Market Characterization of Ultra-Low GWP Space Conditioning Heat Pumps for Commercial Buildings

Final Report

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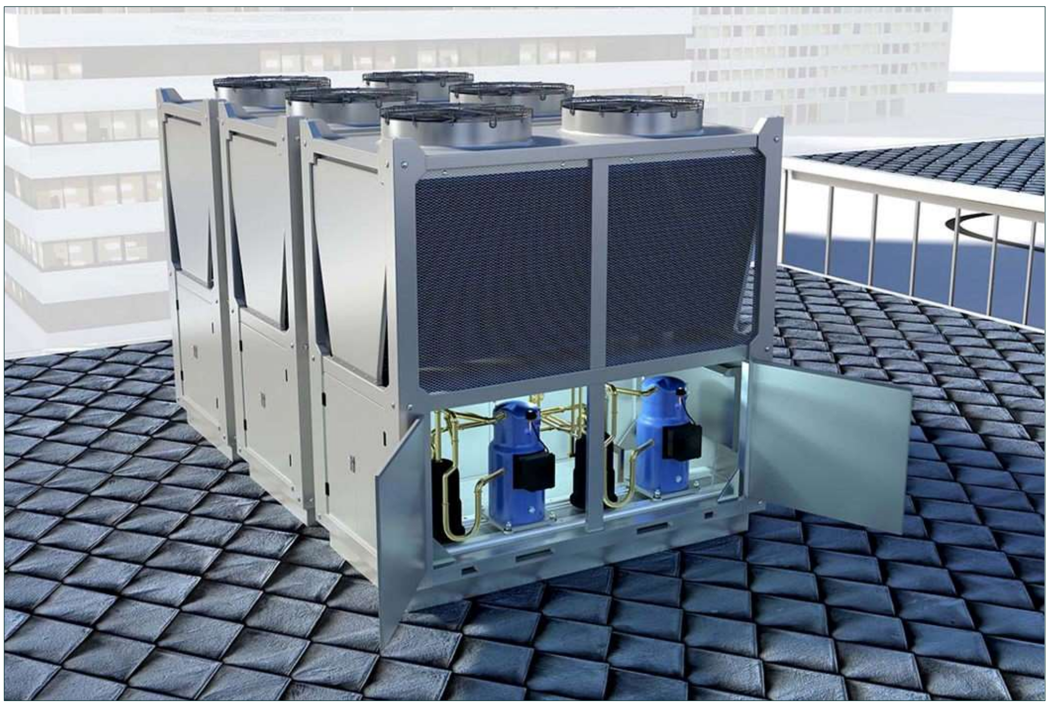

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Disclaimer

Executive Summary

The TRC research team conducted a market study of low and ultra-low global warming potential (GWP) refrigerants and HVAC systems (including heat pumps) that use them. Southern California Edison and the other California investor-owned utilities (IOUs) sponsored the study as part of the CalNEXT initiative.

Heat pumps provide significant energy savings and a path for electrification of space conditioning. But heat pumps typically use refrigerants with a high GWP. Release of high GWP refrigerants (through commissioning, de-commissioning, and/or operating leakage) can offset the greenhouse gas impact reductions from energy savings.

The California Air Resources Board (CARB) will require low-GWP refrigerants (<750) in all new stationary air-conditioning equipment beginning in 2025, with a similar requirement for variable refrigerant flow systems in 2026. There is an opportunity for the California utilities to encourage the market to install equipment that has a lower carbon footprint or higher efficiency compared to this upcoming code requirement. There is no mandatory requirement for UL GWP (≤3 GWP), so there is an opportunity for the California utilities to encourage the adoption of UL GWP equipment. In addition, the California utilities have the opportunity to encourage the adoption of low GWP heat pumps which would offer an electrification pathway compared to low GWP gas-fired equipment and encourage the adoption of other types of low-GWP, high-efficiency equipment.

For market context, air-to-air space conditioning systems provide conditioned supply air and include packaged rooftop units that dominate California commercial buildings—particularly small- and medium-sized buildings. Air-to-water and water-to-water systems condition water to heat and cool and include chillers accompanied by a boiler for heating where needed and are sometimes referred to as hydronic systems. Hydronic systems often serve large commercial buildings or campus-style buildings with a central plant.

This section summarizes the research team's findings and recommendations. Based on the data collected in this study, the California utilities will benefit from encouraging the system types shown in Table 1 below.

Table 1. Recommended Near-future Low or Ultra-low GWP, Efficient HVAC Equipment

Existing Equipment	Near-future Low or Ultra-low GWP, Efficient Option	Applicability
High GWP gas-fired packaged rooftop unit	Low GWP (A2L) rooftop packaged heat pump	Good for small and medium-sized commercial buildings using packaged rooftop units. The research team recommends R32 as an A2L refrigerant since it is not categorized as perfluoroalkyl and polyfluoroalkyl substances (PFAS) and may provide greater efficiency than the 454 series. However, R-454B will be used by several manufacturers and has a lower GWP than R-32. The utilities could evaluate R-32 and R-454B heat pumps using the total equivalent warming impact (TEWI) or Total Systems Benefit (TSB) metric to determine the impact from both efficiency and GWP and incentivize R-454B heat pumps if they have a similar TEWI to R-32 heat pumps.
High GWP gas boiler and chiller	Ultra-low GWP air-to-water heat pump	Good for larger commercial buildings or facilities with central plants using chilled water and heating water. EPA SNAP currently allows 1234yf and 1234ze. EPA SNAP does not allow propane systems in indoor equipment. The research team recommends incentives for air-to-water propane heat pumps suited for outdoors. EPA SNAP may also allow 1233zd or other HFOs in the future. R454B (an HFO/HFC blend) is allowed but has a higher GWP than the ultra-low refrigerants (1234yf, 1234ze, or propane). The research team recommends ultra-low GWP systems instead.
High GWP gas boiler and chiller	Ultra-low GWP heat recovery chiller with gas furnace or boiler back-up.	Same comments as row above. Heat recovery chillers are better suited in buildings with low heating needs.

Recommendation 1: Provide incentives and on-bill financing to accelerate the adoption of the near-future low or ultra-low GWP, efficient option system types, and partner with trade allies to increase uptake. To accelerate the adoption of the equipment listed in Table 1, the research team recommends that utilities incentivize their adoption through the following strategies:

a. **Revise the utility program offerings for commercial heat pumps to require a low-GWP refrigerant**, such as R32 or R454B. Conduct research to compare product efficiencies for low GWP products, compared to Title 24 Part 6 requirements, to identify high efficiency options that should be incentivized more heavily. Work with the California Technical Forum (CalTF) to update the eTRM listings accordingly.
b. Demonstrate cost effectiveness of equipment change outs with examples. Examples can include:
    - Incremental cost of replacing baseline equipment with low-GWP heat pumps
    - Incremental cost after utility incentives
    - Billing impacts
    - Return on investment or payback time.

   Provide examples for the system types identified above as viable. Utilities can include this information on websites for promoting these incentives. In interviews, building owners requested financial information (such as rate of return or payback) before retrofitting to efficient equipment options like heat pumps.
c. **Partner with trade allies (HVAC contractors)** to 1) publicize CARB's and EPA's upcoming changes for new stationary air conditioning equipment, and to 2) market the incentive offerings. Provide the cost effectiveness examples to trade allies as part of their marketing material. Trade allies have direct access to facility managers and building owners. Two building owners mentioned their HVAC contractors are their information sources for upcoming regulations, indicating that building owners view HVAC contractors as trusted resources.
d. **Encourage early retirement (or accelerated replacement) of equipment by providing incentives that are approximately 30–50% of incremental cost and by offering on-bill financing.** While two interviewees recommended incentives around 50% of the incremental cost, one recommended ~20% with a low-interest loan. Incentivizing early retirement of existing HVAC systems will allow building owners to take advantage of the efficiency increase of the new low and ultra-low GWP products that should become available in the California market once California adopts ASHRAE 15-2022 into the mechanical code. This could also encourage a fuel switch from natural gas to all-electric heat pumps because of efficiency gains. On-bill financing provides building owners an inexpensive way to finance a costly replacement project and could give building owners the reason to make a unit replacement earlier than they would under higher interest rates. On-bill financing could also encourage a building owner to replace units in more buildings or replace more than a single unit in one building. Many owners only replace the broken unit.

Recommendation 2: Consider an incentive for building owners to replace R-410A with a low-GWP drop-in refrigerant for existing equipment that will remain in-place. R-410A is one of the most prevalent refrigerants in use today and has a GWP of 2,088. The CARB and EPA restrictions on GWP only apply to new equipment. For HVAC equipment that was installed fairly recently, it could be over 10 years before owners replace it, representing significant refrigerant leak. While the current drop-in replacement for R-410A, R470A, will not meet the CARB GWP requirement, it will still have a GWP of 909, which is less than half of R-410A. It will also require no system changes. This gives building owners an opportunity to reduce their carbon footprint without the expense of completely replacing the piece of equipment. Because a refrigerant replacement will not result in significant changes to energy efficiency, the utilities should emphasize sustainability benefits and advertise the measure as an opportunity to test out a lower GWP refrigerant in preparation for when owners do replace their equipment.

Recommendation 3: Lay the groundwork to accelerate ultra-low GWP, natural refrigerant heat pumps, like CO2 systems, that could be available in approximately three to five years. While the research team identified some CO2 systems, the team is unaware of systems that contractors can install in California. Challenges facing CO2-based systems include that CO2 systems have greater difficulty meeting the cooling efficiency requirements in Title 24 Part 6. In addition, AHRI does not currently provide a certification program for CO2 systems.

In the short-term, utilities can work with the California Energy Commission (CEC) to review efficiency data a manufacturer will release in early 2024 for emerging air-to-water and water-to-water CO2 heat pump systems. According to an interview with an air-to-water CO2 heat pump manufacturer, their system is being tested according to the test procedure referenced in Title 24 Part 6 for hydronic systems (the AHRI Standard 550/590). If the utility's review finds the equipment meets Title 24 Part 6 requirements, they could recommend that the CEC approve this type of CO2 system for use.

a. =

b. **The IOU CASE team could propose a more lenient efficiency requirement for CO2 systems, based on the TEWI or TSB metric.** The Total Equivalent Warming Impact (TEWI describes the global warming impacts of energy consumption and refrigerant leakage over the life of an HVAC system, so TEWI accounts for both efficiency and GWP. While CO2 systems may be less efficient than traditional refrigerants, CO2 is a natural (i.e., no per-and polyfluoroalkyl substances, or PFAS) and ultra-low GWP refrigerant. The CASE team could use the TEWI or Total System Benefits (TSB) metric to determine a lower efficiency requirement for CO2 that would provide the same TEWI as a low-GWP (e.g., 700-GWP) refrigerant meeting the current Title 24 Part 6 requirements.

There are various regulations for commercial HVAC equipment, including EPA and CARB rules for GWP and PFAS, mechanical code requirements for flammability and safety, and efficiency requirements in Title 24 Part 6. The combination of these regulations leaves few low and ultra-low GWP options. However, the research team's study did identify multiple options for low and ultra-low, efficient equipment, including A2L heat pumps, ultra-low GWP air-to-water heat pumps, and ultra-low GWP heat recovery chillers. Utilities can provide a role in increasing the adoption of this equipment through incentives, partnerships with trade allies, and paving the way for natural refrigerants that may emerge in a few years.

Abbreviations and Acronyms

Acronym	Meaning
AIM	American Innovation and Manufacturing
AHRI	Air-conditioning, Heating and Refrigeration Institute
ASHRAE	American Society of Heating Refrigeration and Air-conditioning Engineers
CARB	California Air Resources Board
CO2	Carbon Dioxide
EE	Energy Efficiency
EPA	Environmental Protection Agency
ET	Emerging Technology
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HP	Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IOU	Investor-Owned Utility
kWh	Kilowatt-hour
NRDC	Natural Resources Defense Council
PFAS	Per- and Polyfluoroalkyl Substances
SCE	Southern California Edison
TEWI	Total Equivalent Warming Impact
UL	Ultra-low/Underwriters Laboratory

Introduction

This project provides a market characterization of low global warming potential (GWP) and ultra-low GWP space-conditioning heat pumps in commercial buildings. Heat pumps provide significant energy savings and a path for electrification, but they typically use refrigerants with a high GWP, which can degrade the greenhouse gas reductions from energy savings.

The California Air Resources Board (CARB) has regulations requiring refrigerants in new nonresidential stationary air conditioners to be <750 GWP starting in 2025, and for refrigerants in new variable refrigerant flow (VRF) systems to be <750 GWP starting in 2026. While this is progress compared to traditional refrigerants, there is still potential to decrease GHG emissions and increase energy savings compared to these regulations. For example, projects could install heat pumps with a GWP lower than 750, or heat pumps with a GWP of around 750 but that are more efficient than standard heat pumps. In addition, the requirement only impacts new equipment, so there is opportunity for accelerated replacement, triggering GWP requirements earlier. This project is a market characterization of low-GWP space conditioning heat pumps for commercial buildings, with the purpose of informing California Investor-Owned Utility (IOU) program offerings that push the market beyond CARB and Title 24 Part 6 energy efficiency requirements.

Objectives

The objectives of the study are as follows, where *solutions* focus on heat pumps in commercial buildings:

- Identify at least one ultra-low GWP solution that could be installed now or in the near future, and
- Identify at least one efficient low-GWP solution, which has both a lower GWP than a traditional refrigerant (e.g., R410A) and is more energy efficient than a traditional heat pump.

The project team also identifies limitations to these solutions, such as restricted applicability to certain types or sizes of commercial buildings.

This report uses the term low-GWP to refer to refrigerants <750 GWP to align with the CARB requirement for stationary air conditioners, and ultra-low GWP to refer to refrigerants ≤3 GWP to align with previous studies.[1]

Methods & Approach

The research team describes methods for this research below.

[1] CPUC Group A Report Template (calmac.org), Low-GWP_Refrigerants_Market_Impacts_Final.pdf (calmac.org)

Summarize Regulatory Landscape

The research team reviewed current and upcoming refrigerant requirements for stationary air conditioning equipment.

See the Summary of Relevant Regulations section for discussion of the existing and upcoming regulatory landscape.

Summarize Existing Low GWP Products

The research team conducted a:

- Product review of low and ultra-low GWP refrigerants as well as heat pumps that use these refrigerants
- Literature review of refrigerants

See the Overview of Refrigerants and sections for discussion of the research team's findings.

Conduct Interviews with Market Actors

The research team conducted interviews with a total of 13 market actors for this report.

Table 2: List of Interviewee Category

Interviewee Category	Number Contacted	Number of Interviews Completed
Manufacturers	16	3
Utility Program	4	3
Subject Matter Experts	7	2
Distributor/Manufacturer Representative	1	1
Building Owners (Owners/Developer/Lessee)	7	4
Total	35	13

The research team completed interviews with:

- Three HVAC manufacturers

- Three utility program staff representing two California commercial building programs—one representing an IOU program and the other representing a Publicly Owned Utility (POU) program.
- Subject matter experts:
  - A member of the executive committee for ASHRAE Standard 15 (Safety Standards for Refrigeration Systems)
  - A utility program instructor that works with market actors that install HVAC equipment
- One HVAC Distributor/Manufacturer Representative
- Three Building Owners:
  - A stand-alone restaurant owner (two restaurants)
  - A property owner of multiple properties >50,000 sq ft
  - A pharmaceutical company
- One Building Lessee
  - A stand-alone restaurant lessee (leases space for four restaurants)

See the Interviews section for detailed findings from the team's interviews.

Research Findings

Summary of Relevant Regulations

Overview of Relevant Policies

The research team reviewed several state and federal policies that potentially affect the heat pump market due to the refrigerant phase out. The team analyzed several California regulations including recent policies from CARB and Title 24 parts 4 and 6—the California Mechanical Code and California Building Energy Efficiency Standard, respectively. The team also reviewed federal policies including the Significant New Use Rules on Certain Chemical Substances (SNUR) as well as the Significant New Alternatives Policy (SNAP). The research team has summarized these regulations and their impacts in Table 3 below.

Additionally, the team reviewed ASHRAE Standards 15 (Safety Standards for Refrigeration Systems) and 34 (Designation and Safety Classification of Refrigerants). ASHRAE Standard 15 defines two types of systems: low probability and high probability. A *low probability* system is any system in which the design is such that leakage of refrigerant from a failed connection, seal, or component cannot enter the occupied space. Air-to-water and water-to-water systems used for chillers are low probability systems. A *high probability* system is any system in which the design is such that leakage of refrigerant from a failed connection, seal, or component will enter the occupied space. Air-to-air HVAC systems such as rooftop packaged units or other forced air systems are high probability systems because leaking refrigerant could leak into the delivery air.

The following table shows the relevant policies for new commercial HVAC systems in California. As shown, when the CARB regulations take effect in January 2025, building owners will need to navigate several regulations, which leaves only a few viable options for new HVAC systems.

