek Testing Services to demonstrate safety testing to IEC standards and position for compliance with any AHJ requirement that incorporates elements related to emissions reduction strategies or other environmental regulations addressing issues like air quality or water management.

## US Federal Regulations

### AMERICAN INNOVATION AND MANUFACTURING ACT

The American Innovation and Manufacturing (AIM) Act, passed into law in 2020, gives the EPA authority to phase down HFC consumption and production by 85 percent by 2036. This phasedown will happen on a schedule with phases corresponding to periodic step-downs, as shown in Figure 17.

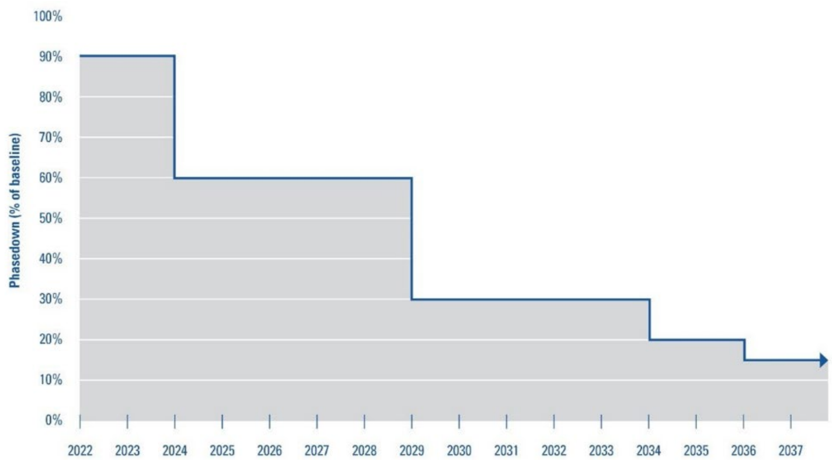


**Figure 17: US AIM Act HFC phasedown schedule.**

Source: USEPA 2023a

As part of its work to meet the AIM Act-mandated schedule, the EPA makes rules about what refrigerants can be used in new equipment by specific dates. These rules set GWP maximum values or "ceilings" for all new and essential equipment by specific equipment type, HVAC sector, and subsector. The "HFC Technology Transitions Rule" proposed in 2022 under Subsection (i) of the AIM Act will restrict the use of refrigerants in residential air conditioning and heat pump systems to a GWP value of 700 or less, beginning January 1, 2025 (USEPA 2023a). This rule is intended to meet the EPA's goals to reduce domestic HFC consumption by 40 percent of the AIM Act's baseline during the phasedown period between 2024 and 2029 (see Figure 17).

When the next phasedown period begins in 2029, the GWP ceiling for HVAC equipment in this category will be reduced even lower than 700, and the value expected for rulemakings issued during that period by industry experts is between 150-300. None of the currently available synthetic-refrigerant-based products for residential heat pump systems have refrigerant GWP values lower than 450.

Lawmakers created the AIM Act's GWP ceilings because climate experts calculated them as necessary to address climate change on a meaningful timescale. Natural refrigerants such as propane are the only available HVAC working fluids with low enough GWP values to meet all future phasedown period restrictions. Using flammable A3 substances like R-290 safely will require new skills, tools, and safety procedures that differ from those used with A2L refrigerants. Since A2L refrigerants installed now cannot be replaced as a "drop-in" with a natural refrigerant since the overall product design and safety considerations differ if systems are installed now with synthetic "slightly flammable" refrigerants categorized as A2L by ASHRAE, then another expensive and complex technology transition from A2L to A3 refrigerants will be required as the AIM Act timeline progresses (Rajendran and Butsch 2023, ASHRAE 2022b).

