GROUP A

Forward-Looking Low-Global Warming Potential Refrigerant Transition Study – Draft Report

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Glossary of key terms and acronyms

Accelerated replacement (AR): The Accelerated Replacement measure application type (MAT) is used for the replacement of existing equipment that could and would remain operational without program intervention. It is used in direct contrast to the normal replacement MAT, which is used when existing equipment either could not or would not remain operational. Early retirement (non-capacity expansion) measures and replacement of "operating equipment that when broken, non-functional, or unable to provide the intended service is typically repaired" can be classified as AR. New construction and capacity expansion cannot be classified as AR.

Add-On Equipment (AOE): An Add-on Equipment (AOE) measure installs new equipment onto an existing or new host, improving the nominal efficiency of the host system. The existing host system must be operational without the AOE, continue to operate as the primary service equipment for the existing load, and is able to fully meet the existing load at all times without the add-on component. The AOE must not be able to operate on its own. The actual energy reduction occurs at the host equipment, not at the add-on component, although any add-on component energy usage must be subtracted from the host savings.

Avoided Cost Calculator (ACC): The ACC is comprised of a platform of tools designed to estimate the avoided cost benefits of demand-side resources associated with programs such as energy efficiency.

Behavioral, Retro-commissioning, and Operational (BRO): The BRO category includes measures that either restore or improve energy efficiency and can be reasonably expected to produce multi-year savings. BRO measures include information or educational programs that influence energy-related practices (behavioral), activities and installations that restore equipment performance to its nominal efficiency (i.e., rated, intended, or original efficiency (retro-commissioning)) but do not enhance the measure's nominal efficiency, and measures that improve the efficient operation of installed equipment (operational). BRO sub-elements are abbreviated as follows:

- BRO-Bhv: BRO Behavioral
- BRO-Op: BRO Operational
- BRO-RCx: BRO Retro-commissioning

California Air Resources Board (CARB or ARB): CARB or ARB refers to the California Air Resources Board.

Charge, or refrigerant charge: The amount of refrigerant by mass contained in a refrigeration system. Charge is generally measured by grams, ounces, pounds (lb), or kilograms.[1]

Charge reduction: To reduce the refrigerant full charge amount through a mechanical system, change in the refrigeration circuit and not simply through a nominal full charge change.[2]

Chiller: A water or heat transfer fluid chilling equipment package custom built in place, or a factory-made and prefabricated assembly of one or more compressors, condensers, and evaporators, with interconnections and accessories including controls, designed for the purpose of cooling or heating water or a heat transfer fluid. A chiller is a machine specifically designed to make use of a vapor compression refrigeration cycle or absorption refrigeration cycle to transfer heat from a cold water or heat transfer fluid circulating system to the air, a heat transfer fluid, or another heat exchange media. Chillers can be water-cooled, air-cooled, or evaporatively cooled, and include, but are not limited to, rotary chillers, centrifugal chillers, and positive displacement chillers, including reciprocating, scroll, and screw chillers. Chillers include those used for

[1] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[2] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

comfort cooling, space and area cooling, or industrial process cooling. A chiller used for refrigeration in a retail food facility is considered an indirect type of "supermarket system."[3]

Cold storage: A refrigerated facility or warehouse used for the storage of temperature-controlled substances.[4]

Commercial ice machine: A non-residential ice machine and/or ice maker used in a commercial establishment to produce ice artificially for consumer use, including, but not limited to, a hotel, restaurant, or convenience store.[5]

Commercial refrigeration, or retail food refrigeration: Equipment designed to store and display chilled or frozen goods for commercial sale or use. This end-use includes, but is not limited to, the following categories of equipment: stand-alone units (equipment), refrigerated food processing and dispensing units (equipment), remote condensing units, and supermarket systems.[6]

Company: All businesses, affiliates, brands, or subsidiaries or franchises, owned or operated by the same parent company.[7]

Component: A part of a refrigeration system, including, but not limited to, condensing units, compressors, condensers, evaporators, and receivers; and all of its connections and subassemblies, without which the refrigeration system will not properly function or will be subject to failures.[8]

Counterfactual: In relation to the RACC, the counterfactual is the system and refrigerant condition contrary to the influence by a program. Can also be considered as the baseline case.

Cumulative replacement: The addition of or change in multiple components within a three-year period.[9]

Custom measure: A custom energy-efficiency measure with site-specific energy savings calculations based on the customer's existing and proposed equipment before installation and is finalized at project completion.

Deemed measure: A prescriptive energy-efficiency measure with predefined savings calculations, costs, eligibility, and other measure attributes.

Effective useful life (EUL): An estimate of median number of years that the measures installed under the program are still in place and operable. EUL values are for the new equipment and are provided as years. Additionally, some industry practices like routine maintenance can extend equipment life beyond the estimated EUL values. The CPUC's Database for Energy Efficiency Resources (DEER) lists EULs for common equipment. The maximum useful life for the new equipment that is replacing the removed item is 20 years.[10]

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[3] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[4] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[5] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[6] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 14. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[7] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 4. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[8] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 5. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[9] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 5. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[10] SW Custom Project Guidance Document, v 1.4, p. 10.