Table 3. Overview of Regulations Impacting Commercial HVAC Refrigerants

Regulation	Description and Effective Date	Practical Impact
CARB regulation "Prohibitions on Use of Certain Hydrofluorocarbons in Stationary Refrigeration, Stationary Air-conditioning, and Other End-Uses"	Requires refrigerants with **<=750 GWP in all new air conditioning equipment installed beginning Jan. 1, 2025.** New variable refrigerant flow (VRF) systems must comply starting Jan. 1, 2026[]. Applies to light commercial air conditioning and comfort cooling chillers	Traditional HFC refrigerants such as R410A can no longer be used in new air conditioning equipment. No changes for existing equipment.
EPA American Innovation and Manufacturing (AIM), regulating the phasedown of Hydrofluorocarbons	Limits GWP to 700 beginning January 1, 2025, or January 1, 2026, for VRF systems. Applies to light commercial air conditioning and comfort cooling chillers	This regulation, while more stringent than the CARB requirement, will have minimal impacts on HVAC systems in California as there are few refrigerants between 750 (the CARB limit) and 700 GWP (EPA's limit)
Title 24 Part 6- 2022: the California Energy Efficiency Standards	Sets efficiency requirements, based on testing with the AHRI 340/ 360 test procedure for air-to-air unitary packaged heat pumps, ISO-13256 for water-to-water heat pumps, and AHRI 550/ 590 for air-to-water and water-to-water chillers. For example, for a 6-ton unit rooftop packaged heat pump, the minimum efficiency is 11.0 EER and 14.1 IEER; a water-to-water heat pump in heating mode must have a minimum COP of 3.7 at 68°F entering water temperature. See Title 24 Part 6 efficiency requirements in the appendix.	Most A2L and A3 refrigerants will have no issue meeting these efficiencies. CO2 systems have challenges meeting these requirements, since the AHRI standards referenced do not have a certification pathway for CO2 equipment, and because traditional CO2 systems have lower cooling efficiency because of the additional energy needed to condense CO2.

Regulation	Description and Effective Date	Practical Impact
Title 24 Part 4- 2022: the California Mechanical Code	Currently A2Ls are only allowed in small amounts and A3s are prohibited. On July 1, 2024 an interim version of Title 24 Part 4-2022 will adopt ASHRAE 15-2022, which will allow much greater amounts of A2Ls including in air-to-air (packaged rooftop) systems, and A3s in low probability systems such as air-to-water and water-to-water equipment used in chillers and heat pumps. Title 24 Part 4-2022 also references ASHRAE 34-2022, which limits the amount of A3s.	A2L's will be allowed in California per the ASHRAE Standard 15-2022 which allows for a much greater amount of refrigerant to be used in HVAC equipment. Additionally, A3 refrigerants could be allowed outside or in limited quantities in machine rooms (e.g., 0.59 lb/1000 ft^3). Refer to Table 18 for refrigerant charging limits.
EPA Significant New Alternatives Policy (SNAP), regulates chemicals, including refrigerants that may have ozone-depleting or other environmental impacts. The EPA updates its refrigerant listings for SNAP on an ongoing basis, with acceptable refrigerants listed on the SNAP website: Substitutes in Refrigeration and Air Conditioning | US EPA. [2]	Several low-GWP refrigerants are "acceptable subject to use conditions". R-290 (propane, an A3 refrigerant) and R-441 (another A3 refrigerant) may be used in small amounts in self-contained equipment; HFC-32, R-452B, R-454A, R-454B, R-454C and R-457A may be used in residential and light commercial applications, including rooftop applications. HFC-32, HFO-1234yf, may be used in centrifugal and positive displacement chillers for comfort cooling and industrial process air conditioning. Use conditions are contained in the SNAP rulings[3] [4]	EPA SNAP limits the low-and ultra-low refrigerants that can be used. According to the rules, neither of the following refrigerants are currently on the approved list under SNAP for chillers: 1233 zd(e), 1234 yz.[5] Other refrigerants may be added to the list of approved residential and light commercial applications since many manufacturers use refrigerants other than R-32 in their light commercial equipment.

[2] For example, the EPA finalized Rule 23 on May 6, 2021, and Rule 25 on April 28, 2023. Both of these final rules list certain refrigerants as "acceptable", sometimes according to specific use conditions.

[3] https://www.federalregister.gov/documents/2023/04/28/2023-08663/protection-of-stratospheric-ozone-listing-of-substitutes-under-the-significant-new-alternatives

[4] https://www.govinfo.gov/content/pkg/FR-2021-05-06/pdf/2021-08968.pdf

[5] It is unclear how the EPA SNAP program treats propane (R290) for chillers, since propane is not listed as either acceptable or unacceptable by the program. TRC contacted the U.S. EPA multiple times requesting clarification but did not receive a response.

Regulation	Description and Effective Date	Practical Impact
EPA Significant New Use Rule (SNUR), which regulates polyfluoroalkyl substances (PFAS), otherwise known as “forever chemicals”	The last proposal was issued June 20, 2023, and comments were accepted until July 20, 2023. A future rule for SNUR may affect some of the refrigerants used in HVAC applications in the future, although none were mentioned in the current rule.	HFO-1234yf is regarded as PFAS by several states, Canada, and the EU. SNUR currently allows it but may eventually ban it and some other HFOs. Natural refrigerants such as CO2, propane, and ammonia do not contain PFAS so should not be banned under SNUR.

For more information on each regulation, please see: Appendix 1: Detailed Information on Regulations

Overview of Refrigerants

Below is a table that identifies the low and ultra-low GWP refrigerants for commercial HVAC equipment. This table is based on information from an ACHR news article titled *A Guide to Low GWP Refrigerants*.[6] As discussed in the Summary of Relevant Regulations section, some of these refrigerants are not permissible in full-scale space conditioning heat pumps for commercial buildings in California. The research team provides more information on the possible (and prohibited) use cases for each refrigerant in the

[6] https://www.achrnews.com/articles/144709-a-guide-to-low-gwp-refrigerants

Product Review section.

This table includes a safety grouping based on an ASHRAE classification. In general, the lower the *letter*, the less toxic the substance—for example, A indicates a lower toxicity than B. And the lower the *number*, the less flammable the refrigerant is—for example, ‘1’ represents “no flame propagation”, ‘2’ is flammable, and ‘3’ is higher flammability. Product class A2L is lower toxicity, lower flammability, and is considered less flammable than A2 but more flammable than A1. Please see the section ASHRAE Safety Classifications for more detail.

Table 4 includes several types of refrigerants:

- Natural refrigerants: naturally occurring substances, as opposed to many traditional refrigerants, which are synthetic. Natural refrigerants include propane, carbon dioxide (CO2), and ammonia.
- HFOs: hydrofluoroolefin, which is an organic compound of hydrogen, fluorine, and carbon.
- HFC: hydrofluorocarbon, and these are currently in the process of being phased out.
- Blends: blends are simply blends of HFCs and HFOs.

Legacy refrigerants include hydrofluorocarbons (HFCs), which are high GWP (in the thousands) CARB and EPA SNAP regulations are phasing out.

Table 4: Current Low and Ultra-Low GWP Refrigerant Details

Low and Ultra-Low Refrigerant Options				
GWP Rating	Refrigerant Name	Refrigerant Type	100 Year GWP	Safety Group
Ultra-Low	R-717 (Ammonia)	Natural	0	B2L
Ultra-Low	R-1234ze	HFO	<1	A2L
Ultra-Low	R-1234yf	HFO	<1	A2L
Ultra-Low	R-1233zd	HFO	1	A1
Ultra-Low	R-744 (CO2)	Natural	1	A1
Ultra-Low	R-290 (Propane)	Natural	3	A3
Low	R-516A	Blend	131	A2L
Low	R-555A	Blend	146	A2L

Low and Ultra-Low Refrigerant Options				
Low	R-454C	Blend	148	A2L
Low	R-515B	Blend	293	A1
Low	R-454B	Blend	466	A2L
Low	R-513A	Blend	573	A1
Low	R-32	HFC	675	A2L
Low	R-470B	Blend	717	A1
Low	R-466A	Blend	733	A1

Product Review

Product Comparison Overview

The ultra-low and low GWP commercial HVAC systems available internationally are not yet available in California due to the various regulations, but some will be available once Title 24 Part 4 adopts the 2022 version of ASHRAE 15. Once the state adopts ASHRAE 15-2022, A2L and some A3 systems will be able to enter the California market for some system types. According to a subject matter expert (SME) that is a member of ASHRAE 15-2022, Title 24 Part 4 (the California Mechanical Code) will adopt ASHRAE 15-2022 as early as July 2024. The adoption will allow installation of A2L refrigerants in many applications including roof-top packaged units. Products developed by large manufacturers with California supply chains have developed these systems and are currently offering them in the European and UK markets. Nine other US states have already adopted codes that allow for the regulated use of these A2L refrigerants through adoption of the 2022 version of ASHRAE 15.[7] The impending moratorium on the sale of new systems that use refrigerants with a GWP of 750 combined with California's decarbonization ambitions will likely contribute to market transformation.

The following tables compare several low and ultra-low GWP heat pump systems based on an online product review and interviews conducted with policymakers, manufacturers, and other market actors. The tables focus on commercial heat pump systems that feature refrigerants that the team's research indicates are most likely to become dominant as high GWP HFC production sunsets. **The ultra-low GWP commercial heat pump front runner refrigerants are R-1234yf, 1234ze, and possibly propane near term, and CO2 (R-744) longer term; these are primarily for large-scale commercial buildings replacing chillers and boilers.** The research team did not identify any currently viable air-to-air system for packaged rooftop units. Unfortunately, the heat pump systems that use these ultra-low GWP refrigerants all have some kind of technical complication that makes them harder to implement than the low GWP refrigerant systems on the market. In the case of R-290 (propane), the EPA rules do not permit this refrigerant in large enough quantities for commercial HVAC applications for self-contained roof air conditioning. The EPA SNAP program does not allow propane in chillers[8] although the research team assumes propane is acceptable in outdoor equipment. There may be options for implementation of some of these systems as the regulations and market evolve, but all of these installations are likely to require custom system design and will require integration with other building systems to reach maximum efficiency levels. This type of design is common for large commercial applications but will have a harder time finding traction in the small and medium commercial HVAC markets that rooftop package units currently dominate.

The front runner refrigerant for low GWP systems is R-32, with R454B as a close second. The research team found R-32, as well as R-454B and R-454C, most likely to become market leaders in

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[7] https://hvac-blog.acca.org/a2l-products-now-allowed-in-many-states-get-ready/

[8] Based on personal communications with the U.S. EPA staff on December 15, 2023. Propane is not listed as either acceptable or unacceptable for chiller equipment on the EPA SNAP website.

commercial heat pumps based on their thermal properties, manufacturer investment, and their adoption rate in other markets. It is worth noting that current commercial heat pump systems that use these refrigerants are largely air-to-water systems. Although, A2Ls (including R-32 and the R-454 series) Title 24 Part 4 will be allow them for air-to-air (rooftop packaged) units once that standard adopts ASHRAE 15-2022. The research team recommends R-32 over the R-454 series because R-32 systems have higher efficiency and because the 454 series contains PFAS.

Some of the heat pump systems presented are *cascade systems*. This means they are modular systems made up of smaller units combined to reach higher levels of performance and output. Cascade heat pump systems is a strategy for providing larger and more adaptable systems for the commercial market that keep the total refrigerant charge of any single unit below legal thresholds. In these systems, a single control panel controls multiple individual units. This allows transferring or splitting heating and cooling loads between multiple units as space conditioning demand increases or changes. This technique keeps each single system's refrigerant charge within legal limits while allowing larger-capacity systems to use a low or ultra-low GWP refrigerant.

The following tables provide an overview of the commercial heat pump systems that are most likely to meet commercial space conditioning needs in California. Table 5 provides a list of each heat pump system described in this report, its capacity, its features, and its likelihood to provide value to the California market.

While the market is evolving, there are unfortunately no perfect solutions, and all system types have at least one type of significant disadvantage.

Table 5. Product Overview and Comparison Table

Heat Pump Type	System Type	Heat Only	Category	Refrigerant	A2L+	Nominal Efficiency Min/Max (EER)[9]	Cooling Capacity Min/Max (kW)	Cooling Capacity Min/Max (kBtu/h)	Unit or Cascade Max	GWP	Near Future CA Option[10]	Potential Long-term CA Option[11]
Air Source A2L	Air to air	N	LowGWP	R-32	Y	2.83/3.44	23/170	78/580	Unit	675	Y	Y
Air Source A2L	Air to water	N	LowGWP	R-32	Y	2.68/2.92	44/537	150/1832	Unit	675	Y	Y
Air Source A2L	Air to water	N	LowGWP	R-32	Y	3.06	74/610	252/2081	Unit	675	Y	Y
Air Source A2L	Air to water	N	LowGWP	R-32	Y	3.07/3.35	150/1080	512/3685	Cascade	675	Y	Y

[9] Nominal efficiencies vary with unit size and configuration.

[10] Subject to California Mechanical Code (Title 24 Part 4) adoption of ASHRAE 15-2022 and 34-2022, which is anticipated in summer 2024.

[11] Includes CO2 systems, which could be accepted if Title 24 Part 6 is revised to reference standards other than AHRI test procedures, and if cooling efficiency requirements are relaxed for CO2 systems. Heat pump systems that use refrigerants that include PFAS chemicals are not included as “Potential Long-term CA Option” due to the evolving environmental concerns.

Heat Pump Type	System Type	Heat Only	Category	Refrigerant	A2L+	**Nominal Efficiency Min/Max (EER)**[9]	Cooling Capacity Min/Max (kW)	Cooling Capacity Min/Max (kBtu/h)	Unit or Cascade Max	GWP	Near Future CA Option[10]	**Potential Long-term CA Option**[11]
Air Source A2L	Air to air	N	LowGWP	R-454B	Y	2.97/3.26	97/237	331/809	Unit	467	Y	N
Air Source A2L	Air to water	N	LowGWP	R-454B	Y	x	492/809	1672/2757	Unit	467	Y	N
Air Source A2L	Air to water	N	LowGWP	R-454B	Y	x	50/900	171/3071	Unit	467	Y	N
Air Source A2L	Air to water	N	LowGWP	R-454C	Y	x	7.8/640	27/2184	Cascade	146	Y	N
Air Source R-290	Air to water	N	Ultra LowGWP	R-290	Y	x	40/160	136/546	Cascade	3	N[12]	Y

[12] If propane (R-290) is allowed by the EPA SNAP program, air-to-water and water-to-water R-290 systems could be installed in the near future outdoors, or in limited quantities in machine rooms.

Heat Pump Type	System Type	Heat Only	Category	Refrigerant	A2L+	**Nominal Efficiency Min/Max (EER)**[9]	Cooling Capacity Min/Max (kW)	Cooling Capacity Min/Max (kBtu/h)	Unit or Cascade Max	GWP	Near Future CA Option[10]	**Potential Long-term CA Option**[11]
Air Source R-290	Air to water	N	Ultra LowGWP	R-290	Y	2.82	45/178	154/607	Cascade	3	N	Y
Air Source R-290	Air to water	N	Ultra LowGWP	R-290	Y	x	100/200	341/682	Unit	3	N	Y
Air Source R-290	Air to water	N	Ultra LowGWP	R-290	Y	3.0/3.2	50/480	171/1638	Cascade	3	N	Y
Air Source Chiller R-290	Air to water	N	Ultra LowGWP	R-290	Y	2.6/3.1	31/192	106/655	Unit	3	N	N
Air Source Chiller R-290	Air to water	N	Ultra LowGWP	R-290	Y	2.84/2.97	173/334	590/1140	Unit	3	N	N
Air Source CO2	Air to water	N	Ultra LowGWP	CO2	N	x	x	x	Unit	1	N	Y

Heat Pump Type	System Type	Heat Only	Category	Refrigerant	A2L+	**Nominal Efficiency Min/Max (EER)**[9]	Cooling Capacity Min/Max (kW)	Cooling Capacity Min/Max (kBtu/h)	Unit or Cascade Max	GWP	Near Future CA Option[10]	**Potential** Long-term CA Option[11]
Water Source CO2	Water to water	N	Ultra LowGWP	CO2	N	2.7	x/69	x/235	Unit	1	N	Y
Water Source CO2	Water to air	Y	Ultra LowGWP	CO2	N	x	x/123	x/420	Unit	1	N	N
Water Source CO2	Water to water	N	Ultra LowGWP	CO2	N	2.9/3.3	35/2200	119/7506	Unit	1	N	Y
Air Source CO2	Air to water	Y	Ultra LowGWP	CO2	N	x	100/600	341/2047	Unit	1	N	N
Water Source 1234ze	Water to water	Y	Ultra LowGWP	1234ze	Y	x	200/2500	682/8530	Unit	6	N	N

Table 6 presents data on researched low GWP heat pumps systems grouped by refrigerant type and described by the characteristics of these systems that define system capacity and applicability.

Table 6: Heat Pump Systems Capacity, and Area Served by Low GWP Refrigerant

Heat Pump Capacity by Refrigerant						
Refrigerant	ASHRAE Flammability Class	GWP	Heat Pump Type	Max Capacity kW/(kBTU/h)	System Units	Approximate Maximum Area (sf) That Could Be Conditioned Per Unit13
R-32	A2L	675	Air to air	170/578	Single	16,500
R-32	A2L	675	Air to water	200/682	Single	19,500
R-32	A2L	675	Air to water	1080/3670	Multiple	104,900
R-454b	A2L	467	Air to air	237/808	Single	23,100
R-454b	A2L	467	Air to water	900/3070	Single	87,700
R-454c	A2L	146	Air to air	640/2175	Multiple	62,200

[13] Based on standard industry estimates for commercial heating load value of 35 BTU/sf in mild/cold climates

Heat Pump Capacity by Refrigerant						
R-290 (Propane)	A3	3	Air to water	200/682	Single	19,500
R-290 (Propane)	A3	3	Air to water	480/1630	Multiple	46,600
R-744 (CO2)	A1	1	Water to water	1500/5100	Single	145,000
R-1234ze	A2L	6	Water to water	2500/8500	Single	243,000

Table 7 provides the regulatory limitations, current market commercial heat pump system types, and potential commercial building applications of low GWP heat pumps. The Summary of Relevant Regulations defines Low probability and high probability systems.