#### EPA SIGNIFICANT NEW ALTERNATIVES POLICY (SNAP)

The US EPA's Significant New Alternatives Policy (SNAP) is a program regulated by section 612 of the amended US Clean Air Act of 1990. Section 612 requires the EPA to assess and recommend substitutes for ozone-depleting substances to reduce risk to human health and the environment. Under SNAP, the EPA creates lists of substitutes that are "acceptable," "unacceptable," or "acceptable subject to narrowed use conditions" based on the industrial use sector. Substances deemed "acceptable without restriction" are regularly released in numbered "Notices of Acceptability" (USEPA 2023d).

Propane (R-290) was listed by SNAP in 2015 as an "Acceptable Substitute in Residential and Light Commercial Air Conditioning and Heat Pumps" for use in new self-contained room air conditioning and heat pump equipment "designed for use in a single room." The 2015 rule also allows R-290 in household refrigerators and freezers, window AC units, wall-mounted AC units, ceiling-mounted AC units, and portable room AC units, with corresponding charge limits (USEPA 2015, 2023e).

The reference to the 2015 rule on SNAP's current list (posted online) means that R-290 is allowed in residential heat pump systems in the US, but only as packaged single-room units. There is no listing for using R-290 in EPA's SNAP rules for systems designed for more than one room in a home, which leaves R-290 AWHP systems in a SNAP regulatory gap. While a home could have multiple single-room units installed, reaching a total charge for the home far above the limits outlined by SNAP, there is currently no larger charge limit allowed for packaged residential heat pump systems.

References to UL HVAC product codes and ASHRAE standards in SNAP rules further complicate the designation of "acceptable" substitute refrigerants. According to the text of the rules, SNAP rules take their charge limit requirements from UL and ASHRAE standards, and in the event of any conflict, the EPA requires compliance with the most conservative option. So, product codes and safety standards created by non-EPA entities (UL and ASHRAE) may determine what is allowable by EPA.

### National Standards and Codes

#### ASHRAE STANDARDS 15 AND 34

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is an American professional association accredited by ANSI. It provides technical guidance based on the best available knowledge around HVAC/R. Among other activities, ASHRAE develops and regularly publishes updates to its Safety Standard 15 for Refrigeration Systems and Safety Standard 34 for Designation and Safety Classification of Refrigerants. The most recent versions of both standards were released in 2022.

ASHRAE Standard 34 establishes the refrigerant numbering system and specifies the safety classification system previously discussed in the Background section of this report and shown in Figure 2.

ASHRAE Standard 15 outlines rules for human safety in installing and using commercial refrigeration equipment and systems. It is the basis for the International Code Council's International Mechanical Code, the International Association of Plumbing and Mechanical Officials' Uniform Plumbing Code, and most federal, state, and local building safety regulations (ASHRAE 2013).

ASHRAE Standard Section 15.2 is the Safety Standard for Refrigeration Systems in Residential Applications, and the 2022 version of Standard 15 excluded it from the scope of the 2022 updates to the standard, so ASHRAE 15-2022 does not apply to residential HVAC applications.

ASHRAE has released a 2022 update to standard section 15.2, but it does not address the use of A3 refrigerants—it only provides updates to the allowable use of "slightly flammable" A2L refrigerants. Therefore, the relevant ASHRAE residential standard for residential, low-leak-probability systems such as R-290 AWHPs is found in the most recent older versions of ASHRAE Standard 15, which are from 2019 and 2016. Section 7.5.3 of the 2019 and 2016 ASHRAE Standard 15 states that "Group A3" refrigerants are prohibited except for "portable unit systems containing no more than 150 grams of Group A3 refrigerant." Compliance with UL codes is also explicitly required in the ASHRAE standard. UL code requirements for residential HVAC will be discussed later in this Report.

ASHRAE Standard 15 sets overall guidelines for technician installation and maintenance procedures, such as the allowable room size based on charge size for indoor spaces where the refrigerant charge could leak, ventilation requirements for closed spaces, and cylinder storage practices. However, the current ASHRAE standard does not state that R-290 may be used in residential systems at different charge sizes in AWHPs or other HVAC products that contain all refrigerant in factory-sealed, entirely outdoor units (which are "low probability" concerning leaks, according to the ASHRAE definition) than the R-290 charge limits for sealed, "portable" HVAC units.