End-of-life (EOL) leakage event: A large portion of the refrigerant leakage from a device comes from the end-of-life (EOL) leakage event, which occurs when a piece of equipment is retired or reaches the end of its EUL.[11]

End-use: processes or classes of specific applications within industry sectors.[12]

Existing conditions baseline:[13] An existing baseline refers to the actual load-serving operation of the existing equipment prior to its replacement, adjusted, where applicable, for the post-installed operation. The existing operations can be suboptimal, but it must reflect equipment performance that maintains essential services. In order to use an existing baseline, the existing equipment is expected to be able to meet the customer's current and anticipated future requirements (e.g., for the remaining life of the equipment). In the case of projects that occur concurrently with a change in ownership or a lessee, or a change in the function of the space (e.g., office to laboratory), or a substantial change (i.e., 30% or more) in the design occupancy there is no reference operation for existing conditions and the pre-existing conditions may not be applicable to the project.

Fuel substitution measure: Fuel substitution measures, in the context of energy efficiency programs, involve energy efficiency projects where all or a portion of the existing energy use is converted from one fuel to another (i.e., natural gas to electricity or vice versa). Only equipment powered by electricity and/or natural gas fuels and provided by a CPUC-regulated investor-owned utility or a municipal utility are eligible to participate under fuel substitution measures.[14] Measures involving non-utility (unregulated) fuels, such as propane or fuel oil, are termed as fuel switching measures. Fuel switching measures are outside the scope of the Fuel Substitution Decision[15] and hence, are not considered in this technical guidance.

Full energy savings: The increase or decrease in site energy usage reported by the investor-owned utility after converting the change in energy into new fuel units as prescribed by D.19-08-009.[16] The full energy savings value is used in utility reporting and not used to calculate cost effectiveness. These energy savings converted into the new fuel units using the conversion factors (1 Therm = 29.3 kWh and 1 kWh = 0.03413 Therms) are defined as full energy savings.

Global warming potential (GWP): The amount that a substance contributes to global warming relative to carbon dioxide. A substance with a GWP of 100 contributes 100 times as much to global warming given the same mass as CO_2. For the purposes of this document, the GWP or Global Warming Potential Value (GWP Value) means the 100-year GWP value first published by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Working Group 1 Report (AR4) (IPCC, 2007); and if not contained in AR4, then the GWP Value means the 100-year GWP value published by the IPCC in its Fifth Assessment Working Group 1 Report (AR5) (IPCC 2013).[17]

Greenhouse gas (GHG): Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen trifluoride (NF_3) sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and other fluorinated gases.[18]

Greenhouse gas potential (GHGp):[19]

[11] 2022 Distributed Energy Resources Avoided Cost Calculator Documentation, September 15, 2022, https://willdan.box.com/v/2022CPUCAvoidedCosts

[12] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 5. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[13] Resolution E-4818, p. 11.

[14] D.19-08-009, pp. 12 and 53.

[15] Ibid, p. 53.

[16] Ibid, p. 37.

[17] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 6. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[18] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 6. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[19] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 7. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

GHGp = Σ (Charge × GWP)

Where:

∑ is the sum of the products of charge multiplied by the GWP for each separate type of refrigerant.

Hydrofluorocarbon (HFC): A class of GHGs that are organic compounds containing hydrogen, fluorine, and carbon; primarily used as refrigerants, foam blowing agents, aerosols-propellants, solvents, and fire suppressants.[20]

Industry standard practice (ISP) or standard practice: An estimate of the activity or installation that would take place absent the energy efficiency program as required by code, regulation, or law, or as expected to occur as standard practice. The standard practice baseline activity or installation must meet the anticipated functional, technical, and economic needs of the customer, building, or process and provide a comparable level of service as the energy efficiency measure.[21] A standard practice baseline must comply with all codes, regulations, and standards when the project commences,[22] including but not limited to minimum building energy efficiency requirements; emissions requirements; federal, state, and local government regulations; other regulatory agencies.[23] The standard practice need not to comply with local reach codes.[24]

The standard practice must represent a typical or commonly implemented practice, although it need not be the predominant (i.e., greater than 50%) practice.[25] The selected standard practice must be reasonable to implement. Industry Standard Practice studies may provide suggestions or requirements for common practices.

Standard practices are generally accepted as superior to other alternatives (e.g., a customer's standard way of complying with legal or ethical requirements, or a customer's preference for the best product with superior efficiency in customized design). Justification for selection of a Standard Practice Baseline (e.g., current purchasing trends, customer considerations) should be provided.[26]

If only one activity or installation meets the customer's anticipated functional, technical, and economic needs, that option defines the standard practice by default. In cases where the existing conditions are more efficient than the standard practice, the existing conditions define the baseline. Use of the less efficient code or standard practice as the baseline is referred to as a "regressive baseline" and is not allowed — the baseline selected for calculating energy savings may not use more energy than existing conditions.[27]

Life-cycle source BTU consumption: Source BTU over the EUL of the measure. For dual-baseline measures, both first and second baseline usage and RUL and EUL-RUL should be used respectively while calculating life-cycle source BTU.

Low temperature refrigeration system: A commercial or industrial process refrigeration system that maintains food, beverages, or other items at temperatures at or below 32 degrees Fahrenheit (0 degrees Celsius).[28]

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[20] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 7. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[21] *Resolution E-4939*, p. 8.

[22] *Resolution E-4795*, p. 39.

[23] California Public Utilities Commission, Energy Division, *Final Ex Ante Review Disposition*, Project ID x240. CPUC *Industry Standard Practice Guide Version 1.2A*, Section 2.7 ISP by Code or Regulation.