Table 7: Low GWP Refrigerant Heat Pump Systems Regulations, Equipment Type, and Potential Application

Heat Pump Limitations & Applications					
Refrigerant	**GWP**	**Regulation Limitations**	**Potential Equipment Type**	**Potential Building Application**	**Disadvantage**
R-32	675	Table 7-1 in ASHRAE 15-2022 limits the amount of A2L refrigerants in high probability systems. There is no limitation for use in low probability systems	Air-to-water heat pumps, air to air heat pumps (unitary), VRF	Office buildings, schools, supermarkets, convenience stores, retail	R-32 is an HFC that just meets CARB and EPA limits for GWP
R-454b	467	Table 7-1 in ASHRAE 15-2022 limits the amount of A2L refrigerants in high probability systems. There is no limitation for use in low probability systems	Air-to-water heat pumps, air to air heat pumps (unitary)	Office buildings, schools, supermarkets, convenience stores, retail	R-454b is an HFC blend of R-32 and R-1234yf which could be banned in the future due to PFAS concerns
R-454c	146	Table 7-1 in ASHRAE 15-2022 limits the amount of A2L refrigerants in high probability systems. There is no limitation for use in low probability systems	Air-to-water heat pumps	Office buildings, schools, supermarkets, convenience stores, retail	R-454c is an HFC blend of R-32 and R-1234yf which could be banned in the future due to PFAS concerns

Table 8 provides the regulatory limitations, current market commercial heat pump system types, and potential commercial building applications of ultra-low GWP heat pumps, as well as ultra-low GWP heat recovery chillers. As shown, the research team did not identify any air-to-air ultra-low GWP options, useable for rooftop packaged units. However, the team did identify options for air-to-water and water-to-water heat pumps or heat recovery chillers that can replace standard chillers.

Table 8: Ultra-Low GWP Refrigerant Heat Pump Systems Regulations, Equipment Type, and Potential Application

Heat Pump Limitations & Applications					
Refrigerant	GWP	Regulation Limitations	Potential Equipment Type	Potential Building Application	Disadvantage
R-290 (Propane)	3	ASHRAE 15-2022 prohibits the use of A3 refrigerants in high probability systems[4]. EPA SNAP does not allow it in chillers. Therefore, this refrigerant must be used in low probability systems[5] outside.	Air to water heat pump, heat recovery chiller	Large commercial and industrial buildings	Limitations on system types due to flammability
R-744 (CO2)	1	CO2 Systems are not specifically regulated by ASHRAE 15-2022 or Certified by AHRI Standards	Water to water heat pumps, air to water heat pumps	Commercial and industrial buildings with large hot water end uses	Systems may have trouble meeting efficiency standards (Title 24 Part 6). Unproven in market.

Heat Pump Limitations & Applications					
R-1234ze	6	Table 7-1 in ASHRAE 15-2022 limits the amount of A2L refrigerants in high probability systems. There is no limitation for use in low probability systems	Water to water heat pumps	Large commercial and industrial buildings	R-1234ze could be banned in the future due to PFAS concerns

This section provides more detail on each system type.

CO2 (R-744) Heat Pumps

Known as R-744, CO2 is a naturally occurring compound that is non-flammable and has a GWP of one. Water-to-water systems currently dominate the market for CO2 heat pumps providing water at very high temperatures for space conditioning or commercial and industrial end uses. Some of these systems are currently offered on the US market. **The research team did not find any air-to-air CO2 heat pump systems that will directly replace rooftop package units** that currently dominate the California commercial space conditioning market.

The largest barrier to the use of CO2 as a refrigerant in heat pumps for commercial space conditioning is cooling efficiency limitations due to the compound's chemical properties. CO2's critical pressure is much higher than other refrigerants, which forces it to operate in a trans-critical refrigeration cycle. Essentially, it will not condense into a liquid in a standard refrigeration cycle and requires additional systems to perform the heat transfer function of the refrigeration cycle. **The trans-critical cycle has a higher operating temperature that has traditionally made CO2 a less efficient refrigerant for cooling applications** due to heat and throttling losses across the expansion valve. The market for commercial CO2 heat pumps reflects this, with most systems the research team found for the US market operating as heating-only systems.

The following schematics show the differences between the traditional condensing refrigeration cycle and the trans-critical cycle. Figure 1 shows the relative simplicity of the standard condensing refrigeration cycle.

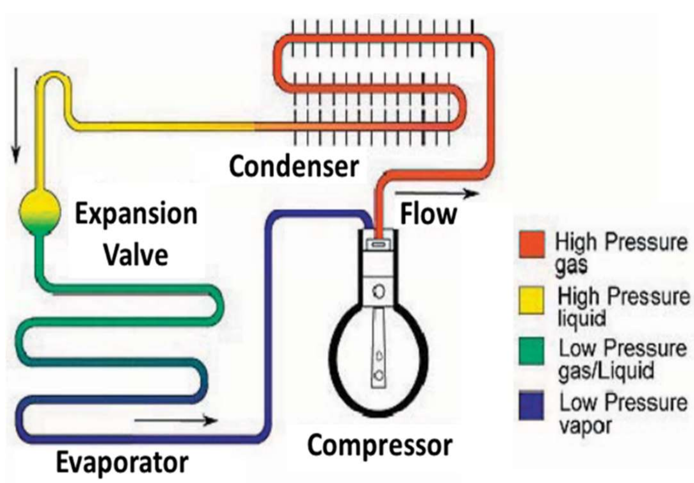

Figure 1: Traditional condensing refrigeration cycle.[14]

[14] https://www.epa.gov/sites/default/files/documents/Refrigeration_101.pdf

Figure 2 shows the typical trans-critical cycle and added pressure regulation and refrigerant loops required to operate at the higher pressures and temperatures required by the trans-critical cycle.

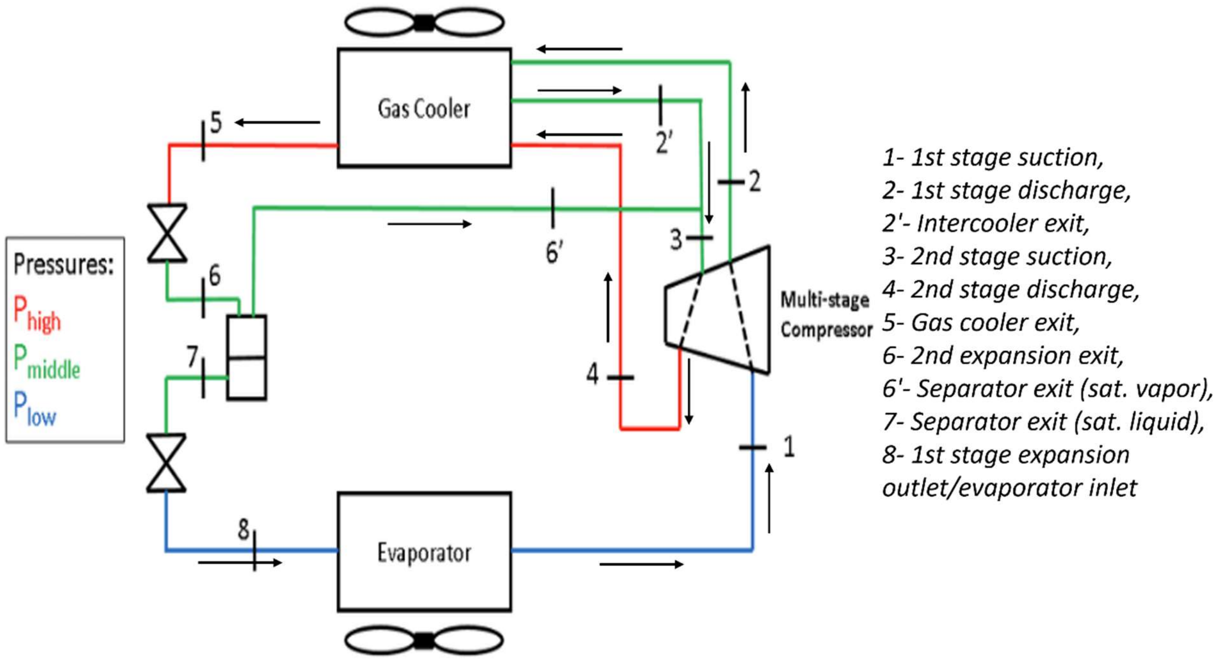

Figure 2: Trans-critical refrigeration cycle.[15]

The higher average temperatures in the gas-cooling process and larger pressure differences across the expansion device produce large heat and throttling losses that reduce system efficiency and cause the system's coefficient of performance (COP) to be lower than other systems in the same conditions.[16] Because of the high pressure in the system, the saturated vapor temperature is relatively high, which leads to less cooling capacity.

Current CO2 heat pump system designers are pursuing multiple strategies to increase the overall efficiency of these trans-critical heat pump systems. It is common to use more complex cycles in trans-critical systems to obtain operating efficiencies similar to conventional systems. These systems include additional subsystems such as parallel compressors, sub-coolers, ejectors, adiabatic gas coolers, and heat reclamation systems.[17]

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[15] Czapla, Nicholas & Inamdar, Harshad & Barta, Riley & Groll, Eckhard. (2016). Theoretical Analysis of the Impact of an Energy Recovery Expansion Device in a CO 2 Refrigeration System.

[16] https://doi.org/10.1093/ijlct/ctab086

[17] https://www.intarcon.com/en/transcritical-co2-refrigeration/#:~:text=What%20is%20a%20transcritical%20cycle,greater%20than%20the%20critical%20pressure.

Some CO2 systems may also include an additional buffer to help reduce the temperature of the gas enough to absorb a functional amount of heat from the air. This can take the form of a water tank supplied with cool water to absorb heat and carry it out to radiators. This buffer system often produces water at temperatures up to 185 degrees Fahrenheit, which can be used by other building systems. However, these systems still tend to have lower efficiency than comparable systems that operate a traditional compression cycle with a COP under three.[18] Furthermore, these systems' COPs can drop rapidly as ambient temperature rises, which can further limit the application of the cycle in the warm regions of California.[19]

Creative application of heat and pressure recovery systems can significantly increase overall system efficiencies. One manufacturer interviewed by the research team claims their CO2 heat pump system can reach an overall COP of 7 with the use of full-time heat reclamation. The design directs the high heat losses of the CO2 cycle into domestic hot water systems and thermal storage when the current heat generation exceeds the building's needs. This CO2 heat pump system does not have a reversing valve. Instead, it runs the cooling and heat cycles simultaneously, shifting the function of the heating and cooling outputs to accommodate the seasonal space conditioning needs, and directing any unused energy into thermal storage systems. While this system design is unproven in the US, the company reported in an interview that the system is undergoing laboratory testing for conformity with pressure standards and will install one in a recreation center in Minnesota.

A Japanese firm known for its industrial compressors, Mayekawa, currently offers two CO2 heat pump systems for the US market. The unimo AWW heat pump system is a hybrid air-to-water and water-to-water heat pump that can provide 92 kW of heating and 69 kW of cooling capacity.[20] Alternatively, Mayekawa offers the unimo AW. This simpler water-to-water heat pump can provide the same heating and cooling capacity by combining a hot-water boiler and chiller in the same unit. These systems claim simultaneous hot water and space conditioning with a maximum COP of 5.3.[21] Mayekawa also offers a water-to-air space heating heat pump system. The Eco Sirocco heat pump air heater does not offer cooling functionality but uses a CO2 heat pump to provide air heating with a COP range of 3.1 to 5.5.[22] Mayekawa's literature claims that they are currently offering these systems to the North American market, but the company did not respond to repeated inquiries from the research team.

Carrier is offering water-to-water CO2 heat pump systems in Europe that provide heating and cooling. Carrier has implemented this heat pump system in a shopping and business center in Norway. Two Carrier HeatCO2OL heat pump systems using ground source water provide 2,000 kW of cooling

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[18] https://yaleclimateconnections.org/2023/02/how-heat-pumps-of-the-1800s-are-becoming-the-technology-of-the-future/

[19] https://doi.org/10.1016/j.pecs.2003.09.002

[20] https://mayekawa.com/americas/mna/products/heat_pumps/

[21] https://r744.com/mayekawa-unveils-co2-heat-pump-for-u-s-residential-market/

[22] https://mayekawa.com/americas/mna/products/heat_pumps/

capacity to the VIA 26 business center.[23] Carrier offers these HeatCO2OL systems in five model sizes ranging from single office applications to district heating with single units offering 35 to 2,200 kW capacity. This is one of the only CO2-based space-conditioning systems proven effective at providing heating and cooling in large commercial settings. The water-to-water HeatCO2OL commercial units currently on the EU market claim a nominal EER of only 2.9 to 3.2 for cooling only but claim a total system COP of 6.4 to 7.1 when the system recovers and uses all heat.[24]

The research team also found that current commercial CO2 heat pump systems only reach efficiencies comparable to current technology by capturing the waste heat produced by the trans-critical cycle. To reach high efficiency, these systems will require custom installations that link them with the domestic hot water systems and other hot water applications in the building; this limits their application, since many commercial building types do not have large hot water needs. However, certain building types that have a use for hot water during cooling months, such as hotels, community centers, or schools with pools, can achieve high system efficiencies with these CO2 heat pump systems.

The efficiency of trans-critical cycle heat pumps must be comparable to current systems to lower Total Equivalent Warming Impact (TEWI). TEWI describes the global warming impacts of energy consumption and refrigerant leakage over the life of an HVAC system. If the installed system uses a low-GWP refrigerant but has a lower efficiency and uses more electricity to operate the systems, net TEWI savings are reduced and this can even lead to increased TEWI from source emissions.[25]

In addition, while air-to-water and water-to-water CO2 heat pumps may be future options for larger buildings with chilled water systems, they will not easily replace the packaged (air-to-air) units that compose the majority of the state's commercial HVAC systems.

This list is intended for illustrative purposes and does not indicate preference or comprehensiveness of all potential manufacturers.

Propane (R-290) Heat Pumps

While the natural refrigerant propane (R-290) is an ultra-low GWP refrigerant (GWP = 3), until recently, regulations in the US have only allowed its use in small-charge refrigeration applications due to its A3 flammability status. R-290 has become a common refrigerant in small commercial refrigerator and reach-in cases in grocery and convenience stores. These stores will often have many R-290-based refrigeration units with up to 160 grams of charge per unit.

[23] https://www.shareddocs.com/hvac/docs/2000/Public/0C/Carrier_HeatCO2OL_brochure_EN.pdf

[24] https://www.carrier.com/commercial-refrigeration/en/eu/products/systems/HeatCO2OL-commercial/

[25] https://neep.org/sites/default/files/media-files/informing_the_evolution_of_hvac_refrigerants_0.pdf

As discussed in Summary of Relevant Regulations, in addition to providing standards for the use of A2L refrigerants, the ASHRAE 15-2022 standard also introduced an exception for the use of A3 refrigerants in machinery rooms and outdoor locations for space conditioning purposes.

However, there are significant restrictions on the application of propane systems. First, from ASHRAE 15-2022, **A3 refrigerants are only allowed in low-probability systems where the refrigerant is kept separate from the air provided by the space conditioning system.** In this design, thermal transference provided by the refrigerant must go through another medium and not be in contact with the supply air. This isolation of the refrigerant precludes the use of an A3 refrigerant in the traditional rooftop packaged units that dominate California's commercial HVAC landscape. This does not mean that A3 systems cannot replace existing rooftop units. However, an R-290 system retrofit requires infrastructure changes that can increase costs significantly. Second, for indoor machinery room applications, the **ASHRAE 34-2022 standard for the use of R-290 limits the charge to 0.56 lbs. per thousand cubic feet of space. This could be very limiting based on the size of the machinery room.** For comparison, a 1,000 cubic foot room (125 square feet by 8 feet) has an A2L refrigerant charge limit of 9.6 lbs.[26] Even more limiting, the EPA SNAP program does not allow propane in chillers, so it can only be installed in equipment located outdoors.

While these restrictions present challenges to system design using A3 refrigerants, some large commercial and industrial building applications are well-suited for systems that could meet the new Title 24 Part 4 regulations (which follow ASHRAE 15-2022 and ASHRAE 34-2022). Many larger commercial buildings looking for an ultra-low GWP system will require a large-scale outdoor HVAC system like the R-290 heat pump systems that are currently entering the European market.

The international market for R-290 ultra-low GWP commercial space conditioning systems has grown significantly in the past few years. The following are systems available in Europe but not available to-date in California due to the regulations noted above.

- The ISH 2023 HVAC conference and show held in Frankfurt, Germany manufacturer offerings of residential and commercial propane heat pumps dominated.[27] In this market, there are strict limitations on the amount of refrigerant allowed in each system. This initially kept R-290 heat pump technology in the residential market due to the lower capacity of systems with lower refrigerant charges. However, manufacturers have begun to offer cascade R-290 heat pump systems as a strategy for providing larger R-290 heat pump systems to the commercial market. In these systems, a single control panel controls multiple individual units. This allows heating and cooling loads to be transferred or split between multiple units as space conditioning demand increases or changes. This technique keeps each single system's refrigerant charge within legal limits while allowing larger-capacity systems to use this ultra-low GWP refrigerant.