A proposed addendum to Standard 15 would amend section 15.2, Safety Standard for Refrigeration Systems in Residential Applications, to allow up to 4.9 kilograms (10.9 pounds) of A3 refrigerants in outdoor-unit-based heat pump systems in the US (Garry 2023).

### AIR-CONDITIONING, HEATING, AND REFRIGERATION INSTITUTE (AHRI)

ANSI accredits the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) for developing American National Standards (ANS) and the Standards Council of Canada (SCC) for developing National Standards of Canada (NSC). AHRI has developed over 100 performance rating standards and guidelines for the HVAC, refrigeration, and water heating industry. Standards are intended to comply with internationally accepted standard principles and best practices and are not designed to introduce barriers or discriminate against products based on place of origin. They are developed to promote consistency in manufacturer specifications and ensure relevant technical regulations and requirements are met regarding legitimate sectoral or local requirements for compatibility, environmental protection, health, and safety (AHRI 2023).

AHRI has several standard subcommittees responsible for finalizing AHRI standards and guidelines and assuring the maintenance of published standards and guidelines. They are also responsible for identifying gaps, addressing harmonization amongst standards and guidelines, and forming standards technical committees to develop, approve, and maintain one or more standards and guidelines.

In September 2023, AHRI created a new AWHP Standards Technical Committee. This committee will be responsible for developing and maintaining AHRI standards and guidelines about consumer AWHP that are single-phase, have rated output capacities below 100,000 Btu/h, are intended for space conditioning applications, and may optionally include domestic hot water capability. There is no current standard in place. This subcommittee's work will be important in shaping market considerations for R-290 AWHP and driving the potential harmonization efforts with other internationally accepted standard principles.

### AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI is the national standards body for the United States. Technically speaking, ANSI does not develop standards but provides a framework and administers the procedures by which other organizations can create standards. ANSI has no enforcement over any standard created.

### UNDERWRITERS LABORATORIES (UL) CODES

Underwriters Laboratories, Inc. is an American private company developing product standards known as UL codes, and ANSI accredits it. These codes are currently referred to in EPA SNAP rulemaking and dictate what refrigerants and charge sizes are allowed in HVAC and refrigeration equipment.

UL 60335-2-40: Standard for Household and Similar Electrical Appliances-Safety-Particular Requirements for Electrical Heat Pumps, Air-Conditioners, and Dehumidifiers covers a wide range of HVAC products. It currently limits propane (R-290) to small HVAC and refrigeration applications within the US due to flammability concerns, although a recent safety code update for commercial refrigeration equipment raised the upper limit from 150 grams to 300 grams for closed cases and to 500 grams for open cases (UL 60335-2-89 2021). US grocery and convenience stores that, with propane equipment, meet their cooling demand by using many of these small charge-size R-290-based refrigeration/cooler units. However, larger charge-size units inside buildings are not yet allowed (Rajendran and Butsch 2023, UL 60335-2-40 2022). Indoor charge limits remain a barrier to using R-290 in larger HVAC systems, such as split systems or VRF systems with refrigerant lines inside the building.

As discussed in the previous section on federal regulations, UL HVAC product codes were used to develop the current EPA SNAP listing for R-290, which is only explicitly allowed in residential heat pump systems as packaged single-room units. The codes do not include allowable R-290 charge sizes for systems designed for more than one room in a home, therefore leaving out R-290 AWHP systems. While a home could hypothetically install multiple single-room units, reaching a total charge for the home far above the limits outlined by these codes, there is currently no larger total charge limit designated for larger residential heat pump systems.