[24] *D.09-05-037*, OP 4.

[25] *Energy Efficiency Policy Manual, v 6.0*, pp. 39-4

[26] SW Custom Project Guidance Document, v. 1.4, p. 9.

[27] *D.12-05-015*.

[28] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 8. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

Measure application type (MAT): A measure must be assigned a MAT to inform baseline, cost, and energy savings calculations. Implementers must classify all proposed energy efficiency measures into one of the approved MATs.[29]

The CPUC recognized standard MATs applicable to this technical guidance document include:

- New construction (NC)
- Normal replacement (NR)
- Accelerated replacement (AR)
- Add-on equipment (AOE)
- Retrocommissioning (BRO-RCx)

Medium temperature refrigeration system: A commercial or industrial process refrigeration system that maintains food, beverages, or other items at temperatures above 32 degrees Fahrenheit (0 degrees Celsius).[30]

Methane leakage: The amount of methane that leaks in between the production and use of natural gas. Upstream in-state methane leakage includes leakage during in-state production, processing, transmission, or distribution, while residential behind the meter methane leakage refers to leakage that happens after the natural gas enters a residential building but before use in a device. It's important to note that upstream out-of-state methane leakage is not included in this calculator since it is not included in the California Air Resources Board inventory.

National supermarket chain: A retail food chain, brand name, or business operating more than 100 retail food facilities in the United States.[31]

New construction (NC): The NC MAT is used where equipment is installed in either a new area or an area that has been subject to a major renovation, to expand the capacity of existing systems, or to serve a new load. The NC MAT is used where there is no reference operation for existing conditions, such as with new construction, expansions, added load, a change in the function of the space (e.g., office to laboratory), or a substantial change (e.g., ~30% or more) in design occupancy.[32]

For NC measures, the baseline is the standard practice, or code baseline in place at the time the permit involving the measure was issued.[33]

New chiller or new chiller equipment: Any chiller equipment or chiller system end-use sectors listed in Table 3, section 95374(c) that is:

- First installed using new components, used components, or a combination of new and used components; or
- Modified such that:
  - The capacity is increased through the addition of motor-bearing components, including evaporators, compressors, or condensers; or

29 Resolution E-4952, p.A-46

30 California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 8. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

31 California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 8. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

32 Resolution E-4818, p. 66.

33 California Public Utilities Commission, August 18, 2016. *Resolution E-4795: Approval of the Database for Energy-Efficient Resources (DEER) updates for 2017 and 2018, in Compliance with D.15-10-028*, p. 39.

– Within any 3-year time period, the system has undergone cumulative replacements of motor-bearing components in full or exceeding 50% of the capital cost of replacing all of the motor-bearing components in the entire chiller system.[34]

New energy service: Serving loads in the existing building that were not served before, such as the addition of an air conditioning system which did not exist prior to the fuel substitution measure.

New facility: Any of the following: (1) new construction; (2) an existing facility not previously used for cold storage, retail food refrigeration, commercial refrigeration, industrial process refrigeration, or ice rinks; or (3) an existing facility used for cold storage, retail food refrigeration, commercial refrigeration, or industrial process refrigeration that has undergone replacement of 75%or more of its evaporators (by number) and 100%of its compressor racks and condensers.[35]

New fuel: The fuel that replaces the original fuel because of a fuel substitution measure.

New refrigeration equipment: Either of the following:

- Any refrigeration equipment that is:
  - First installed using new components, used components, or a combination of new and used components; or
  - Modified such that:
    - The nominal compressor capacity is increased; or
    - The system has undergone cumulative replacements, within any three-year time period, of components in full or exceeding 50%of the capital cost of replacing the entire refrigeration system, excluding the cost of refrigerated display cases.
- Any refrigeration equipment in a new facility that is first installed using new components, used components, or a combination of new and used components, applicable to refrigeration end-use sectors listed in Table 3, section 95374(c) or Table 4, section 95374(d), in the following: (A)New construction; (B)An existing facility not previously used for cold storage, retail food refrigeration, commercial refrigeration, industrial process refrigeration, or ice rinks; or (C) An existing facility used for cold storage, retail food refrigeration, commercial refrigeration, or industrial process refrigeration that has undergone replacement of 75%or more of its evaporators (by number) and 100%of its compressor racks, condensers, and connected evaporator loads.[36]

Normal replacement (NR)[37]: The NR MAT is used where existing equipment (including add-on equipment) has either failed, no longer meets current or anticipated needs, or is planned to be replaced due to normal remodeling or retrofit activities during the normal course of business or ownership. For NR measures, the baseline is the standard practice or code in place at the time the project commenced.[38] The NR MAT may be applied to any measure or program, with certain exceptions, and without a burden of proof.[39] This MAT includes measures that previously fit into the now-retired replace on burnout (ROB) MAT.

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[34] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 9. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[35] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 9. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[36] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 9. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[37] SW Deemed MP Rulebook, v. 4.0, p. 12

[38] *Resolution E-4795*, p. 39.

[39] *Resolution E-4818*, p. 67.

Original fuel: The primary fuel that was in use prior to the fuel substitution measure.

Refrigerant or refrigerant gas: Any substance, including blends and mixtures, that is a compound or gas used in vapor compression cycle refrigeration for heat transfer purposes and provides a cooling or warming effect.[40]

Refrigerant avoided cost calculator (RACC): Models the net-present value of avoided costs benefitted from changes in greenhouse gas emissions from measure or activities that involve refrigerants.