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[26] ASHRAE 15-2022 Table 7-1

[27] https://hydrocarbons21.com/r290-heat-pumps-dominate-the-ish-2023-show-in-germany/

- UK heat pump manufacturer Clade offers single-unit R-290 air source heat pumps for applications of up to 200 kW, with the option to cascade multiple units for larger space conditioning demands. The Clade ASPEN air-to-water heat pumps are available in units of three sizes from 100 kW to 200 kW.[28] Clade has example installs in locations across the UK, including Northumbria University in Newcastle, which received a five-unit R-290 air-to-water heat pump cascade system that provides a total capacity of 900 kW.[29]
- Manufacturer Panasonic is now offering an air-to-water cascade R-290 heat pump system that can reach capacities of up to 480 kW. The ECOi-W AQUA-G BLUE system is built of individual units with rated capacities of 50–80 kW. These units come with a prebuilt control system for plug-and-play cascade system configuration and can produce water temperatures that range from -15 to 70 °C.[30]
- Designed specifically for commercial applications, the RHOSS poker290 heat pump is an air-to-water heat pumps that uses R-290 as the refrigerant and has a heating capacity of 47.4 kW and a cooling capacity of 44.8 kW. Designed for cascade system configuration, these R-290 heat pumps can reach a capacity of up to 178 kW with four cascaded units.[31]
- Swegon is another manufacturer focusing on offering R-290 products to the commercial space conditioning market. The BlueBox TITAN Sky single-unit system is a R-290 heat pump or chiller system. The air-to-water heat pump single-unit systems are available in three sizes with a capacity range of 31–192 kW.[32]
- German manufacturer Viessmann has also begun production of a commercial space conditioning R-290 heat pump system to meet the demands of the evolving European market. They are using the cascade system configuration to reach higher capacities. Their latest offering is the R-290 Vitocal 250A Pro heat pump with a unit capacity of 40 kW, combining up to four systems into a single cascade system with capacities of up to 160 kW. Viessmann has developed these units with a focus on retrofit as well as new construction applications.[33]

This list is intended for illustrative purposes and does not indicate preference or comprehensiveness of all potential manufacturers.

Ultra-low GWP Heat Recovery Chillers

While heat pumps are the focus of this study, heat recovery chillers may be a technology that could be useful to space heating in California. A heat recovery chiller possesses the ability to capture the heat from the condenser side of the chiller. As refrigerant pressure increases so, too, does its temperature when compressed. In a typical water-cooled chiller application, the condenser water

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28 https://clade-es.com/

29 https://hydrocarbons21.com/clade-decarbonizes-u-k-university-buildings-with-r290-heat-pumps/

30 https://www.aircon.panasonic.eu/GB_en/news/new/panasonics-new-r290-air-to-water-reversible-heat-pumps-in-capacities-50-80-kw/

31 https://www.rhoss.it/products/thaetp-250/

32 https://www.swegon.com/products/cooling-heating/air-cooled/bluebox-titan-sky-r0/

33 https://www.viessmann.family/en/newsroom/solution-offering/viessmanns-most-important-new-products-in-2023-at-a-glance.html

from a cooling tower captures that heat and rejects it to the outside. In a heat recovery application, adding a separate heat exchanger to the system so that the condenser heat is run through a heat exchanger where a separate water stream can absorb its heat. That separate water loop can then provide heat to another source. The recovered heat can preheat domestic hot water for example. However, it is not out of the question that the recovered heat could provide heat to reheat coils in VAV boxes to provide some space heating.

Heat recovery chillers only provide heating when another part of the space requires cooling, so the chiller is actively producing chilled water. For heating only buildings, or where heating capacity exceeds the heating output of the heat recovery chiller, this will require another heating source, such as a boiler or furnace. However, the heat recovery chiller will offset some of the load of this heating system.

In general, the same low and ultra-low GWP systems that can serve an air-to-water or water-to-water heat pump could also serve a heat recovery chiller.

HFO / HFC Blend (A2Ls: R-32 and R-454 series) Heat Pumps

The US EPA SNAP program rule 23 listed low GWP A2L refrigerants R-32, R-452B, R-454A, R-454B, R-454C. and R-457A as acceptable for residential and light commercial air conditioning and heat pumps subject to use conditions[34]. While Title 24 Part 4 outlawed the use of these refrigerants in California, many states changed laws to allow the use of A2L refrigerant heat pumps and some products are already available on the national market. When California adopts the ASHRAE 15-2022 standards, this will open the California market to A2L space conditioning heat pump systems. While ASHRAE 15-2022 does provide limits on the allowable limit of A2L refrigerant charge in the largest circuit of human comfort equipment[35], these limits are high enough that the research team does not foresee these charging restrictions creating barriers to the implementation of these systems in most commercial spaces.

There are several class A2L HFO/HFC blend and HFC refrigerants that have a GWP below the impending EPA AIM maximum of 700 GWP. Of these refrigerants, R-32 and R-454B are the current front runners for market replacement of current commercial space conditioning heat pump refrigerants.

With a GWP of 466, the refrigerant R-454B is a low GWP option. This class A2L refrigerant is gaining traction in the US commercial HVAC market and should be available in California after Title 24 Part 4 adopts ASHRAE 15-2022. Manufacturer TRANE currently offers a commercial capacity R-454B heat pump systems in North America. The Ascend® Air-to-Water Heat Pump provides 140 to 230 tons of

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[34] https://www.govinfo.gov/content/pkg/FR-2021-05-06/pdf/2021-08968.pdf

[35] ASHRAE 15-2022 Table 7-1

cooling and 1,500 to 2,500 MBH of heating capacity using R-454B refrigerant.[36] The commercial HVAC R-454B market in the EU is also growing. For example, the Heloclima VHA 4T air-to-water heat pump uses R-454B and provides 50 to 900 kW of heating and cooling capacity.[37]

HFO blend refrigerant R-454C is another emerging low GWP option. This refrigerant has a GWP of only 146, one of the lowest among the approved class A2L refrigerants. While market research did not find any commercial HVAC systems using R-454C in the US market, some manufacturers currently offer these systems in Europe and the UK. The Ecodan CAHV-R air-to-water R-454C heat pump cascade system from Mitsubishi Electric reaches capacities of 640 kW. The multi-unit cascade system can handle up to 16 units, which allows system sizing in 0.5kW increments of capacity in a range from 7.8kW to 640kW.[38] This system also won "Heat Pump Product of the Year" at the 2023 National ACR & Heat Pump Awards in the UK.[39] The research team also only identified air-to-water, but no air-to-air heat pumps, using 454C.

However, the refrigerant blends R-454B and C include the PFAS substances R-1234yf. It is possible that the EPA will phase out R-454 series in the future due to PFAS content.

Unlike the other A2L refrigerants discussed, R-32 is not a new low GWP blend but is a pure HFC that has been an element of many high GWP refrigerant blends for decades. US manufacturer Daikin currently offers residential heat pumps that use R-32 in the North American market. With a GWP of 675, CARB classifies R-32 as low (but not ultra-low) GWP. Daikin has been heavily investing in R-32 heat pump technology with over 190 million R-32 heat pumps sold worldwide as of 2021.[40] These R-32 units also show significant efficiency improvements over comparable R-410A units and report up to 12% higher SEER and up to 18% higher HSPF. The ATMOSPHERA line of residential heat pumps, first released in 2022, does not have enough capacity for multizone commercial applications, but could still serve for single zone applications.[41] Their North American market presence also exemplifies how existing internationally available A2L heat pumps poise themselves for entrance into the US market.

Commercial grade R-32 space conditioning products are not yet available in the US, but the technology is available in the European market from several manufacturers with supply chains in North America. Carrier currently produces an R-32 commercial air-to-water heat pump available in

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[36] https://www.trane.com/commercial/north-america/us/en/products-systems/chillers/air-cooled-chillers/ascend-air-to-water-heat-pump.html

[37] https://www.hecoclima.com/en/portfolio/vha-4t/

[38] https://les.mitsubishielectric.co.uk/products/commercial-heat-pumps-and-chillers/commercial-heat-pumps/ecodan-cahv-r450ya-hpb-commercial-air-source-heat-pump

[39] https://www.acrjournal.uk/national-acr-heat-pump-awards/winners-of-the-2023-national-acr-heat-pump-awards/

[40] https://nesea.org/session/path-greener-hvac-refrigerants

[41] https://backend.daikincomfort.com/docs/default-source/product-documents/residential/brochures/cb-atmosphera.pdf

the EU with a cooling capacity of 44–537 kW.[42] Based on standard industry estimates for commercial heating load these systems could provide space conditioning for 16,000 to 91,000 square feet of commercial space.[43] Mitsubishi also offers the EAHV modular R-32 air-to-water heat pump. This cascade system can combine up to six individual units to reach capacities of up to 1,080 kW.[44] Daikin, who already offers residential R-32 air-to-air systems in the US, offers a commercial R-32 air-to-water heat pump in the European market with a capacity of up to 610 kW.[45]

While air-to-water heat pumps can accommodate many commercial buildings that previously had boilers and chillers, most of California's commercial retail and office buildings require an air-to-air packaged system for replacements. Manufacturer Carrier has developed an air-to-air R-454B commercial heat pump packaged unit that is currently on the European market. This packaged system has a nominal cooling capacity of 97–237 kW and a nominal heating capacity of 97–299 kW, which provides conditioning for approximately 9,000 to 26,000 square feet of commercial space.[5] These packaged rooftop models are reported to operate at a SEER of up to 5.16.[46]

Low-GWP A2L systems include options for air-to-air packaged rooftop systems and less complex, and thus cheaper, air-to-water and water-to-water system replacement than the ultra-low GWP refrigerant heat pumps that are currently available. However, these HFC blends may become the next target of the national HFC phasedown—particularly R-32 with its higher GWP, or some, such as R-454B and C, the EPA may be prohibited in the future due to PFAS. The implication is that these HFC/HFO blend systems may prove to be a transition technology. However, they may also be a necessary step in some commercial applications on the path to ultra-low refrigerant heat pump systems.

This list is intended for illustrative purposes and does not indicate preference or comprehensiveness of all potential manufacturers.

HFO (R-1234yf, R-1234ze) Systems

Hydrofluoroolefins (HFOs) are a newer group of environment-friendly refrigerants. Many regard these refrigerants as the future of refrigerants and the replacement for current market HFC refrigerants. These refrigerants have many advantages over HFCs. They have zero ozone depletion potential (ODP), similar to HFCs, but unlike HFCs, HFOs are ultra-low GWPs with some having a GWP of less than one. Much like the HFO/HFC blends discussed in the previous section, these refrigerants fall under the A2L classification as mildly flammable and will be legal for commercial applications in California under the adoption of ASHRAE 15-2022 through the Title 24 Part 4-2022 supplement in

[42] https://www.carrier.com/commercial/en/eu/products/heating-air-conditioning/air-to-water-heat-pumps/30rq--30rqp/

[43] Standard industry estimates for commercial heating load value of 35 BTU/sf in mild/cold climates

[44] https://les.mitsubishielectric.co.uk/products/commercial-heat-pumps-and-chillers/commercial-heat-pumps/eahv-r32-modular-air-source-heat-pump

[45] https://www.daikinapplied.eu/products/r-32-heat-pump-ewyt-b/

[46] https://www.carrier.com/commercial/en/eu/products/air-treatment/rooftop-units/50ff-fc-100-280-r-454b/

July 2024.

Of the various HFO refrigerants, R-1234ze and R-1234yf have found the most market traction internationally and in the US. Nationally, HFO R-1234yf replaced R-410A as the standard for use as a refrigerant in new vehicle A/C systems in 2022.[47] With a GWP below one, this HFO may seem ideal for application in California's emerging ultra-low GWP space conditioning market, but **there are some technical issues that have prevented this refrigerant form finding a place in larger refrigeration systems.** Research conducted on the performance of R-1234yf in actual systems found it to be compatible with the existing compressor oils such as POE oil, but in vapor compression refrigeration cycles like those present in heat pumps it showed degradation of system cooling capacity and efficiency when compared with traditional HFCs.[48] One study found that when operating at cooling capacities between 2 and 4 kW, the COP of an R-1234yf system decreased by nearly 50%.[49] These limiting factors have prevented this HFO from finding a place in space conditioning systems in pure form, but it is in the emerging low GWP blends R-454A, B, and C.

Fellow HFO R-1234ze has greater potential for large heat pump system applications. Also classified as an A2L refrigerant, this HFO has appeared on the European commercial heat pump market. Manufacturer Carrier is currently offering the AquaForce® high-temperature water-to-water R-1234ze commercial heat pump. Carrier has designed this heat pump as a heat-only system and can provide space and process heating with a nominal capacity of 200 to 2500 kW with water temperatures up to 85°C and a COP of up to 6.[50] This system does not meet the commercial space conditioning heat pump needs of most California commercial buildings, which are cooling dominated. However, this system could be combined with chiller systems to provide large-scale water and space heating for specific applications.

The EPA SNAP has listed 1233zd(e) as an acceptable alternative for industrial air conditioning, but not for chillers (either centrifugal or displacement) for comfort cooling in commercial buildings.

This list is intended for illustrative purposes and does not indicate preference or comprehensiveness of all potential manufacturers.

The chemical composition of these HFO refrigerants qualifies them as PFAS. The carcinogenic effects of PFAS are an area of growing international concern. In 2023, five EU nation, including Germany, the Netherlands, Norway, Sweden, and Denmark, proposed a restriction on PFAS-

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[47] https://www.epa.gov/snap/regulations-proposed-rules-and-final-rules-determined-epa

[48] https://doi.org/10.1016/j.ijrefrig.2020.10.039

[49] https://doi.org/10.1016/j.ijrefrig.2020.06.014

[50] https://www.carrier.com/commercial/en/uk/news/news-article/carrier-ultra-low-gwp-hfo-heat-pumps-help-decarbonise-the-city-of-london.html

containing refrigerants.[51] The state of Maine has also passed a law mandating the reporting of all products containing a PFAS beginning in 2025, and will ban the sale of any product containing intentionally added PFAS in 2030.[52]

Based on market research and the limitations of these refrigerants in their pure form, most HFOs are unlikely to be long-term viable options for California ultra-low GWP commercial refrigerant applications. However, EPA SNAP does allow R-1234yf and R-1234ze as acceptable alternatives for chillers currently. In addition, as discussed in the previous section, contractors are likely to install the R-454 blends that contain R-1234yf at least in the near-term, to meet the upcoming CARB and EPA AIM regulations.

Interviews

The following section provides findings the research team collected from market actor interviews.

Products in the Market

Because California currently prohibits A2L refrigerants in any substantial quantities and prohibits the use of A3 refrigerants, there are currently no products available in the California market. However, two manufacturers that we spoke to stated that they have A2L products that they are lining up for sale in California once Title 24 Part 4 approves their use. One reported they plan to use R-32. A sales representative for a different manufacturer reported they are updating their product lines for California to use R-454B for unitary heat pumps and 1234ze for chillers; the sales representative noted that 454B has a lower GWP than R-32. Manufacturers also stated that they do have their low GWP products installed in other US states that allow their use.

Another manufacturer the team interviewed does not currently have any products installed in California, but their first US installation of a CO2 heat pump is underway in Minnesota. According to the manufacturer, the unit will be capable of producing heating water, chilled water, and domestic hot water simultaneously. The manufacturer has produced air-to-water and water-to-water CO2 systems that can replace boilers and chillers, but no air-to-air systems. Consequently, this equipment is better suited for large commercial and industrial spaces with existing boilers and chillers, as opposed to smaller spaces with rooftop units. The manufacturer claims the equipment has a COP of seven when tested according to AHRI Standard 550. However, AHRI has not certified the equipment since AHRI has not certified CO2 systems under one of their certification programs to date. The manufacturer reported they expect Underwriters Laboratory (UL) sign-off of their equipment in December 2023, and that a third-party laboratory is independently verifying the equipment efficiency, with verification by a national laboratory, for completion in January 2024. Since AHRI does not list the equipment in the AHRI directory, the research team notes that the California Energy

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[51] https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal
[52] https://www.maine.gov/dep/spills/topics/pfas/PFAS-products/

Commission will need to approve it before a contractor can install it in California.

Awareness of Upcoming CARB Regulation

The research team asked interviewees whether they had previously heard about the upcoming CARB regulation that all new air conditioning equipment meet a GWP of <750 GWP beginning in 2025 (and 2026 for VRF systems). The building developer was not at all aware of the regulation, one building owner and the building lessee were somewhat familiar with it but did not know the specifics, and another building owner was very familiar with it since his company's sustainability plan includes phasing out HFCs and HCFCs. The building owner and building lessee that were somewhat familiar with the regulation had heard about it from their HVAC contractors who conduct regular maintenance.

The manufacturers were very aware of the upcoming regulation. One manufacturer expressed dismay at the regulation change, and felt as though they were switching to a technology that they currently did not believe in. One SME believed that the industry does not feel the need for the regulation change right now and that regulators are bullying them into accepting it.

Current Equipment and Practices

The building owners and building lessee primarily have gas-fired packaged rooftop units for the small buildings, and boilers and chillers for larger buildings. The research team notes this is similar to general industry trends.