The most recent fourth edition updates to the UL 60335-2-40 focused only on changing requirements for A2L refrigerants, not A3s. Therefore, the prior UL code edition limit for AC and heat pump systems with flammable refrigerants remains applicable, and it designates a maximum charge limit for A3 of 3 times the Lower Flammability Limit (LFL) for self-contained equipment (m1) based on Clause GG1.2, which equals 114 grams total maximum charge.

The seventh edition IEC 60355-2-40 code updates were done based on extensive research over seven years and were adopted by a universal consensus vote by 17 countries in May 2022, including the representative US National Committee. Requests have been made for the UL code to update to align with the most recent, seventh edition of the IEC code 60355-2-40, which allows up to 988 grams of R-290 in indoor and split-style fixed HVAC units, as well as up to 4.9 kilograms for factory-sealed outdoor type systems such as AWHPs.

Future editions of the UL codes will consider the broader use of R-290, but the timeline and outcome of any A3 updates are still unknown (Rajendran and Butsch 2023). If the proposed A3 refrigerant Addendum to Standard 15.2 discussed in the previous section is adopted by ASHRAE, then UL will review it for adoption in its corresponding product codes.

## California Policies and Codes

### CALIFORNIA AIR RESOURCES BOARD (CARB)

CARB develops and oversees the state's air quality regulations, including those governing GHG emissions reduction. According to the text of the most recent CARB rule makings, natural refrigerants' ultra-low GWP values will meet the requirements of all future phasedown periods. A GWP ceiling for refrigerants in the new residential heat pump 750 will take effect on January 1, 2025, indirectly banning R-410A at the state level at the same time as the federal AIM Act.

In its published 2020 rulemaking, CARB clearly stated that state refrigerant GWP limits were intended to encourage innovation and to push the state toward new technology and that the California Building Code requires updates to allow the safe use of certain next-generation refrigerants in some types of HVAC equipment (CARB 2020).

### CALIFORNIA BUILDING CODE

The California Building Standards Code, like other state-specific codes, consists of a series of model codes, such as the electrical code, mechanical code, and fire code, and is designed to protect public health, safety, and general welfare as they relate to the construction and occupancy of buildings and structures. The California Building Standards Code, or California Building Code, is in the California Code of Regulations, Title 24. The California Mechanical Code is a section (Part 4) of the California Building Standards and includes safety requirements for refrigeration and AC systems. The California Building Standards Code and its subsection, the California Mechanical Code, are state laws. Standards and codes developed by non-governmental entities are enforced at the state level through the California Building Code (CARB 2020).

The current California Mechanical Code for HVAC equipment (2022 version) requires that the 2016 versions of ASHRAE Standards 15 and 34 be adhered to for HVAC installations within the state. Since ASHRAE standards do not say that R-290 or A3 refrigerants may be used in factory-sealed outdoor units for multi-room heat pump systems, the California Mechanical Code does not create a clear path to their use in residential monobloc AWHPs.

California Title 24, Part 4 of the Mechanical Code allows slightly flammable A2L synthetic refrigerants in HVAC systems for commercial buildings. The California State Fire Marshal proposed using A2Ls in residential HVAC systems. This was approved on June 27 and August 1 by the Building Standards Commission to go into effect in July 2024 (CABSC 2023). However, A3 refrigerants have not yet been proposed by the Office of the State Fire Marshal nor approved by the Building Standards Commission for use in residential buildings.

#### AUTHORITIES HAVING JURISDICTION (AHJ)

"Authority Having Jurisdiction" (AHJ) refers to an organization or individual with the legal power to enforce building and electrical codes, fire safety standards, or other regulations within a particular jurisdiction designed to ensure the safety of structures and their occupants. The AHJ can vary depending on the context and the nature of the regulations involved. It could be a government agency at the local, state, or national level, or it might be a specific department within a government. In some cases, the AHJ could be a fire marshal, a building code inspector, a zoning official, or a regulatory body, depending on the specific area of concern.