Refrigerant charge, or charge: See “Charge, or refrigerant charge”.

Refrigerant leakage: The amount of refrigerant that leaks from a device during its lifetime. Many electric-powered temperature regulation devices use refrigerants (e.g., air conditioning units, refrigerators, freezers, heat pumps, and more). Most devices that contain refrigerants allow the refrigerant to slowly leak throughout their life. Some devices require top-ups of refrigerant throughout their usable life, thus potentially causing the lifetime amount of refrigerant leaked to be greater than 100% for a single device. At the end of life, federal law mandates the recovery of refrigerants, but many are vented, creating a high end-of-life (EOL) leakage. Not all refrigerants impact global warming equally.

Refrigerant registration and reporting system or R3 database: The web-based tool for registration, reporting, and fee payment by facilities using at least one refrigeration system containing more than 50 lbs of refrigerant.[41]

Refrigerated food processing and dispensing equipment: Equipment that dispenses and/or processes a variety of food and beverage products by either combining ingredients, mixing or preparing them at the proper temperature, or by function as a holding tank to deliver the product at the desired temperature or to deliver chilled ingredients for the processing, mixing and preparation. Some may use a refrigerant in a heat pump or utilize waste heat from the cooling system to provide hot beverages. Some may also provide heating functions to melt or dislodge ice or for sanitation purposes. This equipment can be self-contained or connected by piping to a dedicated condensing unit located elsewhere. Equipment within this end-use category include but are not limited to chilled and frozen beverages (carbonated and noncarbonated, and alcoholic and non-alcoholic); frozen custards, gelato, ice cream, Italian ice, sorbets, and yogurts; milkshakes, slushies, and smoothies; and whipped cream.[42]

Refrigeration: The use of a refrigerant gas to mechanically move heat from one region to another to create a cooled region via a vapor compression cycle.[43]

Refrigeration equipment or refrigeration system: Any stationary device that is designed to contain and use refrigerant gas, including any device listed in section 95374(a), Table 1 under the general end-use “Refrigeration,” section 95374(b), Table 2 under the general end-use “Household Refrigerators and Freezers,” section 95374(c), Table 3 under the general end-use “Cold Storage Warehouses,” “Industrial Process Refrigeration,” or “Ice Rinks,” or section 95374(d), Table 4 under the general end-use “Retail Food Refrigeration.”. For a device with multiple independent circuits, each circuit is considered a separate article of equipment. Refrigeration equipment is used in retail food refrigeration, cold storage, industrial process refrigeration and cooling (not using a chiller), ice rinks, and other refrigeration applications.[44]

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[40] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 12. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[41] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 13. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[42] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 12. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[43] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 12. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[44] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 13. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

Remaining useful life (RUL): An estimate of the median number of years that equipment being replaced under the program would have remained in place and operable had the program not intervened.[45]

Remote condensing units: Refrigeration equipment or units that have a central condensing portion and may consist of one (and sometimes two) compressor(s), one condenser, and one receiver assembled into a single unit, which is normally located external to the sales area. The condensing portion (and often other parts of the system) is located outside the space or area cooled by the evaporator. Remote condensing units are commonly installed in convenience stores, specialty shops (e.g., bakeries, butcher shops), supermarkets, restaurants, and other locations where food is stored, served, or sold.[46]

Retail food facility: A facility that sells food and uses at least one retail food refrigeration equipment unit or refrigeration system with more than 50 lbs of a refrigerant with a GWP value of 150 or greater. “Retail food facility” includes supermarkets, grocery stores, and all other food merchandising stores.[47]

Retail Food Refrigeration or Commercial Refrigeration: See "Commercial refrigeration, or retail food refrigeration"

Retirement: The permanent removal from service of a refrigeration system or component, rendering it unfit for use by the current or any future owner or operator.[48]

Retro-commissioning: Measures that either restore or improve energy efficiency and that can be reasonably expected to produce multi-year savings. They result in performance that does not exceed the nominal (rated or original) efficiency of the existing condition. Resolution E-4818 directed that all measures which utilize a degraded performance baseline and/or are restorative of performance in nature be classified as retro-commissioning (BRO-RCx).

Retrofit or refrigerant retrofit: The replacement of the refrigerant used in refrigeration equipment with a different refrigerant, and any related changes to the refrigeration equipment required to maintain its operation and reliability following refrigerant replacement.[49]

Site Energy Consumption: Energy consumed at the site of the fuel substitution measure installation, such as a home or business.

Site Energy Savings: Energy savings evaluated at the “site” level which include the net savings from the displaced original fuel usage and the increased new fuel usage.

Source energy consumption: Conversion of retail energy forms (kWh, Therm) into the Btu required to generate and deliver the energy to the site. Only the source energy from depletable fossil-fuel resources such as natural gas and coal are considered; the source energy from non-depletable (i.e., renewable energy) sources such as solar, wind, and hydro-electric is considered as zero Btus. This conversion is used to compare the relative impacts of switching between fuel sources at the source or Btu level for the fuel substitution test required for fuel-substitution measures.

Source energy savings: Energy savings evaluated at the “site” level which—for fuel substitution measures—include the net savings from the displaced original fuel usage and the increased new fuel usage.

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[45] SW Custom Project Guidance Document, v 1.4, p. 11.