The developer reported using primarily gas-fired packaged rooftop units and occasionally a heat pump prior to 2020 but began transitioning to VRF systems around 2020 since it is more efficient. The restaurant owner that leased multiple properties also reported using gas-fired packaged rooftop units. The other building owner, who owns a San Francisco bar/ lounge, did not have any heating or cooling, because of the mild climate, and reported that his other restaurant had cooling only.

The owner of the campus with multiple laboratory spaces had a chilled water plant and boiler.

Current Program Offerings and Future Opportunities for Utility Intervention

Most current program offerings for commercial heat pumps in California limit themselves to fuel switching and electrification for HVAC and domestic hot water. Only one program mentioned an incentive for GWP and that was an incentive based on GWP levels: 750–150, 150–10, and <10 GWP.

The two utility program staff representing the IOU program expressed interest in measure offerings for low and UL GWP equipment. One stated that they are proposing the idea for the next program iteration based on measure cost and energy savings findings from different CalNEXT projects. Another expressed hesitancy on how to push the market if the technology is still very new.

The research team discussed with building owners their interest in participating in a utility program that supports going beyond the CARB regulations through one of the following activities:

- Replacing equipment before failure so that CARB regulations take effect earlier.
- Replacing existing equipment with a heat pump that uses a low GWP refrigerant, instead of a standard gas-fired packaged rooftop unit with a low GWP refrigerant [for packaged rooftop systems]. This meets the CARB requirement (due to the low GWP refrigerant) and provide energy efficiency gains from switching to a heat pump.

In terms of interest from building owners for utility support:

- All building owners were interested in rebates/incentives for low GWP equipment if available.
    - In terms of the amount needed to either replace equipment early, **the developer and the building lessee recommended an incentive around 50% of the incremental cost of the equipment, and one building owner recommended 20% with low interest financing** and “an easy process”. The developer that recommended incentives around 50% reported, "Even if it is a crappy system, it is cheaper to operate inefficient equipment than offsetting buying new equipment. It is always a financial decision." One building owner reported the availability of rebates could push him to make a purchase when it is not necessary (i.e., when a repair sufficed).
    - Similarly, one developer reported that he wants an incentive around 50% of the incremental cost of the equipment to install a heat pump with low GWP refrigerant instead of a traditional split system with low GWP refrigerant.

- In terms of other recommendations for a low-GWP measure offering:
    - One building owner and the building lessee reported it would be helpful if the utilities could provide estimated bill savings and a rate of return when deciding whether to purchase low-GWP heat pumps.
    - The developer recommended targeting customers directly instead of a third-party contractor, since in his experience the contractors are the only ones that benefit. He prefers to work directly with the utility.
    - The building lessee asked if low-GWP systems have to be charged more frequently, and the developer asked about the cost of low-GWP refrigerants.

Drivers and Barriers to Shifting to Low-GWP Heat Pumps

Several interviewees noted that the **primary reason for shifting to any type of low-GWP air conditioning equipment is meeting the upcoming regulations.** The second primary driver for moving to **low or ultra-low GWP heat pumps was potential energy bill savings**; the developer, building owner, and building lessee all mentioned some financial motivation for such a retrofit. This aligns with findings from the utility program manager interviews, who cited savings on electric bills as well as increased program incentives for customers to offset the additional cost of the new equipment. **Sustainability reasons were not often cited**, but the building owner of the pharmaceutical company is shifting to an ultra-low GWP space conditioning system for sustainability reasons, and to an ultra-low

GWP heat recovery system for the additional efficiency from heat recovery.

For barriers, manufacturers and SMEs noted that regulations needed to change before low-GWP and ultra-low GWP systems could be feasible—in particular, the California Mechanical Code (which could change as early as July 2024). One manufacturer of CO2 equipment cited another regulation barrier in AHRI, since AHRI currently does not certify CO2 products. Other barriers cited included liability concerns due to flammability issues of A2L and A3 refrigerants. Manufacturers also noted the challenge the factories will face switching production and engineering to accommodate A2L refrigerants as R-410A is phased out. A manufacturer also noted that low GWP products will be more expensive ("premium") products initially.

Building owners echoed concerns regarding the incremental cost of low and ultra-low GWP systems. Several noted that if they were purchasing new equipment that was more expensive, they want to see bill savings. As discussed in the next section, this may be difficult to achieve for customers with high heating loads where the pre-retrofit system was natural gas, due to the lower cost per BTU of natural gas compared to electricity.

Costs, Cost Effectiveness, and Retrofit Considerations

Cost Information from Interviews

Not surprisingly, costs and cost effectiveness were of significant concern to many interviewees. Manufacturers noted costs in changing manufacturing processes. While it was difficult to estimate the additional cost of low GWP and ultra-low GWP systems, one manufacturer expects low GWP products to cost 15–20% more than standard units.

All building owners interviewed mentioned costs as the primary concern with shifting to low-GWP or ultra-low GWP systems, including more efficient (but more expensive) equipment like low-GWP heat pumps. A utility program staff member expressed concerns that efficiency gains due to low GWP units do not present a significant savings potential compared to heat pumps already in the market and the replacement cost is very expensive; the benefits are not proportionate to the costs to the participant.

Shifting from traditional refrigerants to low or ultra-low GWP refrigerants in standard (non-heat pump) space conditioning equipment typically does not save the customer energy, or therefore reduce energy bills. One exception is R-32, as described in Section HFO / HFC Blend (A2Ls: R-32 and R-454 series) Heat Pumps. However, shifting from standard (non-heat pump) space conditioning equipment with traditional refrigerants to a low-GWP heat pump both reduces the GWP and saves energy on a BTU-basis. One challenge is if the building previously used gas heat and had high heating loads, shifting to a low GWP heat pump may not lead to significant bill savings because the cost per BTU is lower for natural gas than electricity. For example, the customer with the sustainability goal of phasing out HFCs and HCFCs is estimating that they will achieve bill neutrality (i.e., no changes to bills, but no savings) in shifting from a chiller and gas boiler to an ultra-low GWP heat recovery chiller. However, the building lessee with restaurants in the Central Valley reported cooling dominates their energy bills (and almost no heating needs), so shifting from electric split A/C to low-GWP heat pumps could result in energy bill savings for these types of customers.

Cost Effectiveness Example

The following figure comes from a current TRC reach codes study[53] and shows the lifecycle cost savings of retrofitting a gas-fired packaged rooftop unit with a heat pump. While this is not representative of a low-GWP heat pump, this is representative of a commercial building with three HVAC units on the roof serving three of its zones. While the incremental cost of installing heat pumps over the life of the equipment is approximately $8,200, the lifecycle energy savings of the heat pumps is nearly three times that cost. Even with an increase of 20% to move to a low-GWP heat pump, the incremental cost shifts from $8,200 to approximately $9,840, and the lifecycle energy cost savings is still twice as high as the incremental first cost.

[53] Not yet published, but should be published soon on LocalEnergyCodes.com under Resources.

Baseline- Retail Gas Packs	Package- Retail Heat Pumps	cz	lookup	Elec Savings (kWh)	Gas Savings (therms	GHG savings (tons)	Incremental Package Cost	Lifecycle Energy Cost Savings
re-alt-mf-p3-v3/cz03	re-alt-ae-p3-v3	cz03	re-alt-ae-p3-v3/cz03	(9,232)	1,383	6.4	$8,201	$24,305

Figure 3: Lifecycle analysis of retrofitting a gas-fired packaged rooftop unit with a heat pump

Retrofit Considerations

A major consideration for a retrofit is which components of the existing air conditioning system a contractor need to replace. The following table describes the level of retrofit needed for switching from a high-GWP standard efficiency system (e.g., R-410A gas-fired packaged rooftop unit) to a low-GWP heat pump. As shown below, contractors could retrofit existing equipment with a low or ultra-low GWP heat pump (or heat recovery chiller, another efficient option) with equipment swap outs. It does not require changing out refrigerant lines for rooftop packaged system or replacing the chilled water or heating water piping for delivering space conditioning to the space.

Table 9: Qualitative Description of Scope to Transition to Low and Ultra-Low GWP Systems

Existing Equipment	Low-GWP heat pump option	Space conditioning equipment needing replacement
R-410A gas-fired packaged rooftop unit	**Like for like with low-GWP refrigerant:** A2L gas-fired packaged rooftop unit (used as the baseline comparison for retrofits)	Equipment swap – packaged unit replaced. Potential addition of adapter curb.
R-410A gas-fired packaged rooftop unit	**Heat pump retrofit with low-GWP refrigerant:** A2L rooftop packaged heat pump	Same as above. Light demolition of gas line. Possibly add another electric circuit for defrost protection. Potential addition of adapter curb.
Boiler and High GWP chiller	**Like for like with low-GWP refrigerant for chiller**	Equipment swap. Refrigerant is part of the chiller system
Boiler and High GWP chiller	**Ultra-low or Low-GWP heat recovery chiller**, with gas heating backup if needed	Same as above. Potential to downsize boiler.

Due to CARB regulations only impacting new air conditioning, building owners with recently replaced air conditioning equipment may not need to replace their equipment for over ten years. These owners could continue to use R-410A in the meantime. However, building owners may opt to do a refrigerant drop-in for equipment that is still functioning. A drop-in refers to replacement of the refrigerant, with no or minimal replacement of HVAC equipment. While it was beyond the scope to fully explore drop-in options, the research team did identify R-470A as a drop-in replacement for R-410A. R-470A has a GWP of 909, which is less than half of R-410A (GWP of 2,088). Because refrigerants leak over time, dropping in a lower GWP refrigerant like R-470A can reduce global warming impacts compared to recharging the system with R-410A over its lifetime.

Recommendations

The California and federal GWP requirements become mandatory for new equipment in 2025. VRF systems have until 2026. Stationary HVAC must meet a maximum of 700 GWP.

While low-GWP stationary air conditioning equipment will become mandatory for all new equipment, there are still opportunities for the California utilities to encourage the market to install equipment that has a lower carbon footprint or higher efficiency compared to code requirements.

- There is no mandatory requirement for UL GWP (≤3 GWP), so there is an opportunity for the California utilities to encourage the adoption of UL GWP equipment. As downsides UL GWP equipment, that the research team did not identify any UL GWP refrigerant that could be installed in packaged rooftop units. In addition, the UL GWP equipment that could be installed in hydronic equipment (e.g., such as chillers or other air-to-water or water-to-water equipment) are natural refrigerants that are A3s (such as propane), which have higher flammability risks, so must be installed outdoors or in limited amounts in machine rooms; or HFOs that are A2Ls but contain at least some PFAS (forever chemicals). Despite these caveats, some commercial or industrial buildings that could meet the regulations for A3s should be encouraged to use UL GWP equipment, given its lower carbon footprint.
- In addition, the California utilities have the opportunity to encourage the adoption of low GWP heat pumps which would offer an electrification pathway compared to low GWP gas-fired equipment and encourage the adoption of other types of low-GWP, high-efficiency equipment. Because these products have not yet been available in California, the research team did not identify product equipment that would allow a comparison of efficiency performance compared to the Title 24 Part 6 efficiency standards. Based on interviews, most low GWP and UL GWP refrigerants should be able to meet (or possibly exceed) efficiency requirements. However, most CO2 equipment has a lower cooling efficiency and difficult meeting the Title 24 Part requirements, as discussed below. To inform the efficiency performance of different low GWP and UL GWP equipment, further research should be conducted that includes field performance and measurement of efficiency levels compared to T24 part 6 requirements, particularly in California climate zones.

In terms of market availability of products, there are many manufacturers producing HVAC equipment utilizing low and UL refrigerants in other countries that may offer this equipment to California once regulations allow it. The interviews identified at least three major HVAC manufacturers that are planning to sell low GWP (A2L) heat pumps for packaged rooftop applications once Title 24 Part 4 allows the use of A2Ls.

Based on the data collected in this study, California utilities should be encouraging the system types shown in Table 10 below.

Table 10. Recommended Near Future Low or Ultra-Low GWP, Efficient HVAC Equipment

Existing Equipment	Near-future Low or Ultra-low GWP, Efficient Option	Applicability
High GWP gas-fired packaged rooftop unit	Low GWP (A2L) rooftop packaged heat pump	Good for small and medium-sized commercial buildings using packaged rooftop units. The research team recommends R32 as an A2L refrigerant since it is not categorized as PFAS so is listed as an allowable refrigerant in EPA SNAP and may provide greater efficiency than the 454 series. However, R-454B will be used by several manufacturers and has a lower GWP than R-32. The utilities could evaluate R-32 and R-454B heat pumps using the TEWI or Total Systems Benefit (TSB) metric to determine the impact from both efficiency and GWP and incentivize R-454B heat pumps if they have a similar TEWI to R-32 heat pumps.
High GWP gas boiler and chiller	Ultra-low GWP air-to-water heat pump	Good for larger commercial buildings or facilities with central plants using chilled water and heating water. EPA SNAP currently allows 1234yf and 1234ze. EPA SNAP does not allow propane systems in chillers, but these could be installed in air-to-water heat pumps where equipment is located outdoors. EPA SNAP may also allow 1233zd or other HFOs in the future. R454B (an HFO/HFC blend) is allowed but has a higher GWP than the ultra-low refrigerants (1234yf, 1234ze, or propane). The research team recommends ultra-low GWP systems instead.
High GWP gas boiler and chiller	Ultra-low GWP heat recovery chiller with gas furnace or boiler back-up.	Same comments as row above. Heat recovery chillers are better suited in buildings with low heating needs.

Recommendation 1: Provide incentives and on-bill financing to accelerate the adoption of the near-future low or ultra-low GWP, efficient option system types, and partner with trade allies to increase uptake. To accelerate the adoption of the equipment listed in Table 10, the research team recommends that utilities incentivize their adoption through the following strategies:

a. Revise the utility program offerings for commercial heat pumps to require a low-GWP refrigerant, such as R32 or R454B. Conduct research to compare product efficiencies for low GWP products, compared to Title 24 Part 6 requirements, to identify high efficiency options that should be incentivized more heavily. Work with the California Technical Forum (CalTF) to update the eTRM listings accordingly.
b. Demonstrate cost effectiveness of equipment change outs with examples. Examples can include:
    - Incremental cost of replacing baseline equipment with low-GWP heat pumps
    - Incremental cost after utility incentives
    - Billing impacts
    - Return on investment or payback time.

   Provide examples for the system types identified above as viable. Utilities can include this information on websites for promoting these incentives. In interviews, building owners requested financial information (such as rate of return or payback) before retrofitting to efficient equipment options like heat pumps.
c. Partner with trade allies (HVAC contractors) to 1) publicize CARB's and EPA's upcoming changes for new stationary air conditioning equipment, and to 2) market the incentive offerings. Provide the cost effectiveness examples to trade allies as part of their marketing material. Trade allies have direct access to facility managers and building owners. Two building owners mentioned their HVAC contractors are their information sources for upcoming regulations, indicating that building owners view HVAC contractors as trusted resources.
d. Encourage early retirement (or accelerated replacement) of equipment by providing incentives that are approximately 30–50% of incremental cost and by offering on-bill financing. While two interviewees recommended incentives around 50% of the incremental cost, one recommended ~20% with a low-interest loan. Incentivizing early retirement of existing HVAC systems will allow building owners to take advantage of the efficiency increase of the new low and ultra-low GWP products that should become available in the California market once California adopts ASHRAE 15-2022 into the mechanical code. This could also encourage a fuel switch from natural gas to all-electric heat pumps because of efficiency gains. On-bill financing provides building owners an inexpensive way to finance a costly replacement project and could give building owners the reason to make a unit replacement earlier than they would under higher interest rates. On-bill financing could also encourage a building owner to replace units in more buildings or replace more than a single unit in one building. Many owners only replace the broken unit.

Recommendation 2: Consider an incentive for building owners to replace R-410A with a low-GWP drop-in refrigerant for existing equipment that will remain in-place. R-410A is one of the most prevalent refrigerants in use today and has a GWP of 2,088. The CARB and EPA restrictions on GWP only apply to new equipment. For HVAC equipment that was installed fairly recently, it could be over 10 years before owners replace it, representing significant refrigerant leak. While the current drop-in replacement for R-410A, R470A, will not meet the CARB GWP requirement, it will still have a GWP of 909, which is less than half of R-410A. It will also require no system changes. This gives building owners an opportunity to reduce their carbon footprint without the expense of completely replacing the piece of equipment. Because a refrigerant replacement will not result in significant changes to energy efficiency, the utilities should emphasize sustainability benefits and advertise the measure as an opportunity to test out a lower GWP refrigerant in preparation for when owners do replace their equipment.