In addition to ensuring that established standards and regulations are adhered to, some jurisdictions may have specific local amendments to the adopted codes. These modifications or additions are made locally to address specific regional concerns, environmental conditions, or other factors related to how a building meets a specific health, safety, and welfare criterion. In this context, an AHJ can decide to incorporate and enforce specific consideration of building practices that support specific efficiency or GHG reduction requirements.

Across CA, there is already an increasing awareness by AHJs to integrate environmental considerations into building regulations. Many city jurisdictions have incorporated sustainability criteria into their codes and practices by requiring standards such as LEED or Net-Zero[18] for their residential and commercial buildings (Ramanujam 2019). Community Choice Aggregators (CCAs), Peninsula Clean Energy (PCE), and Silicon Valley Clean Energy (SVCE) are also working with cities and counties within their jurisdiction to adopt building codes that go above California mandates and national model code requirements (Woodruff 2019). New and upcoming regulations around NOx emissions[19] will also likely focus AHJs attention on the adoption of zero-emission appliances, and the rapidly evolving legal landscape around PFAS will necessitate a focus on refrigerants and elevate naturals as the only PFAS-free option and choice (Whitehouse 2023).

### Regulatory Path to R-290 AWHP Adoption in California

Although the US AIM Act is driving the domestic HVAC market toward ultra-low GWP refrigerant options, the federal path to R-290 in residential multi-room heat pump equipment appears to pass through updates to ASHRAE standards and UL HVAC product codes. US HVAC industry representatives and the US Energy Information Administration have shown public support for harmonizing U.S. safety standards and building codes with other international equivalents that enable the safe use of A3 refrigerants in outdoor equipment such as monobloc AWHPs. Current international standards and codes, including IEC 60335-2-40, allow up to a 4.9kg charge size of A3 refrigerant outdoors (Garry 2023).

California has been a national leader in GHG emissions reduction legislation at the state level, and there is an opportunity for the state to forge a faster path to R-290 and A3 refrigerant use in HVAC equipment, including residential AWHPs by following the lead of international markets. In Europe, R-

[18] Sacramento, San Diego, San Fransisco, San Jose all require LEED certification per their building ordinance.

[19] The Bay Area Air Quality Management District (BAAQMD) and the South Coast Air Quality Management District (SCAQMD) are also currently developing regulations to regulate NOx emissions in space and water heating.

290 AWHPs are supported by clearly established equipment safety and performance standards such as EN 378-1:2016, which guides the safe use of R-290 as a refrigerant in heat pump systems. Standards for using R-290 as a flammable refrigerant in heat pumps in the US have not kept up with the international HVAC sector, limiting market confidence for US manufacturers and public perception of safety.

If the California Building Code referred to European product standards as an acceptable alternative to UL, or if the state could develop a unique rating standard specifically for cutting-edge refrigerant technology, it is possible that equipment could make its way into homes years sooner than waiting on updates to US national standards by UL and ASHRAE.

Currently, existing regulation in the U.S. only permits 150 g (0.3lb) of R290 in residential HVAC equipment. However, these national regulations could be harmonized with the IEC as many other IEC-participating countries do. Also, every US state, county, and municipality can introduce its safety standards. As such, CA could choose to be an early adopter and align its local standards with IEC and/or EN standards, while groups like the Environmental Investigation Agency (EIA) continue to push for harmonization of national and international standards that accept R-290 for use in heat pump applications where the refrigerants remain outdoors.

Whether an alternative California A3 HVAC product approval pathway is created or A3 allowance updates are made at the federal level, state fire safety officials must be updated and encouraged to propose the addition of A3 refrigerants to building codes to the Buildings Standards Commission as soon as possible.

# Recommendations

## R-290 AWHPs are Poised for Rapid Uptake in California

AWHPs generally (and R-290 AWHPs in particular) have great potential to drive not just electrification but total decarbonization results for California in single-family homes. Market forces already at work as part of the clean energy and lower-GWP refrigerant transition are creating the potential for California to enjoy the same rapid uptake of near-zero GWP R-290 AWHP seen recently in international markets.