[46] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 13. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[47] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 14. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[48] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 14. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[49] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 14. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

Stand-alone units or equipment: Refrigerators, freezers, and reach-in coolers (either open or with doors) where all refrigeration components are integrated and, for the smallest types, the refrigeration circuit is entirely brazed or welded. These systems are fully charged with refrigerant at the factory and typically require only an electricity supply to begin operation. "Stand-alone Units or Equipment" does not include commercial ice machines.[50]

Standard practice baseline: Estimates the annual energy consumption of the activity or installation that would take place absent the energy efficiency program as required by code, regulation, or law, or as expected to occur as standard practice. The standard practice baseline activity or installation must meet the anticipated functional, technical, and economic needs of the customer, building, or process and provide a comparable level of service as the energy efficiency measure.[51] A standard practice baseline must comply with all codes, regulations, and standards when the project commences,[52] including but not limited to: minimum building energy efficiency requirements; emissions requirements; federal, state, and local government regulations; other regulatory agencies.[53] The standard practice need not comply with local reach codes.[54]

The standard practice must represent a typical or commonly implemented practice, although it need not be the predominant (i.e., greater than 50%) practice.[55] The selected standard practice must be reasonable to implement. Industry standard practice studies may provide suggestions or requirements for common practices.[56]

Standard practices are generally accepted as superior to other alternatives (e.g., a customer's standard way of complying with legal or ethical requirements, or a customer's preference for the best product with superior efficiency in customized design). Justification for selection of a standard practice baseline (e.g., current purchasing trends, customer considerations) should be provided.

If only one activity or installation meets the customer's anticipated functional, technical, and economic needs, that option defines the standard practice by default. In cases where the existing conditions are more efficient than the standard practice, the existing conditions define the baseline.

Stationary: The system meets at least one of the following conditions:

- Installed in a building, structure, or facility
- Attached to a foundation, or if not attached, will reside at the same building, structure, or facility for more than 12 consecutive months
- Located permanently at the same facility for at least two consecutive years and operates at that facility a total of at least 90 days each year[57]

Supermarket systems: Multiplex or centralized systems designed to cool or refrigerate, which operate with rack(s) of compressors installed in a machinery room. Two main design classifications are used: direct and indirect systems.

- "Direct Systems" means the refrigerant circulates from the machinery room to the sales area, where it evaporates in display-case heat exchangers, and then returns in vapor phase to the suction headers of the compressor racks. Another

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[50] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 16. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[51] Resolution E-4939, p. 8.

[52] Resolution E-4795, p. 39.

[53] California Public Utilities Commission, Energy Division, Final Custom Project Review Disposition, Project ID x240. CPUC Industry Standard Practice Guide Version 1.2A, Section 2.7 ISP by Code or Regulation.

[54] D.09-05-037, p. 4.

[55] Energy Efficiency Policy Manual v.6, p. 38-40.

[56] To see active Industry Standard Practice documents, visit https://www.cpuc.ca.gov/General.aspx?id=4133

[57] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 16. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

direct supermarket design, often referred to as a distributed refrigeration system, uses an array of separate compressor racks located near the display cases rather than having a central compressor rack system.

- "Indirect Systems" means the system uses a central refrigeration system to cool a secondary fluid that is then circulated throughout the store to the cases. This includes secondary loop systems and cascade refrigeration. A chiller used in retail food facilities to cool a secondary fluid subsequently used to cool food, beverage, and displayed products is considered an indirect refrigeration system.[58]

Total system benefit (TSB):[59] An expression, in dollars, of the lifecycle energy, ancillary services, generation capacity, transmission and distribution capacity, and greenhouse gas (GHG) benefits of energy efficiency activities, on an annual basis. The 2021 Energy Efficiency Potential and Goals study states that TSB represents the total benefits, or "avoided costs," that a measure provides to the electric and natural gas systems. The factors included in avoided costs are defined through the CPUC Integrated Distributed Energy Resources (IDER) proceeding."

Vending machines: Self-contained units that dispense goods that must be kept cold or frozen.[60]

Very low temperature refrigeration or cooling: A refrigeration or cooling system that maintains temperatures below -58 degrees Fahrenheit (-50 degrees Celsius), including, but not limited to, medical and laboratory freezers, specialized industrial process cooling applications, and extreme temperature environmental testing.[61]

Weighted average of cost of capital (WACC): Represents the average cost of all capital assets that a company currently holds.[62]

Weighted-average GWP: Means ∑ (charge x GWP)/ ∑ charge where charge equals the weight, in pounds (lb.), of each individual type of refrigerant, refrigerant blend, or heat transfer fluid used in refrigeration equipment and systems. ∑ in the numerator is the sum of the products of charge multiplied by the GWP for each separate type of refrigerant. ∑ in the denominator is the sum of all refrigerant charge in all refrigeration equipment with more than 50 pounds of refrigerant.[63]

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[58] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 16. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[59] 59 California Public Utilities Commission, "Total System Benefit Technical Guidance, Version 1.1.," PDA Energy Data Web, 08-16-2021, https://pda.energydataweb.com/api/view/2530/DRAFT%20TSB%20Tech%20Guidance%20081621.pdf

[60] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 17. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[61] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 17. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[62] https://www.britannica.com/money/weighted-average-cost-of-capital-wacc

[63] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4, p. 17. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