Recommendation 3: Lay the groundwork to accelerate ultra-low GWP, natural refrigerant heat pumps, like CO2 systems, that could be available in approximately three to five years. While the research team identified some CO2 systems, the team is unaware of systems that contractors can install in California. Challenges facing CO2-based systems include that CO2 systems have greater difficulty meeting the efficiency requirements in Title 24 Part 6. In addition, AHRI does not currently provide a certification program for CO2 systems. However, AHRI Standard 550/590, referenced by Title 24 Part 6 as the method of testing for compliance with chiller efficiency requirements, would still be used to test hydronic CO2 systems.

a. In the short-term, utilities can work with the California Energy Commission (CEC) to review efficiency data for emerging air-to-water and water-to-water CO2 heat pump systems. According to an interview with an air-to-water CO2 heat pump manufacturer, AHRI has not certified the product, but it has a high coefficient of performance (COP) (up to 7 at full load conditions). Under Title 24 Part 6 Section 110.2, an air to water heat pump must have a minimum COP of 3.29 at a 105°F leaving water temperature; typically, CO2 equipment has a lower COP under partial load conditions. The manufacturer reported their system as independently tested, and they are working with a national lab to review the efficiency results. It is possible this system could meet the alternative compliance path noted in Exception 1 to Section 110.2(a), or the CEC could potentially approve this type of CO2 system under an alternative compliance path.

b. The IOU CASE team could propose a more lenient efficiency requirement for CO2 systems, based on the TEWI or TSB metric. The Total Equivalent Warming Impact (TEWI) is used to describe the global warming impacts of energy consumption and refrigerant leakage over the life of an HVAC system, so TEWI accounts for both efficiency and GWP. While CO2 systems may be less efficient than traditional refrigerants, CO2 is a natural (i.e., no per-and polyfluoroalkyl substances, or PFAS) and ultra-low GWP refrigerant. The CASE team could use the TEWI or Total System Benefits (TSB) metric to determine a lower efficiency requirement for CO2 providing the same TEWI as a low-GWP (e.g., 700-GWP) refrigerant meeting the current Title 24 Part 6 requirements.

There are various regulations for commercial HVAC equipment, including EPA and CARB rules for GWP and PFAS, mechanical code requirements for flammability and safety, and efficiency requirements in Title 24 Part 6. The combination of these regulations leaves few low and ultra-low GWP options. However, the research team's study did identify multiple options for low and ultra-low, efficient equipment, including A2L heat pumps, ultra-low GWP air-to-water heat pumps, and ultra-low GWP heat recovery chillers. Utilities can provide a role in increasing the adoption of this equipment through incentives, partnerships with trade allies, and paving the way for natural refrigerants that may emerge in a few years.

Appendix 1: Detailed Information on Regulations

This section describes key regulations, including federal regulations, regulations specific to California, and ASHRAE standards and safety classifications referenced in California building codes.

Federal Regulations

In 2014, the United States Department of Energy released a Research and Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants[54]. Since then, there has been a more aggressive push to incorporate low GWP and ultra-low GWP refrigerants into HVAC equipment applications.

EPA AIM

On December 27, 2020, the American Innovation and Manufacturing (AIM) Act of 2020 was enacted. As part of this legislation, AIM authorized the Environmental Protection Agency (EPA) to address hydrofluorocarbons (HFCs) by providing new authorities in three main areas: to phase down the production and consumption of listed HFCs, manage these HFCs and their substitutes, and facilitate the transition to next generation technologies through sector-based restrictions.[55] Absent from the original list or substances regulated by AIM was HFC-410a, which is one of the most widely used HVAC refrigerants on the market today. Later petitions to the EPA from the California Air Resources Board (CARB) and the Natural Resources Defense Council (NRDC) resulted in HFC-410a and a number of other refrigerants to be added to the regulation.

To add another layer of potential challenge to the phasedown of refrigerants, in late 2022 the EPA issued a proposal to the AIM Act to propose a limit of 700 GWP for refrigerants. Comments were accepted until January 31, 2023. On October 5, 2023, the EPA released its final rule on the Phasedown of Hydrofluorocarbons: Restrictions on the Use of Certain Hydrofluorocarbons under Subsection (i) of the AIM Act of 2020.[56] Under this rule, among many other provisions, is the limit of 700 for the GWP of refrigerants used in new stationary air conditioning and heat pumps as well as comfort cooling applications in HVAC equipment. Depending on the type of equipment, the rule is set to take effect January 1, 2025, or January 1, 2026. Refer to Summary of Relevant Regulations for details.

EPA SNUR

Another relevant federal regulation is the significant new use rule (SNUR) proposed in January 2023

[54] https://www.energy.gov/eere/buildings/articles/research-development-roadmap-next-generation-low-global-warming-potential

[55] https://www.achrnews.com/articles/147113-finalizing-the-a2l-provisions-in-2024-mechanical-codes#:~:text=Several%20states%20have%20already%20updated,release%20their%202024%20mechanical%20codes.

[56] https://www.epa.gov/system/files/documents/2023-10/technology-transitions-final-rule-fact-sheet-2023.pdf

by the EPA strengthening the regulation of per- and polyfluoroalkyl substances (PFAS)[57], otherwise known as *forever chemicals*. This rule prevents anyone from resuming the use of inactive PFAS without EPA review. This proposal comes from the current administration and is a key action in the EPA's PFAS Strategic Roadmap. As discussed in the

[57] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas

Product Review, some HFO and HFO/HFC refrigerant blends are low-GWP but categorized as PFASs.

EPA SNAP

The Significant New Alternatives Policy (SNAP) Program in April of 2023 listed acceptable substitute refrigerants due to the upcoming GWP limit. For commercial HVAC systems, these refrigerants include HFC-32, HFO-1234yf, R-452B, R-454A, R-454B, and R-454C for new centrifugal chillers for comfort cooling. HFC-32, HFO-1234yf, R-452B, R-454A, R-454B, and R-454C are also allowable for new positive displacement chillers for comfort cooling. HFC-32, R-452B, R-454A, R-454B, R-454C, and R-457A are the allowable refrigerant for residential and light commercial rooftop air conditioning and heat pumps. Currently, propane is not an allowable refrigerant for residential and light commercial applications under SNAP.

California Regulations

CARB Prohibitions on Use of Certain Hydrofluorocarbons in Stationary Refrigeration, Stationary Air-conditioning, and Other End-Uses

In addition to the federal requirements, CARB has adopted an approach to refrigerant phasedown in California. Senate Bill 1383 specifies a target of 40% reduction in statewide HFC emissions below 2013 by 2030.[58] As described at the beginning of this report, the California Air Resources Board (CARB) has regulations that will require refrigerants in stationary air conditioners in nonresidential buildings to be <750 GWP starting in 2025, and for refrigerants in variable refrigerant flow (VRF) systems to be <750 GWP starting in 2026, in its Final Regulation Order effective January 1, 2022. The table below includes an excerpt from that Regulation Order.

Table 11: List of Prohibited Substances

General End-Use	Specific End-Use	Prohibited Substances	Effective Date
New Air-conditioning Equipment, Stationary			
Air-conditioning Equipment	Room/wall/window air-conditioning equipment, PTACs, PTHPs, portable air-conditioning equipment, and residential dehumidifiers (new)	Refrigerants with a GWP of 750 or greater	Prohibited as of January 1, 2023

[58] https://ww2.arb.ca.gov/our-work/programs/refrigerant-management-program/about

Air-conditioning Equipment	Other air-conditioning (new) equipment, residential and non-residential	Refrigerants with a GWP of 750 or greater	Prohibited as of January 1, 2025
Air-conditioning Equipment	Variable Refrigerant Flow (VRF) system (new)	Refrigerants with a GWP of 750 or greater	Prohibited as of January 1, 2026
New Chillers			
Chillers – Air-conditioning	Chillers (new)	Refrigerants with a GWP of 750 or greater	Prohibited as of January 1, 2024

On May 13, 2021, CARB released proposed amendments to the prohibitions of certain hydrofluorocarbons on stationary refrigeration, chillers, aerosols-propellants, and foam end-uses regulation.[59] This amendment noted that the original compliance date for 750 GWP limit for refrigerants was January 1, 2023. The Board listened to equipment manufacturers who stated that the most viable refrigerants with a GWP less than 750 ASHRAE categorizes as lower flammability refrigerants, or A2L, which were prohibited under California code. The Board realized that it will take the state some time for codes to be in alignment with this restriction, so the date moved to January 1, 2025 (and 2026 in some cases).

Title 24 Part 4 – California Mechanical Code

California Mechanical Code (CMC) 2022 references ASHRAE 15-2016 for Safety Standards as shown in Table 12 below.

Table 12: CMC Referenced Standards

Table 1701.1 Referenced Standards			
Standard Number	Standard Title	Application	Referenced Section
ASHRAE 15-2016	Safety Standard for Refrigeration Systems	Refrigeration Systems	1102.1, 1106.1, Table 1113.5

[59] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

There is a change expected to come in July of 2024 which will adopt ASHRAE 15-2022. This will allow for greater use of A2L refrigerants that meet the CARB and AIM GWP limits.[60]

[60] 2022 California Mechanical Code (iapmo.org)

Title 24 Part 6 – California Building Efficiency Standard

Section 110.0 of Title 24 Part 6 states the requirements that need to be met in order to install an appliance in a building. Of particular note is subsection 2 of section (b) noted below.

Figure 4: Section (b) of Title 24 Part 6, subsections 1 and 2

(b) **Certification Requirements for Manufactured Systems, Equipment, Appliances and Building Components.**

1. Appliances that are within the scope of Section 1601 of the Appliance Efficiency Regulations shall only be installed if they have been certified to the Energy Commission by the manufacturer, pursuant to the provisions of Title 20 California Code of Regulations, Section 1606; or

2. Systems, equipment, appliances and building components that are required by Part 6 or the Reference Appendices to be certified to the Energy Commission, which are not appliances that are within the scope of Section 1601 of the Appliance Efficiency Regulations, shall only be installed if they are certified by the manufacturer in a declaration, executed under penalty of perjury under the laws of the State of California, that:

    A. all the information provided pursuant to the certification is true, complete, accurate and in compliance with all applicable requirements of Part 6; and

    B. the equipment, product, or device was tested using the test procedure specified in Part 6 if applicable

This would suggest that even if a piece of equipment could not be certified by a certifying body, as long as the equipment was tested to the appropriate standard per T24 Part 6 (e,g., AHRI or ISO) and the manufacturer swore under penalty of perjury that the information was correct the equipment could legally be installed.

Table 13 below identifies minimum efficiencies for heat pumps as well as testing procedures required for the equipment.

Table 13: Title 24 Part 6 Minimum Efficiency Requirements for Heat Pumps

TABLE 110.2-B HEAT PUMPS, MINIMUM EFFICIENCY REQUIREMENTS

Equipment Type	Size Category	Rating Condition	Efficiency [a]	Test Procedure[b]
Air Cooled (Cooling Mode), both split system and single package	≥ 65,000 Btu/h and < 135,000 Btu/h		11.0 EER 14.1 IEER	AHRI 340/360
Air Cooled (Cooling Mode), both split system and single package	≥ 135,000 Btu/h and < 240,000 Btu/h		10.6 EER 13.5 IEER	AHRI 340/360
Air Cooled (Cooling Mode), both split system and single package	≥ 240,000 Btu/h		9.5 EER 12.5 IEER	AHRI 340/360
Water source (cooling mode)	≥ 65,000 Btu/h and < 135,000 Btu/h	86ºF entering water	13.0 EER	ISO-13256-1
Groundwater source (cooling mode)	< 135,000 Btu/h	59ºF entering water	18.0 EER	ISO-13256-1
Ground source (cooling mode)	< 135,000 Btu/h	77ºF entering water	14.1 EER	ISO-13256-1
Water source water-to-water (cooling mode)	< 135,000 Btu/h	86ºF entering water	10.6 EER	ISO-13256-2
Groundwater source water-to-water (cooling mode)	< 135,000 Btu/h	59ºF entering water	16.3 EER	ISO-13256-2
Ground source brine-to-water (cooling mode)	< 135,000 Btu/h	77ºF entering water	12.1 EER	ISO-13256-2
Air Cooled (Heating Mode) Split system and single package	≥ 65,000 Btu/h and < 135,000 Btu/h (cooling capacity)	47° F db/43° F wb outdoor air	3.4 COP	AHRI 340/360
Air Cooled (Heating Mode) Split system and single package	≥ 65,000 Btu/h and < 135,000 Btu/h (cooling capacity)	17° F db/15° F wb outdoor air	2.25 COP	AHRI 340/360

Air Cooled (Heating Mode) Split system and single package	≥ 135,000 Btu/h and < 240,000 Btu/h (cooling capacity)	47° F db/43° F wb outdoor air	3.3 COP	AHRI 340/360
Air Cooled (Heating Mode) Split system and single package	≥ 240,000 Btu/h and < 760,000 Btu/h	47° F db/43° F wb outdoor air	3.2 COP	AHRI 340/360
Air Cooled (Heating Mode) Split system and single package	≥ 135,000 Btu/h (cooling capacity)	17° F db/15° F wb outdoor air	2.05 COP	AHRI 340/360
Water source (heating mode)	< 135,000 Btu/h (cooling capacity)	68ºF entering water	4.3 COP	ISO-13256-1
Water source (heating mode)	≥ 135,000 Btu/h and < 240,000 Btu/h	68ºF entering water	2.90 COP	ISO-13256-1
Groundwater source (heating mode)	< 135,000 Btu/h (cooling capacity)	50ºF entering water	3.7 COP	ISO-13256-1
Ground source (heating mode)	< 135,000 Btu/h (cooling capacity)	32ºF entering water	3.2 COP	ISO-13256-1
Water source water-to-water (heating mode)	< 135,000 Btu/h (cooling capacity)	68ºF entering water	3.7 COP	ISO-13256-2
Groundwater source water-to-water (heating mode)	< 135,000 Btu/h (cooling capacity)	50ºF entering water	3.1 COP	ISO-13256-2
Groundwater source water-to-water (heating mode)	< 135,000 Btu/h (cooling capacity)	50ºF entering water	3.1 COP	ISO-13256-2
Ground source brine-to-water (heating mode)	< 135,000 Btu/h (cooling capacity)	32ºF entering water	2.5 COP	ISO-13256-2

The table below identifies minimum efficiencies for water chilling packages as well as testing procedures required for the equipment.

Table 14: Title 24 Part 6 Minimum Efficiencies for Water Chilling Packages (Chillers)

TABLE 110.2-D WATER CHILLING PACKAGES – MINIMUM EFFICIENCY REQUIREMENTS [a,b]

Equipment Type	Size Category	Path A Efficiency [a,b]	Path B Efficiency [a,b]	Test Procedure [c]
Air Cooled, With Condenser Electrically Operated	< 150 Tons	≥ 10.100 EER ≥ 13.700 IPLV	≥ 9.700 EER ≥15.800 IPLV	AHRI 550/590
Air Cooled, With Condenser Electrically Operated	≥ 150 Tons	≥ 10.100 EER ≥ 14.000 IPLV	≥ 9.700 EER ≥16.100 IPLV	AHRI 550/590
Air Cooled, Without Condenser Electrically Operated	All Capacities	Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements.	Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements.	AHRI 550/590
Water Cooled, Electrically Operated, Reciprocating	All Capacities	Reciprocating units must comply with the water-cooled positive displacement efficiency requirements.	Reciprocating units must comply with the water-cooled positive displacement efficiency requirements.	AHRI 550/590
Water Cooled, Electrically Operated Positive Displacement	< 75 Tons	≤0.750kW/ton ≤ 0.600 IPLV	≤ 0.780 kW/ton ≤ 0.500 IPLV	AHRI 550/590
Water Cooled, Electrically Operated Positive Displacement	≥ 75 tons and < 150 tons	≤ 0.720 kW/ton ≤ 0.560 IPLV	≤ 0.750 kW/ton ≤ 0.490 IPLV	AHRI 550/590
Water Cooled, Electrically Operated Positive Displacement	≥ 150 tons and < 300 tons	≤ 0.660 kW/ton ≤ 0.540 IPLV	≤ 0.680 kW/ton ≤ 0.440 IPLV	AHRI 550/590
Water Cooled, Electrically Operated Positive Displacement,	≥ 300 Tons and < 600 tons	≤ 0.610kW/ton ≤ 0.520 IPLV	≤ 0.625 kW/ton ≤ 0.410 IPLV	AHRI 550/590
Water Cooled, Electrically Operated Positive Displacement	≥ 600 tons	≤ 0.560 kW/ton ≤ 0.500 IPLV	≤ 0.585 kW/ton ≤ 0.380 IPLV	AHRI 550/590

Water Cooled, Electrically Operated, Centrifugal	< 150 Tons	≤ 0.610 kW/ton ≤ 0.550IPLV	≤ 0.695 kW/ton ≤ 0.440 IPLV	AHRI 550/590
Water Cooled, Electrically Operated, Centrifugal	≥ 150 tons and < 300 tons	≤ 0.610 kW/ton ≤ 0.550 IPLV	≤ 0.635 kW/ton ≤ 0.400 IPLV	AHRI 550/590
Water Cooled, Electrically Operated, Centrifugal	≥ 300 tons and < 400 tons	≤ 0.560 kW/ton ≤ 0.520 IPLV	≤ 0.595 kW/ton ≤ 0.390 IPLV	AHRI 550/590
Water Cooled, Electrically Operated, Centrifugal	≥ 400 tons and < 600 tons	≤ 0.560 kW/ton ≤ 0.500 IPLV	≤ 0.585 kW/ton ≤ 0.380 IPLV	AHRI 550/590
Water Cooled, Electrically Operated, Centrifugal	≥ 600 tons	≤ 0.560 kW/ton ≤ 0.500 IPLV	≤ 0.585 kW/ton ≤ 0.380 IPLV	AHRI 550/590
Air Cooled Absorption, Single Effect	All Capacities	≥0.600 COP	N.A. [d]	AHRI 560
Water Cooled Absorption, Single Effect	All Capacities	≥ 0.700 COP	N.A. [d]	AHRI 560
Absorption Double Effect, Indirect-Fired	All Capacities	≥ 1.000 COP ≥ 1.050 IPLV	N.A. [d]	AHRI 560
Absorption Double Effect, Direct-Fired	All Capacities	≥ 1.000 COP ≥1.000 IPLV	N.A. [d]	AHRI 560
Water Cooled Gas Engine Driven Chiller	All Capacities	≥ 1.2 COP ≥ 2.0 IPLV	N.A. [d]	ANSI Z21.40.4A

The table below identifies minimum efficiencies for heat pump and heat recovery chillers as well as testing procedures required for the equipment.