The following actions are recommended for utilities and other key stakeholders to promote and facilitate the significant adoption of R-290 AWHPs within the state .These initiatives will help align efficiency programs with TSB metrics, ensure ongoing-compliance with emerging environmental regulations concerning PFAS and related forming substances. Additionally, they will secure future compliance with the GWP phasedown requirements stipulated under the AIM Act.

### 1. R-290 AWHPs Incentives

Starting January 1, 2024, IOUs must demonstrate their portfolio performance in alignment with the TSB. This metric encourages programs to target efficiency measures that maximize longer-duration GHG reductions and deliver grid benefits. Utilities should invest in the ongoing review of AWHPs as an energy efficiency measure against the Total System Benefit metric as a priority.

Further, the incentivization of R-290 AWHP+TES presents a single single-end-to-end decarbonization strategy for both retrofit and new construction. It ensures alignment in perpetuity with TBS metrics as R-290 AWHPs deliver building electrification with no significant $CO_2e$ penalty from the refrigerant leaks' endemic to all heat pump technology.

### 2. AWHP Thermal Energy Storage Incentives

As equipment capable of incorporating thermal energy storage into AWHP systems becomes increasingly available to the California market, the value under the TSB metric will likely be significantly improved. It will require separate measurements and demonstrations and further updating of the measured value to the grid and atmosphere.

Utilities should incentivize indirect domestic hot water heating/storage tanks connected to AWHPs in the same way they incentivize heat pump water heaters for retrofit and new construction. AWHPs accomplish the same result and have the added benefit of eliminating the need for a separate circuit and heat pump with additional refrigerant. Further, a single central heat pump for space conditioning and DHW can avoid triggering a panel upgrade for heat-pump-driven hot water heating. These avoided costs for electrical upgrades and avoided separate equipment are particularly valuable to disadvantaged communities and ratepayers with high energy burdens.

### 3. R-290 AWHP Adoption Pathway for Retrofit and New Construction

Authorities Having Jurisdiction reference IEC standards to support adoption while manufacturers leverage Nationally Recognized Testing Laboratories to secure product certification.

The regulatory and standardization process is intrinsically intertwined, and utilities, along with the California Energy Commission, can encourage and support other actors who have overlapping interests and related purview to achieve the state's net-zero GHG emissions policy objectives, mainly the Short-Lived Climate Pollutant emissions reduction target of 7.5 million MTCO2e. The following recommendations delineate potential simultaneous collaborative efforts needed among these entities to attain this objective.

### AUTHORITIES HAVING JURISDICTION (AHJS)

Collaboration between utilities and AHJs is common to ensure the safety, compliance, and reliability of utility services within a given jurisdiction. While AHJs may not be the sole authority addressing broader environmental concerns, their role in enforcing codes and standards can indirectly contribute to environmental goals, including reducing carbon emissions through energy-efficient building practices.

The evolution and adoption of net zero building codes across California, Washington, DC, New York City, and Massachusetts exemplify how this relationship creates precedence for compliance pathways that go beyond code and influence utility program design and incentive strategies. Local building codes and performance mandates that limit existing building emissions, such as New York City's Local Law 97, further highlight the ability of AHJs to create complex compliance structures that are singularly focused on driving decarbonization investments.

As noted in this report, numerous cities across California are already adopting building codes that go above California and national model code requirements, and it is highly likely that as new and upcoming regulations around NOx emissions and PFAS containment evolve, natural-refrigerant technologies will become the required future-proofed strategy to adopt across all sectors.

For California to support the market reality of this technology today—and avoid locking in unnecessary emissions with mid-GWP refrigerants (that are also PFAS)—AHJs have the ability and opportunity to lead by recognizing and harmonizing with IEC 60335-2-40 and support the immediate adoption of R-290 AWHP in monobloc design in both retrofit and new construction. When an AHJ also owns and operates a utility (such as the case with the municipal utility structure), an AHJ can significantly influence the introduction of these high-efficiency measures.