1 EXECUTIVE SUMMARY

California has enacted laws and regulations to reduce the emissions of hydrofluorocarbons (HFCs) and other synthetic greenhouse gases (GHGs). California aims to achieve zero net GHG emissions by 2045[1], and a 40% reduction in HFC emissions by 2030.[2] Furthermore, under SB 1013, the "California Cooling Act," the CPUC and other state regulatory agencies are called upon to assess the operational performance of refrigerants with low global warming potentials (GWP) and to develop a strategy to encourage the adoption of those low-GWP refrigerants in equipment funded by energy efficiency programs overseen by the CPUC. Given the rapid pace with which refrigerant policy updates are currently being passed in California and the U.S., clear guidance that defines appropriate baseline and install conditions is needed. This study helps CPUC, California Program Administrators (PAs) and stakeholders understand the low-GWP refrigerant transition and maximize the Total System Benefit (TSB) of low-GWP refrigerants in heating, ventilation, and air conditioning (HVAC) equipment, commercial refrigeration, heat pump appliances and other stationary applications containing refrigerant. In 2021, DNV completed a forward-looking research study to speed up the adoption of low-GWP refrigerants in HVAC equipment. This low-GWP refrigerant transition study builds on and expands the 2021 Low-GWP HVAC study.

1.1 Introduction

Decarbonization efforts often involve replacing gas-fired HVAC, water heating, and clothes drying equipment with all-electric heat pumps. However, heat pumps all rely on refrigerants that can have negative environmental impacts. To achieve the climate goals underlying decarbonization, negative environmental impacts must be monitored and mitigated. Most refrigerants used today have a harmful GHG effect when emitted into the atmosphere. All equipment containing refrigerant gas can emit refrigerant through operational leakage and end-of-life emissions. Refrigerants allow heat to be transferred from one source to another and are present in all heat pump applications, air conditioners, commercial refrigeration, chillers, refrigerators, and more. The most common refrigerant class used today is HFCs. HFCs emerged in the 1990s as the preferred replacement for ozone-depleting refrigerants. However, the scientific community soon realized HFCs also raise severe environmental concerns with respect to global warming. GWP is the most widely recognized metric for the long-term impact refrigerants have on atmospheric temperature. The GWP metric represents the heat-trapping impact that one metric ton of a refrigerant gas has relative to that of one metric ton of carbon dioxide (CO_2).

The CPUC oversees the Avoided Cost Calculator (ACC), which is a platform of tools and supporting documentation that includes the Refrigerant Avoided Cost Calculator (RACC). In 2024, the TSB metric replaced annual electricity, electric demand, and gas (kWh, kW, and therm) savings as the metric for setting goals and measuring the accomplishments of the California energy efficiency portfolio. TSB represents the lifecycle energy, capacity, and GHG benefits of an energy efficiency program or project. The environmental impact of gases associated with the use of fossil fuel and changes in the amount or type of refrigerant resulting from projects funded by the energy efficiency portfolio are included in the TSB. The RACC is the tool used to quantify the contribution of refrigerants to the TSB. The outputs of the RACC feed into the Fuel Substitution Calculator (FSC) that is required for projects where all or a portion of the existing energy use is converted from one CPUC-regulated fuel to another CPUC-regulated fuel[3]. The FSC determines measure eligibility by testing if the overall energy consumption does not increase, and if the total greenhouse gas emissions from all sources do not increase. The RACC yields a dollar value for either the costs associated with introducing refrigerant where there was none before (such as when a gas water heater is replaced with a heat pump water heater) and in cases where a project reduces the global warming potential of

[1] The California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32, Nunez

[2] California Senate Bill (SB) 1383, Lara

[3] Fuel Substitution in Energy Efficiency, CPUC, https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency

the refrigerants in-use by selecting a low-GWP refrigerant relative to standard practices in the market. This study provides comprehensive guidance to users of the RACC and explores strategies for minimizing ongoing refrigerant emissions.

1.2 Study objectives and methodology

Table 1-1 details DNV's study objectives and approach for collecting data, conducting research, and analyzing findings:

Table 1-1. Study objectives and methodology approach

Study objectives	Methodology
Define and characterize baseline conditions for deemed and custom projects containing refrigerants.	• DNV included a full review of project or application types in the latest version of the RACC to understand upcoming regulations and standard practices. • We combined interviews with subject matter experts (SMEs) from the Deemed and Custom Program teams and other refrigerant policy SMEs with current laws regulating refrigerants in CA and nationally to characterize baseline parameters for existing and emerging energy efficiency projects containing refrigerants.
Expand and enhance the existing RACC to include the latest refrigerant policy and emerging technology updates.	• DNV reviewed the equations and data in the existing RACC workbook and identified improvement opportunities. • The team proposed a series of improvements to the RACC that addressed baseline GWP requirements, corrected errors, and enabled the tool to be updated more efficiently. • DNV also combined the RACC with an enhanced and expanded FSC.
Provide a technical guidance document for users of the RACC/FSC.	• DNV developed a technical guidance document to help calculate eligibility for energy efficiency projects that contain refrigerants and the resultant contribution to the TSB. • The document leverages information gathered during the baseline review and modeling tools review tasks. • The team also incorporated guidance on how the RACC-FSC could support end-of-life recovery and reclamation best practices.
Recommend modeling tool improvements to adequately capture the performance of various HVAC, commercial refrigeration, and water heating systems.	• DNV identified energy modeling tools capable of simulating the performance of alternative refrigerants in refrigeration systems and refrigerant-using equipment. • A key area of focus was to assess the identified modeling tools' ability to produce hourly load shapes for low-GWP refrigerant projects.
Summarize and recommend refrigerant resources and trainings available to contractors and market actors.	• DNV investigated the readiness of the HVAC workforce to implement low-GWP alternatives. • The analysis leveraged secondary research and information gathered through workforce interviews and a web survey to identify knowledge gaps and provide recommendations on how to bridge those gaps.
Summarize recovery, reclamation, and disposal options and explore ways to increase recovery rates documentation.	• DNV reviewed current refrigerant recovery, reclamation, and disposal practices and explored strategies to increase recovery rates and develop recommended documentation best practices.