Table 15: Title 24 Part 6 Heat Pump and Heat Recovery Chiller Package Minimum Efficiencies

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

Equipment Type	Size Category, (tons)	Cooling-Only Operation Cooling Efficiency [a] Full Load Efficiency (EER orkW/ton) IPLV (EER or kW/ton)		Heating Operation									Test Procedure
				Heating Source Conditions [d,e]	Heat-Pump Heating Full-Load Efficiency (COP_H)[b]				Heat Recovery Chiller Full-Load Efficiency (COP_{HR})[b,c] Simultaneous Cooling and Heating Full-Load Efficiency (COP_{SHC})[b]				
					Leaving Heating Water Temperature				Leaving Heating Water Temperature				
					Low	Medium	High	Boost	Low	Medium	High	Boost	
		Path A	Path B		105°F	120°F	140°F	140°F	105°F	120°F	140°F	140°F	
Air source	All sizes	≥9.595 EER ≥13.02 IPLV	≥9.215 EER ≥15.01 IPLV	47°F [d] / 43°F [d]	≥ 3.290	≥2.770	≥2.310	NA	NA	NA	NA	NA	AHRI 550/590
		≥9.595 EER ≥13.30 IPLV	≥9.215 EER ≥15.30 IPLV	17°F [d] / 15°F [d]	≥2.230	≥1.950	≥1.630	NA	NA	NA	NA	NA	
Water source electrically operated positive displacement	<75	≤0.7885 kW/ton ≤0.6316 IPLV	≤0.7875 kW/ton ≤0.5145 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	AHRI 550/590
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥75 and <150	≤0.7579 kW/ton ≤0.5895 IPLV	≤0.7140 kW/ton ≤0.4620 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥150 and <300	≤0.6947 kW/ton ≤0.5684 IPLV	≤0.7140 kW/ton ≤0.4620 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥300 and <600	≤0.6421 kW/ton ≤0.5474 IPLV	≤0.6563 kW/ton ≤0.4305 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	
	≥600	≤0.5895 kW/ton ≤0.5263 IPLV	≤0.6143 kW/ton ≤0.3990 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	
Water source electrically operated centrifugal	<75	≤0.6421 kW/ton ≤0.5789 IPLV	≤0.7316 kW/ton ≤0.4632 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	AHRI 550/590
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥75 and <150	≤0.5895 kW/ton ≤0.5474 IPLV	≤0.6684 kW/ton ≤0.4211 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥150 and <300	≤0.5895 kW/ton ≤0.5263 IPLV	≤0.6263 kW/ton ≤0.4105 IPLV	54°F [e] / 44°F [e]	≥4.640	≥3.680	≥2.680	NA	≥8.330	≥6.410	≥4.420	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.550	NA	NA	NA	≥6.150	
	≥300 and <600	≤0.5895 kW/ton ≤0.5263 IPLV	≤0.6158 kW/ton ≤0.4000 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	
	≥600	≤0.5895 kW/ton ≤0.5263 IPLV	≤0.6158 kW/ton ≤0.4000 IPLV	54°F [e] / 44°F [e]	≥4.930	≥3.960	≥2.970	NA	≥8.900	≥6.980	≥5.000	NA	
				75°F [e] / 65°F [e]	NA	NA	NA	≥3.900	NA	NA	NA	≥6.850	

a. Cooling-only rating conditions are standard rating conditions defined in AHRI550/590, Table 1.
b. Heating full-load rating conditions are at rating conditions defined in AHRI550/590, Table1.
c. For water-cooled heat recovery chillers that have capabilities for heat rejection to a heat recovery condenser and a tower condenser, the COP applies to operation at full load with 100% heat recovery (no tower rejection). Units that only have capabilities for partial heat recovery shall meet the requirements of Table 110.2-D
d. Outdoor air entering dry-bulb (db) temperature and wet-bulb (wb) temperature.
e. Source-water entering and leaving water temperature.

Model Codes and Test Standards Referenced by Title 24

ASHRAE Safety Classifications

The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) develops standards that federal and state building codes either adopted or reference. The tables below by *ASHRAE Standard 34-2022 Designation and Safety Classification of Refrigerants* describe the classifications of refrigerants, and they are referenced in California's Mechanical Code (CMC) in Table 1102.3. As shown below, ASHRAE classifies refrigerants by a letter and a number. Letters later in the alphabet indicate higher toxicity, and higher numbers indicate higher flammability. Title 24 Part 4, the California Mechanical Code, references these safety group classifications.

Table 16: Refrigerant Safety Group Classification

INCREASING FLAMMABILITY

Higher flammability	A3	B3
Flammable	A2	B2
Lower flammability	A2L	B2L
No flame propagation	A1	B1
	Lower toxicity	Higher toxicity

INCREASING TOXICITY

Table 17: ASHRAE 34 Table 4-1 Refrigerant and Safety Data

Table 4-1 Refrigerant Data and Safety Classifications ***(Continued)***

Refrigerant Number	Chemical Name [a,b]	Chemical Formula[a]	OEL[f], ppm v/v	Safety Group	RCL[c] ppm v/v	RCL[c] lb/1000 ft³	RCL[c] g/m³	LFL ppm v/v	LFL lb/1000 ft³	LFL g/m³	Highly Toxic or Toxic[d] Under Code Classification
Ethane Series *(continued)*											
116[e]	hexafluoroethane	CF_3CF_3	1000	A1	97,000	34	550				Neither
123	2,2-dichloro-1,1,1-trifluoroethane	$CHCl_2CF_3$	50	B1	9100	3.5	57				Neither
124	2-chloro-1,1,1,2-tetrafluoroethane	$CHClFCF_3$	1000	A1	10,000	3.5	56				Neither
125[e]	pentafluoroethane	CHF_2CF_3	1000	A1	75,000	23	370				Neither
134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3	1000	A1	50,000	13	210				Neither
141b	1,1-dichloro-1-fluoroethane	CH_3CCl_2F	500		2600	0.78	12	60,000	17.8	287	Neither
142b	1-chloro-1,1-difluoroethane	CH_3CClF_2	1000	A2	20,000	5.1	82	80,000	20.4	329	Neither
143a	1,1,1-trifluoroethane	CH_3CF_3	1000	A2L	21,000	4.4	70	82,000	17.5	282	Neither
152a	1,1-difluoroethane	CH_3CHF_2	1000	A2	12,000	2.0	32	48,000	8.1	130	Neither
170	ethane	CH_3CH_3	1000	A3	7000	0.54	8.6	31,000	2.4	38	Neither
Ethers											
E170	methoxymethane (dimethyl ether)	CH_3OCH_3	1000	A3	8500	1.0	16	34,000	4.0	64	Neither
Propane Series											
218[e]	octafluoropropane	$CF_3CF_2CF_3$	1000	A1	90,000	43	690				Neither
227ea[e]	1,1,1,2,3,3,3-heptafluoropropane	CF_3CHFCF_3	1000	A1	84,000	36	580				Neither
236fa	1,1,1,3,3,3-hexafluoropropane	$CF_3CH_2CF_3$	1000	A1	55,000	21	340				Neither
245fa	1,1,1,3,3-pentafluoropropane	$CHF_2CH_2CF_3$	300	B1	34,000	12	190				Neither
290	propane	$CH_3CH_2CH_3$	1000	A3	5300	0.59	9.5	21,000	2.4	38	Neither

The last line of this table indicates that propane (R290), an A3 refrigerant, is only allowable in extremely small quantities in a closed space such as a mechanical room, 0.59lbs/1000ft3.

ASHRAE defines two types of systems in Standard 15: low probability and high probability. A *low probability* system is any system in which the basic design or the location of the components is such that leakage of refrigerant from a failed connection, seal, or component cannot enter the occupied space. A *high probability* system is any system in which the basic design or the location of the components is such that leakage of refrigerant from a failed connection, seal, or component will enter the occupied space.

Many low GWP and ultra-low GWP refrigerants ASHRAE classifies as A2L or A3. As of August of 2023, California's 2022 Mechanical Code only permitted very small quantities of A2L refrigerants captured in table 1102.3 of the CMC.[61] Section 1104.6 in the CMC states, "In nonindustrial occupancies, Group A2, A2L, A3, B1, B2, and B3 refrigerants shall not be used in high-probability systems for human comfort." There are two exceptions to that section:

> Exception 1 allows for listed equipment with up to 2.2 pounds of A2L refrigerants in factory-sealed refrigerating systems.

Exception 2 allows for listed equipment with up to four pounds of A2L refrigerants in factory-sealed refrigerating systems in nonresidential applications.[62]

These exceptions allow for a very small amount of A2L refrigerants, which could be used to condition very small spaces such as a deli cooler and some standalone freezers. While the use of A2L refrigerants in heat pump systems remains illegal in California except in small quantities, nine other US states that have already legalized the use of class A2L refrigerants in recent years.[63]

If, according to CARB, the California mechanical code adopts AHSRAE standard 15-2022 by July 1, 2024, it will make sweeping changes to the refrigerants allowed under the new code. Currently, California mechanical code references ASHRAE 15-2019. If the code were to adopt the latest version of that standard, ASHRAE 15-2022 allows several exceptions to the use of A2L and A3 refrigerants. The exceptions in Figure 5 and Figure 6 are referring to the restriction of A3 refrigerants from HVAC systems.

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[61] https://up.codes/viewer/california/ca-mechanical-code-2022/chapter/11/refrigeration#11

[62] https://up.codes/viewer/california/ca-mechanical-code-2022/chapter/11/refrigeration#11

[63] https://hvac-blog.acca.org/a2l-products-now-allowed-in-many-states-get-ready/

ASHRAE 15-2019

Exceptions to 7.5.3:

1. This restriction does not apply to laboratories with more than 100 ft^2 (9.3 m^2) of space per person.
2. This restriction does not apply to industrial *occupancies.*
3. This restriction does not apply to *listed self-contained systems* containing no more than 0.331 lb (150 g) of Group A3 *refrigerant*, provided that the equipment is installed in accordance with the listing and the *manufacturer*'s installation instructions.

Figure 5: ASHRAE 15-2019 Exceptions

ASHRAE 15-2022

Exceptions to 7.5.3:

1. This restriction does not apply to laboratories with more than 100 ft^2 (9.3 m^2) of space per person.
2. This restriction does not apply to *industrial occupancies.*
3. This restriction does not apply to *listed self-contained systems* containing no more than 0.331 lb (150 g) of Group A3 *refrigerant*, provided that the equipment is installed in accordance with the listing and the *manufacturer*'s installation instructions.
4. This restriction does not apply to equipment *listed* to UL 60335-2-89 [7]/CSA C22.2 No. 60335-2-89 [8] containing no more than 0.459 × *LFL* (lb), where *LFL* is in lb/1000 ft^3 (13 × *LFL* [kg], where *LFL* is in kg/m^3) of Group A3 *refrigerant*, provided that the equipment is installed in accordance with the listing and the *manufacturer*'s installation instructions. Refrigeration systems containing more than 0.141 × *LFL* (lb) (4 × *LFL* [kg]) in an *independent circuit shall not* be installed within 20 ft (6 m) of an open flame.
5. This restriction does not apply to equipment *listed* to UL 60335-2-40 [5]/CSA C22.2 No. 60335-2-40 [6] containing no more than 0.106 × *LFL* (lb) (3 × *LFL* [kg]) of Group A3 *refrigerant*, provided that the equipment is installed in accordance with the listing and the *manufacturer*'s installation instructions.
6. This restriction does not apply to refrigeration systems located in *machinery rooms* or outdoors.

Figure 6: ASHRAE 15-2022 Exceptions

The last exception in the ASHRAE 15-2022 list states that, "This restriction does not apply to refrigeration systems located in machinery rooms or outdoors." This will open an entirely new market for heat pumps in the state of California. Additionally, Table 7-1 from ASHRAE 15-2022 presents a refrigerant charge limit for A2L refrigerants in high-probability systems.

Table 18: ASHRAE 15-2022 Table 7-1

Table 7-1 Refrigerant Charge Limit (M_{def}), lb (I-P)

Floor Area, ft²	Height, ft							
	≤2.0	3.3	4.6	5.9	6.6	7.2	8.0	≥9.0
50	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.3
100	4.0	4.0	4.4	5.6	6.3	6.9	7.7	8.6
125	4.0	4.0	5.5	7.0	7.8	8.6	9.6	10.7
150	4.0	4.7	6.5	8.4	9.3	10.3	11.4	12.8
175	4.0	5.0	7.1	9.1	10.1	11.1	12.4	13.8
200	4.0	5.4	7.6	9.7	10.8	11.9	13.2	14.8
225	4.0	5.7	8.0	10.3	11.4	12.6	14.0	15.7
250	4.0	6.0	8.4	10.9	12.1	13.3	14.8	16.5
300	4.0	6.6	9.3	11.9	13.2	14.5	16.2	18.1
350	4.3	7.1	10.0	12.8	14.3	15.7	17.5	19.6
400	4.6	7.6	10.7	13.7	15.3	16.8	18.7	20.9
450	4.9	8.1	11.3	14.6	16.2	17.8	19.8	22.2
500	5.1	8.5	11.9	15.4	17.1	18.8	20.9	23.4
600	5.6	9.3	13.1	16.8	18.7	20.6	22.9	25.6
700	6.1	10.1	14.1	18.2	20.2	22.2	24.7	27.7
800	6.5	10.8	15.1	19.4	21.6	23.7	26.4	29.6
900	6.9	11.4	16.0	20.6	22.9	25.2	28.0	31.4
1000	7.2	12.1	16.9	21.7	24.1	26.5	29.6	33.1
1200	7.9	13.2	18.5	23.8	26.4	29.1	32.4	36.3
1400	8.6	14.3	20.0	25.7	28.6	31.4	35.0	39.2
1600	9.2	15.3	21.4	27.5	30.5	33.6	37.4	41.9
1800	9.7	16.2	22.7	29.1	32.4	35.6	39.7	44.4
2000	10.2	17.1	23.9	30.7	34.1	37.5	41.8	46.8
2250	10.9	18.1	25.3	32.6	36.2	39.8	44.3	49.6
2500	11.4	19.1	26.7	34.3	38.2	42.0	46.7	52.3
2750	12.0	20.0	28.0	36.0	40.0	44.0	49.0	54.9
3000	12.5	20.9	29.3	37.6	41.8	46.0	51.2	57.3
3500	13.5	22.6	31.6	40.6	45.1	49.7	55.3	61.9
4000	14.5	24.1	33.8	43.4	48.3	53.1	59.1	66.2
4500	15.4	25.6	35.8	46.1	51.2	56.3	62.7	70.2
5000	16.2	27.0	37.8	48.6	54.0	59.4	66.1	74.0
6000	17.7	29.6	41.4	53.2	59.1	65.0	72.4	81.1
7000	19.2	31.9	44.7	57.5	63.8	70.2	78.2	87.6
8000	20.5	34.1	47.8	61.4	68.3	75.1	83.6	93.6
9000	21.7	36.2	50.7	65.2	72.4	79.6	88.7	99.3
10000	22.9	38.2	53.4	68.7	76.3	83.9	93.5	104.7
15000	28.0	46.7	65.4	84.1	93.5	102.8	114.5	128.2
20000	32.4	54.0	75.5	97.1	107.9	118.7	132.2	148.0
25000	36.2	60.3	84.5	108.6	120.7	132.7	147.8	165.5
28000	38.3	63.8	89.4	114.9	127.7	140.5	156.4	175.1

To put this table into perspective, a 20-ton rooftop heat pump is capable of conditioning approximately 7,000 square feet[64] of building area and runs on a charge of approximately 48 pounds of R-410A refrigerant.[65]

Air-Conditioning, Heating and Refrigeration Institute (AHRI) Standards

AHRI is a certifying body that certifies HVAC equipment to a certain standard that they have set forth for the industry. Their certification means that the equipment will perform in the manner the manufacturer says it will perform. Unitary AC and heat pumps test in accordance with AHRI Standard 340/360, and water chilling and heat pump water heating packages in accordance with AHRI standard 550/590.

Title 24 Part 6—the California building energy efficiency standards—require an efficiency level as measured according to these AHRI standards.

The AHRI standards currently do not certify CO_2 products. The research team reached out to AHRI to ask about this and this was their response:

“You are correct that AHRI does not operate any certification programs for CO_2 products. As the industry moves to lower GWP refrigerants, a certification program may be developed if market demand requires it. To date, we have not discussed it.”[66]

Though CO_2 systems currently do not have a certification program from AHRI, there is an exception in the energy code that seems to indicate CO_2 systems will be allowed provided they meet efficiency requirements as tested according to the appropriate AHRI testing procedure. See Figure 7 below.

3. The certification status of any system, equipment, appliance or building component shall be confirmed only by reference to:
   A. A directory published or approved by the Commission; or
   B. A copy of the application for certification from the manufacturer and the letter of acceptance from the Commission staff; or
   C. Written confirmation from the publisher of a Commission-approved directory that a device has been certified; or
   D. A Commission-approved label on the device.