There are many municipal utilities throughout California, but if, for instance, California's largest municipal utility (that is also the largest in the US) Los Angeles Department of Water and Power (LADWP), or Sacramento Municipal Utility District (SMUD), or any of the municipal utilities serving the Bay area referenced their safety standards to IEC 60335-2-40, California could quickly achieve the downstream emissions reduction estimates and upstream grid emission benefits alluded to in this report.

Separately AHJs with existing building performance standards in place, or under consideration can revise and require these to focus on ultra-low GWP PFAS free refrigerant options to ensure they align with the current code and future legal and liability landscape . Simliarly, it will be imperative for the CEC to adopt this approach under its statewide building performance standard that is currently in development (SB 48) as a means to strengthen implementation of existing benchmarking law and achieve the state's GHG goals.

### CODE OFFICIALS

Code officials operate as a type of AHJ, dependent upon local enforcement procedures. Building codes are often considered hindrances to adopting flammable refrigerants, even if other flammable substances, such as natural gas, are already running through buildings for heating and cooking purposes.

Parties revising California building codes, such as the Office of the State Fire Marshall and Building Safety Commission, can ensure that current efforts include harmonization with the IEC 60335-2-40:2013 standard.

As noted above, building code officials and fire marshals are considered AHJs in many instances and, therefore, can require modifications or additional requirements to existing codes that may support broader environmental concerns. In this capacity, they can also serve as a critical advocate and have a platform to join other state, local, and national code officials to petition ANSI to adopt the IEC R-290 heat pump standard.

Separate from all other codes related actions, local building code officials should review the IEC 60335-2-40:2013 standard and UK outdoor location requirements for monobloc AWHPs and move to demonstrate and make locally acceptable the application of R-290 AWHPs with all refrigerant outside the building immediately. A coordinated working group of climate-progressive municipalities can share the tasks associated with such a review and the results of demonstrations of R-290 AWHP installations.

As discussed in the Findings section of this Report, the most recent edition of the UL 60335-2-40 codes made no updates to the unreasonably strict charge limitations for A3 refrigerants. UL codes have downstream effects on all federal-level standards and regulations.

The seventh edition IEC 60355-2-40 code updates made in 2022 were adopted by a universal consensus vote by 17 countries in May 2022, including representation from a US National Committee, based on extensive research and safety testing over seven years. Requests have been made for the UL code to update to align with the current IEC code 60355-2-40, which allows up to 988 grams of R-290 in indoor and split-style fixed HVAC units, as well as up to 4.9 kilograms for factory-sealed outdoor type systems such as AWHPs. AHJs and policymakers in California can leverage the extensive research and oversight of the IEC process by immediately supporting the use of IEC charge limits in R-290 and other A3 refrigerant equipment.

OEMs can support this effort by leveraging the installation experience of their EU/UK staff and have their US-version R-290 AWHPs certified as meeting the IEC 60335-2-40:2013 standard.

### MANUFACTURERS

As this report highlights, the industry is looking ahead to natural refrigerant options for products, and R-290 is considered to be a solid investment because of its efficiencies and because it does not generate PFAS in the environment. Original Equipment Manufacturers (OEMs) will move quickly and bring R-290 AWHP models to California when they receive clear support signals.

OEMs can partner in the short term with the most progressive utilities and AHJs to support local pilots and demonstration installations. They should also seek ETL or TUV-SUD certification leveraging California’s Nationally Recognized Testing Laboratories (NRTLs) and share these results with US national committees (e.g., AHRI subcommittee on AWHPs) to help national harmonization of codes and standards with IEC 60335-2-40 and SNAP approval.