1.3 Data sources and tools

The research team drew from an assortment of data sources, which included:

Secondary research: The research team performed a comprehensive review of refrigerant related resources, including California and national publications covering the low-GWP refrigerant transition, U.S. Environmental Protection Agency (EPA) regulations and webinars, California Air Resources Board (CARB) regulations and webinars, industry journal articles, manufacturer publications, North American Sustainable Refrigeration Council (NASRC) publications and webinars, and research findings for other refrigerant related studies funded by the California PAs.

RACC: The research team conducted a thorough review of the then current[4] and prior versions of both the RACC and the other ACC tools. The team reviewed the technical guidance document for the ACC and the changes and reasoning for changes to the RACC since its first release.

Stakeholder interviews: The research team interviewed PA representatives and supporting consultants to better understand their experiences with the RACC and to identify any pain points encountered using the tool.

In-depth interviews (IDIs) with refrigerant policy SMEs: DNV conducted IDIs focused on refrigerant policy and low-GWP transition timelines with representatives from CARB, the EPA, the Environmental Investigation Agency (EIA), the Carbon Containment Lab (formerly the Yale CCL), the Institute for Governance and Sustainable Development (IGSD), and the NASRC. Policy SMEs also shared insights about emerging natural refrigerant applications globally, and strategies for improving refrigerant recovery and reclamation.

IDIs with HVAC and Refrigeration (HVAC-R) SMEs: The research team interviewed six different California HVAC-R contractors about the ongoing transition to low-GWP refrigerants, training, and refrigerant recovery and reclamation. We asked interviewees about the following:

- General knowledge of current and future low-GWP refrigerants available in the market
- Training and guidance resources they use to stay informed about code changes
- End-of-life refrigerant recovery and reclamation

Existing tools review: The team performed secondary research to assess the features and capabilities existing models have for predicting refrigerant impacts on energy efficiency, capacity, and load shapes. Researchers worked with DNV's Deemed measure team to identify which measure types are in most need of simulation tools and prioritized review of these measures.

Focus group: In March 2024, DNV led a 90-minute virtual focus group to explore strategies to reduce refrigerant emissions and improve end-of-life refrigerant recovery and reclamation. The focus group participants included various SMEs from the in-depth interviews and other key market actors. The 23 attendees included four CA-licensed HVAC-R contractors, representatives from the EPA, CARB, the Carbon Containment Lab, the Environmental Investigation Agency (EIA Global), two EPA-licensed refrigerant reclaimers, two major HVAC distributors, and CPUC study leads.

HVAC-R web survey: DNV conducted a web survey with 44 known HVAC-R contractors and technicians in April 2024. Survey questions used findings from the HVAC-R in-depth interviews and the focus group.

1.4 Results

This section summarizes task-level findings.

1.4.1 Baseline characterization

A baseline provides a standard from which benefits of implementing an energy efficiency measure can be calculated and represents what would have happened if the energy efficiency measure was not adopted. New refrigerant regulations change the assumptions that can be made about what would have happened. Understanding the baseline for refrigerants involves looking at upcoming state and federal regulations that address refrigerants in various equipment types and sizes. Table 1-2 provides an overview of current and future refrigerant GWP limits by end-use or project type. End-use categories sometimes contain multiple GWP policy limits for a single year. For these cases, the values presented in each cell represent the most

[4] 2022 ACC Refrigerant Calculator v1b updated

restrictive GWP limit or maximum approved refrigerant GWP value found on the CARB[5] or EPA[6] websites. The green arrows indicate the previous regulation or no regulation is in place along the timeline. For some end-use categories, no GWP restrictions exist for a given year at either the state or federal level. For these instances, the research team sourced the typical refrigerant type and GWP values from the Energy Star® product finder website.[7]

Table 1-2. Current and future refrigerant GWP limits by end use

Sector	End-Use	2024	2025	2026	2027	2030
Stationary Refrigeration	Existing Retail Refrigeration (<50 lb. refrigerant)	No regulation	→	EPA: GWP ≤300 (remote units only)	EPA: GWP ≤300	→
	Existing Retail Refrigeration (> 50 lb., ≥ 20 stores)	No regulation	→	→	CARB GWP: <2,500 (avg. across all stores)	CARB GWP: <1,400 (avg. across all stores)
	New Retail Refrigeration (>50 lb.)	CARB GWP: <150	→	→	→	→
	New Stand-alone Refrigeration Units	No regulation (ENERGY STAR® GWP: 2)	EPA GWP: ≤ 150	→	→	→
Stationary Air-conditioni	HVAC Systems and Chillers	No regulation	EPA: GWP ≤700	→	→	→
	HVAC Products	CARB: GWP <750	EPA: GWP ≤700	→	→	→
	HVAC: Variable Refrigerant Flow	No regulation	→	EPA: GWP ≤700	→	→
Heat Pump Applian	Heat Pump Water Heaters	No regulation	→	→	→	→
	Heat Pump Clothes Dryers	No regulation	→	→	→	→