Figure 7: Section 3 of Part b of Section 110.0, California Title 24 Part 6

[64] Based on accepted industry estimates of 350 sf/ton in mild climate zones

[65] https://www.shareddocs.com/hvac/docs/1005/Public/00/50FCQ-17-28-01PD.pdf

[66] Per an email received from Alison Andrews, Director Data Services Product Management AHRI

Appendix 2: Interview Guide

Mapping of Interview Questions to Research Topics

Introduction

Southern California Edison (SCE) on behalf of CalNEXT has tasked the research team (TRC) to perform a market characterization study for low and ultra-low (UL) global warming potential (GWP) space conditioning heat pumps for commercial buildings. This study is investigating two product types: (1) high efficiency commercial heat pumps that use refrigerants with a GWP ≤750, and (2) commercial heat pumps that use refrigerants with a GWP significantly lower than 750, and ideally ≤3.

TRC will interview utility program staff, HVAC and refrigerant manufacturers, subject matter experts (SMEs), and commercial building owners. The purpose of the interviews is to gather information regarding their experience with UL GWP refrigerants, UL GWP commercial space conditioning heat pumps, and low GWP heat pumps with an efficiency greater than code minimum. TRC has developed the interview guide so that the interview will last no more than 30 minutes.

The interview will cover three major research topics. First, TRC is attempting to discern what current measure offerings are available from other utilities. Second, TRC is attempting to evaluate which UL GWP refrigerants and heat pump products as well as efficient, low GWP products are currently available and can be used in California. Additionally, TRC will look to HVAC manufacturers and SMEs to determine what products are available for installation in California. Third, TRC is attempting to investigate what UL GWP products have been installed in California by building owners and learn the drivers and barriers of getting these units into the market.

Table 19 identifies the interview questions related to each research topic for utility program staff.

Table 19: Mapping of Interview Questions to Research Topics – Utility Program Staff

Research Topic	Research Sub-topic	Interview Question
Program Offerings for Low and UL GWP Products	• Current Program Offerings • Upcoming program offerings • Applications Received	1–6
Program Adoption	• Drivers and Barriers • Further Information Required • Market Shift	1–4

Table 20 identifies the interview questions related to each research topic for HVAC and refrigerant manufacturers.

Table 20: Mapping of Interview Questions to Research Topics – HVAC and Refrigerant Manufacturers

Research Topic	Research Sub-topic	Interview Question
Review of Current Products in the Market	• Available products • Drivers and Barriers • Perceived Demand	1-9
Products in Design	• Low GWP offerings • Challenges • Costs	1-3

Table 21 identifies the interview questions related to each research topic for SMEs.

Table 21: Mapping of Questions to Research Topics – SMEs

Research Topic	Research Sub-topic	Interview Question
Review of Current Products in the Market	• Available products • Drivers and Barriers • Perceived Demand	1–9
Products in Design	• Low GWP offerings • Challenges	1–2

Table 22 identifies the interview questions related to each research topic for commercial building owners.

Table 22: Mapping of Interview Questions to Research Topics – Commercial Building Owners

Research Topic	Research Sub-topic	Interview Question
Current Behavior for Heat Pump Technology Adoption	• Available products • Drivers and Barriers • Perceived Demand	1–3
Plan to Meet CARB move to <750 GWP Refrigerants	• Lowest GWP • Challenges • Costs	1–8

Recruiting Description

The research team plans to use our industry connections, literature review, and blog postings to identify utility program staff, refrigerant and HVAC manufacturers, SMEs, and commercial building owners to request interviews. An email will contain an explanation of the research and provide suggested meeting times. The team will email them up to three times. Additionally, if a phone number is available, TRC will call potential interviewees up to two times before deeming the contact non-responsive. A $150 e-gift card will be sent to each interview participant as a thank you for their time.

Utility Program Staff Interviews

Introduction

Thank you for taking the time to speak with us today. As a reminder, we are conducting this interview on behalf of the California Investor-Owned Utilities' emerging technology program, known as CalNEXT. Our goal is to understand how the utilities can accelerate the adoption of ultra-low GWP commercial space conditioning heat pumps and efficient low GWP products. Specifically, we are interested in your program experience with low and UL GWP commercial space conditioning heat pumps. All answers will be kept anonymous. TRC will provide a $150 e-gift card as a thank you for your time today. Just to make you aware, the team has defined low GWP refrigerants as those with a GWP <750, and a UL GWP refrigerant as those <3. Additionally, it has recently been brought to our attention that as soon as July 1, 2024, A2L and A3 refrigerants will be allowed by California code, subject to the constraints of ASHRAE 15-2022. Please keep this in mind as you consider our questions.

Do we have your permission to record this interview? This is solely for note-taking purposes.

a. Yes [RECORD CONTACT INFORMATION; SETUP INTERVIEW TIME; EMAIL INTERVIEW TOPICS]
b. No [DISCUSS CONCERNS; ANSWER QUESTIONS; ATTEMPT TO CONVERT TO "YES"]

Interviewee Background

1. What is your role within your organization?
2. What types of commercial heat pump programs have you worked on?
3. Program Offerings for Low and UL GWP Product
4. What are your current measure offerings for space conditioning heat pumps in commercial buildings?
5. Do you have any GWP requirements for that equipment?
6. Are you currently incentivizing low or UL GWP refrigerants?
    - If yes, please describe them.
    - How many of these applications have you received?
    - Have you gotten any feedback from customers om measure offering?
        - If yes, what has it been?
7. Do you have any upcoming measure offerings for low and ultra-low GWP commercial space conditioning heat pumps?
    - If yes, please describe them.
8. Do you have any current or upcoming measure offerings for low GWP commercial space conditioning heat pumps with greater efficiency than required under Title 24 Part 6?
    - If yes, please describe them.
    - How many of these applications have you received?
    - Have you gotten feedback from customers on measure offering?
        - If yes, what has it been?

Program Adoption

9. What are your drivers for incentivizing low and ultra-low GWP commercial heat pumps?
10. What are your barriers to incentivizing low and ultra-low GWP commercial heat pumps?
11. What information would you need to have about a low or ultra-low GWP heat pump product for you to incorporate it into your measure offerings?
12. Given CARB's upcoming requirements, what role do you see utilities providing to further push the market with either low GWP equipment or high efficiency equipment?

Closing

Great! Thank you so much for your time. Those are all the questions we have for you today. For taking the time to speak to me today we will be emailing you a $150 e-gift card as a thank you. Before we finish, do you have any questions for me or anything else you would like to add?

HVAC and Refrigerant Manufacturer Interviews

Introduction

Thank you for taking the time to speak with us today. As a reminder, we are conducting this interview on behalf of SCE on behalf of CalNEXT to understand the current market conditions of UL GWP commercial space conditioning heat pumps. Specifically, we are interested in your experience with low and UL GWP refrigerants/products for commercial space conditioning heat pumps as well as efficient low GWP products. All answers will be kept anonymous. TRC will provide a $150 e-gift card as a thank you for your time today. Just to make you aware, the team has defined low GWP refrigerants as those with a GWP <750, and a UL GWP refrigerant as those <3. Additionally, it has recently been brought to our attention that as soon as July 1, 2024, A2L and A3 refrigerants will be allowed by California code, subject to the constraints of ASHRAE 15-2022. Please keep this in mind as you consider our questions.

Do we have your permission to record this interview? This is solely for note-taking purposes.

a. Yes [RECORD CONTACT INFORMATION; SETUP INTERVIEW TIME; EMAIL INTERVIEW TOPICS]
b. No [DISCUSS CONCERNS; ANSWER QUESTIONS; ATTEMPT TO CONVERT TO “YES”]

Interviewee Background

1. What is your role within your organization?
2. For the sake of this research project, TRC is defining low GWP refrigerants as those with a GWP <750 and ultra-low GWP refrigerants as those with a GWP ≤3. Are you involved in Low or UL GWP refrigerant development or HVAC product design?
    - If yes, what part?
3. What is your role in developing or bringing low and UL GWP products to market?

Review of Current Products in the Market

4. What ultra-low GWP refrigerants/heat pump products are available that could be installed in California commercial buildings currently? We’re looking for products significantly less than 750 GWP since that’s the upcoming requirement, and ideally ≤3 GWP.
5. What ultra-low GWP refrigerants/heat pump products do you think could be installed in California commercial buildings in the near future?
6. What barriers need to be overcome for these to be available?
7. We are also interested in heat pump products that just meet the CARB requirements (around 750 GWP) but that are more efficient than code requirements. Do you have any such products now or that are upcoming which could be installed in California commercial buildings?
8. What barriers need to be overcome for these to be available?
9. How can utilities assist overcoming the barriers, for either ultra-low GWP products or efficient, low GWP products?
10. How does your organization perceive the demand of these products?
11. Do you have examples of any ultra-low GWP heat pump installations in California commercial buildings?

12. Do you have examples of any efficient, low GWP heat pump installations in California commercial buildings?

Products in Design

13. What is the lowest GWP product you are attempting to bring to market?
14. Are there challenges in doing so?
    - If yes, please describe.
    - [If time]: Are you running into pressure issues within the refrigeration system itself?
    - [If time]: Are you running into any issues with regulatory bodies (UL, EPA, etc.) in trying to bring new products to market?
15. What are you anticipating the incremental costs to the customer to be for ultra-low GWP equipment compared to equipment with a GWP around 750?

Closing

Great! Thank you so much for your time. Those are all the questions we have for you today. For taking the time to speak to me today we will be emailing you a $150 e-gift card as a thank you. Before we finish, do you have any questions for me or anything else you would like to add?

SME Interviews

Introduction

Thank you for taking the time to speak with us today. As a reminder, we are conducting this interview on behalf of SCE on behalf of CalNEXT to understand the current market conditions of UL GWP commercial space conditioning heat pumps. Specifically, we are interested in your experience with low and UL GWP refrigerants/products for commercial space conditioning heat pumps as well as efficient low GWP products. All answers will be kept anonymous. TRC will provide a $150 e-gift card as a thank you for your time today. Just to make you aware, the team has defined low GWP refrigerants as those with a GWP <750, and a UL GWP refrigerant as those <3. Additionally, it has recently been brought to our attention that as soon as July 1, 2024, A2L and A3 refrigerants will be allowed by California code, subject to the constraints of ASHRAE 15-2022. Please keep this in mind as you consider our questions.

Do we have your permission to record this interview? This is solely for note-taking purposes.

a. Yes [RECORD CONTACT INFORMATION; SETUP INTERVIEW TIME; EMAIL INTERVIEW TOPICS]
b. No [DISCUSS CONCERNS; ANSWER QUESTIONS; ATTEMPT TO CONVERT TO “YES”]

Interviewee Background

1. What is your role within your organization?
2. For the sake of this research project, TRC is defining low GWP refrigerants as those with a GWP <750 and ultra-low GWP refrigerants as those with a GWP ≤3. Are you involved in low or UL GWP refrigerant development, HVAC product design, or code or standard adoption?
   - If yes, what part?
3. What is your role in developing or bringing low and UL GWP products to market?

Review of Current Products in the Market

4. What ultra-low GWP refrigerants/heat pump products are available that could be installed in California commercial buildings currently? We're looking for products <u>significantly</u> less than 750 GWP since that's the upcoming requirement, and ideally ≤3 GWP.
5. What ultra-low GWP refrigerants/heat pump products do you think could be installed in California commercial buildings in the near future?
6. What barriers need to be overcome for these to be available?
7. We are also interested in heat pump products that just meet the CARB requirements (around 750 GWP) but that are more efficient than code requirements. Are you aware of any such products now or that are upcoming which could be installed in California commercial buildings?
8. What barriers need to be overcome for these to be available?
9. How can utilities assist overcoming the barriers, for either ultra-low GWP products or efficient, low GWP products?
10. How does your organization perceive the demand of these products?
11. Are you aware of any ultra-low GWP heat pump installations in California commercial buildings?
    - If yes, please describe.
12. Are you aware of any efficient, low GWP heat pump installations in California commercial buildings?
    - If yes, please describe.

Products in Design

13. What is the lowest GWP refrigerant you find feasible to design around?
14. Are there challenges in doing so?
    - If yes, please describe.
    - [If time]: Are you aware of any issues with regulatory bodies (UL, EPA, etc.) in trying to bring new products to market?

Closing

Great! Thank you so much for your time. Those are all the questions we have for you today. For taking the time to speak to me today we will be emailing you a $150 e-gift card as a thank you. Before we finish, do you have any questions for me or anything else you would like to add?

Commercial Building Owner Interviews

Introduction

Thank you for taking the time to speak with us today. As a reminder, we are conducting this interview on behalf of SCE on behalf of CalNEXT to understand the current market conditions of UL GWP commercial space conditioning heat pumps. Specifically, we are interested in your interest in low and UL GWP heat pumps. I'll explain those terms during the interview. All answers will be kept anonymous. TRC will provide a $150 e-gift card as a thank you for your time today.

Do we have your permission to record this interview? This is solely for note-taking purposes.

a. Yes [RECORD CONTACT INFORMATION; SETUP INTERVIEW TIME; EMAIL INTERVIEW TOPICS]
b. No [DISCUSS CONCERNS; ANSWER QUESTIONS; ATTEMPT TO CONVERT TO "YES"]

Interviewee Background

1. What is your role within your organization?
2. Are you responsible for purchasing or specifying HVAC equipment?

Current Behavior for Heat Pump Technology Adoption

3. Let's start by discussing your current equipment. What type of equipment are you using for heating and cooling your buildings? For example, do you have rooftop packaged units, boilers and chillers, or something else?
4. Does your equipment use a heat pump technology? [*Briefly describe what a heat pump is and its efficiency gain.]*
    - If so, why did you choose to install heat pumps?
    - If not, why not?

Plan to Meet New California Air Resources Board (CARB) Move to <750 GWP Refrigerants, EPA Move to 700 GWP

Now let's talk about low GWP and ultra-low GWP equipment. GWP refers to global warming potential—how potent a chemical is at causing global warming compared to CO_2. The traditional refrigerant R-410A has a GWP of 2,088, meaning it causes over 2000 times more global warming than the same amount of CO_2.

California Air Resources Board (CARB) imposed a requirement that all new stationary air conditioning equipment have a GWP < 750 starting in 2025. The EPA passed a similar requirement, which will limit GWP to 700 or less in new equipment beginning in 2025. These requirements will effectively phase out traditional refrigerants like R-410A in new air conditioning equipment beginning in 2025.

5. Were you familiar with the regulations I just described? We are trying to gauge the market's understanding of these policy changes, so it's okay if you haven't.

We'd like to think through with you how you plan to meet these upcoming requirements. I'll start by describing some of the system types that can comply with the upcoming regulations. There is a class of refrigerants called A2Ls, which have a GWP between 450 and 680. These were previously prohibited by code because they are mildly flammable but will be permitted by code in California beginning in July 2024. A2L refrigerants can be used in various types of heat pumps, including air-to-water heat pumps and air-to-air heat pumps like packaged rooftop top systems.

6. This regulation only affects new equipment. When do you think you'll replace your heating

and cooling equipment?

7. How could utilities encourage you to replace your existing equipment earlier?
    - About what percent of the cost of equipment would utilities need to incentivize for you to replace your heating and cooling equipment early?
    - What type of training or information would be helpful from utilities to encourage you to replace your equipment earlier than planned?

Whenever you do choose to replace equipment, you could use this opportunity to retrofit to a heat pump with an A2L refrigerant. As I mentioned earlier, a heat pump is more efficient than standard equipment.

8. Would you be interested in retrofitting to a heat pump with an A2L refrigerant?
    - Why or why not?
    - What would be your motivations for installing this equipment?
    - What concerns would manufacturers need to address for you to install them?
    - How could utility programs help you retrofit your existing system with an A2L heat pump?
        - About what percent of the cost of equipment would utilities need to incentivize for you to replace your heating and cooling equipment with heat pumps?
        - What type of training or information would be helpful from utilities to encourage you to replace your equipment with a heat pump?

9. There are at least two types of A2Ls that can be used in heat pumps that will meet requirements: R-32 has a higher GWP of 675 but is more efficient than the energy code. R-454B has a lower GWP of 467 but is less efficient than R-32. Which system do you think you would be more interested in installing: R32 - more efficient than code, just meets GWP requirements, or 454B – just meets code requirements for efficiency, but has a lower (better) GWP than regulations?
    - Why?
    - If you don't know, what information would you want before making a decision?

10. [ONLY ASK IF THEY HAVE BOILER/CHILLER SYSTEM] Another possible system type is a propane-based system. Propane is an A3 refrigerant, which means it's more flammable than the A2Ls I just described. Because of this flammability concerns, code limits to propane systems to air-to-water systems such as air-to-water heat pumps or chillers that provide chilled water. Propane isn't allowed for air-to-air systems like packaged rooftop systems. The benefit of propane is it is an ultra-low GWP, because it has a very low GWP (GWP = 3).
    - Would you be interested in installing a propane system?
    - Why or why not?
    - What would be your motivations for installing them?
    - What concerns would manufacturers need to address for you to install them?
    - How could utility programs help you install a propane system?

Closing

Great! Thank you so much for your time. Those are all the questions we have for you today. For taking the time to speak to me today we will be emailing you a $150 e-gift card as a thank you. You should receive the card in your email within 10 business days. Before we finish, do you have any questions for me or anything else you would like to add?