Further, OEMs are in a position to support broad public outreach and education around propane (R-290) as a refrigerant (not a fuel) and support workforce development efforts that give boiler and furnace installers a heat pump option to profit from in converting gas-supplied properties to decarbonized and electrified heating and cooling.

These broader workforce initiatives are vital strategies that can be integrated into existing utility contractor training and state-led programs.

#### CALIFORNIA AIR RESOURCES BOARD

CARB's ongoing work to implement the HFC emissions reduction target driven by SB 1383 should include specific actions under the R4 program to support and document the removal and recovery of high-GWP refrigerants from Central Air Conditioning systems before end-of-life in conjunction with the installation of near-zero R-290 heat pumps, achieving a maximum HFC emission reduction per each CAC unit removed of approximately 7 to 10 tons of $CO_2$ equivalent.

#### TRAINERS AND WORKFORCE DEVELOPMENT ACTORS

The variety of parties providing refrigerant handling training along with heat pump OEMs and workforce development actors must include instruction on how appropriate non-sparking tools and best practices are necessary to the servicing of refrigeration and heat pump equipment using A3 refrigerants, even if these are not necessary to AWHP monobloc installation.

## 4. Further Research

Recommendations for further research are listed below.

- Increase research collaboration on ultra-low GWP technology among energy efficiency organizations working to accelerate market adoption of AWHPs, focusing on organizations with GHG reduction goals.
    - An alliance or public report development initiative should be formed and announced. Potential partners include advocacy groups such as the Advanced Heat Pump Coalition, AHRI's subcommittee on AWHP technology, national researchers, ETL certifiers Intertek Group, and TUV SUD.

- Conduct a comprehensive cost-benefit analysis to assess the financial implications and cost savings associated with the initial cost, installation, and ongoing operating and maintenance costs of an AWHP as a retrofit opportunity.
    - This could be directed under a follow up CalNEXT project.

- California should conduct a comprehensive regional impact and sales assessment of AWHPs to help support market adoption rates.
    - Several market leaders are converting their sales portfolios to fully natural by 2027 to avoid to the uncertainties related to fluorinated refrigerants that are PFAS. They are actively seeking insights into the relative size of the residential market in key states such as CA and any associated utility, grid and customer benefit that may drive their investment strategies, market entry approach including public outreach and education.

- At the national level, according to the US Energy Information Administration (EIA), as of 2020, 72.85 million US homes used natural gas, propane, or fuel oil for space heating, and 66 million used natural gas, propane, or fuel oil for water heating alone. This represents a total annual household site end-use consumption for fossil-fuel-based space and water heating of 5156 trillion BTUs. Potential energy and emissions savings from decarbonizing and modernizing homes' heating and domestic hot water systems alone are significant. AWHPs can also provide chilled water for cooling, representing a vast market opportunity for AWHP adoption as it can address both heating and cooling source needs.

- Southern California Edison should support the field testing of R-290 AWHP equipment in its new laboratory for verification and validation testing of technology at the Irwindale facility.
    - The rapid evolution of AWHP technology and the advent of commercially demonstrated EU/UK R-290 AWHP models will likely require updating data on operating efficiency and default $CO_2e$ values for this technology separate from other same-capacity range heat pumps under the TSB.

- A follow up market study should be conducted on R-290 AWHP technology in a split system configuration to determine the achievable HFC reduction impact beyond the residential single-family market adoption of the monobloc design.
    - As is noted in this report AWHP systems can be divided into monobloc or split systems. While this study focuses on the application of the monobloc design that is well suited for single-family housing, the target market for AWHP includes multifamily alongside small commercial buildings and public facilities that require heating and cooling. The unit configuration of these buildings is best suited for the split system design that can heat domestic hot water at a residential /small office scale while simultaneously providing either space heating or cooling.
    - Similar to the monobloc design, split systems can be designed with flammable refrigerants such as R-290, and are available in international markets, although units sized for application in the multi-family and commercial sector are not yet common and specifications and performance data are not readily available online.

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