Research and IDI findings indicate that natural refrigerants are by far the most environmentally responsible refrigerant solution. Natural refrigerants have GWP levels below 4 compared to a typical air conditioner installed in 2024 which has a GWP of 2,088. Natural refrigerants also have zero ozone depletion potential and no per- and polyfluoroalkyl (PFAS) chemicals, which are persistent in the environment and can have negative health impacts to all living organisms. However, current safety and design limitations prevent widespread adoption of natural refrigerants, as shown in Table 1-3.

Table 1-3. Natural refrigerant barriers to adoptions

Natural Refrigerants	Barriers
Propane (R-290), isobutane (R-600a)	**Safety:** High flammability. Current 300-500 gram charge size restrictions in the U.S. limit effective hydrocarbon use to residential and smaller self-contained commercial refrigeration equipment.
Ammonia (R-717)	**Safety:** Toxic, mildly flammable. Limited use outside of industrial refrigeration.
Carbon dioxide (R-744)	**Design:** Higher system pressures due to gas properties increase system component costs, and design requirements compared to synthetic higher-GWP HFC alternatives.

[55] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4. Final Regulation Order. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[6] Environmental Protection Agency. *Significant New Alternatives Policy (SNAP) Program.* https://www.epa.gov/snap/

[7] Energy Star Product Finder. https://www.energystar.gov/productfinder/

Currently, natural refrigerants are found in many applications including retail refrigeration, industrial refrigeration, residential refrigerators, small heat pump and air-conditioning systems (internationally), and commercial ice machines. In 2022, the International Electrotechnical Commission (IEC) approved standards for increased charge limits for hydrocarbons in HVAC systems, leading to the rapid growth of R-290 heat pump systems in Europe and Asia[8]. A proposal to adopt the increased charge standard is underway in the U.S.

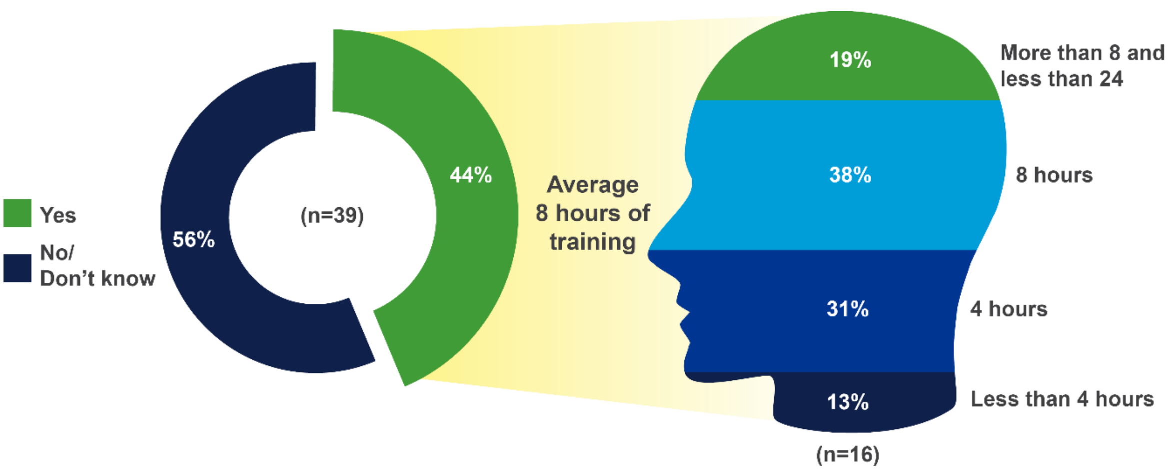
1.4.2 Workforce knowledge

The market transition to low-GWP and natural refrigerants is contingent on a skilled workforce with the resources and training to both install and service emerging low-GWP applications. For grocery stores and other stationary refrigeration projects, the NASRC provides a growing workforce development and policy arena. While ample training and development is still needed, the transition to low-GWP and natural refrigerants in stationary refrigeration is well ahead of the HVAC refrigerant transition. For these reasons, HVAC workforce knowledge was the primary focus of this task.

The research team attended more than a dozen refrigerant-related webinar trainings targeting HVAC-R service professionals. Some of the trainings focused on the low-GWP refrigerant transition while others focused on detecting leaks and best practices for minimizing refrigerant emissions. Six different California HVAC contractors were asked about their knowledge of the low-GWP refrigerant transition between September 2023 and January 2024. Each contractor interviewed was aware of the pending transition to lower-GWP refrigerants in HVAC, but as of the time we spoke with them, all reported receiving <4 hours in training specific to the mildly flammable refrigerants that will be mandated in 2025.

In April 2024, the research team conducted a 13-question web survey seeking feedback from HVAC technicians and contractors who had participated in prior PA sponsored energy efficiency HVAC projects. In total, 39 contractors and technicians responded to the survey question asking if anyone at their company had received training on the use of mildly flammable refrigerants. As shown in Figure 1-1, only 17 (44%) of those respondents reported someone from their company having received training.

Figure 1-1. Web survey responses who received training, and how many hours they received



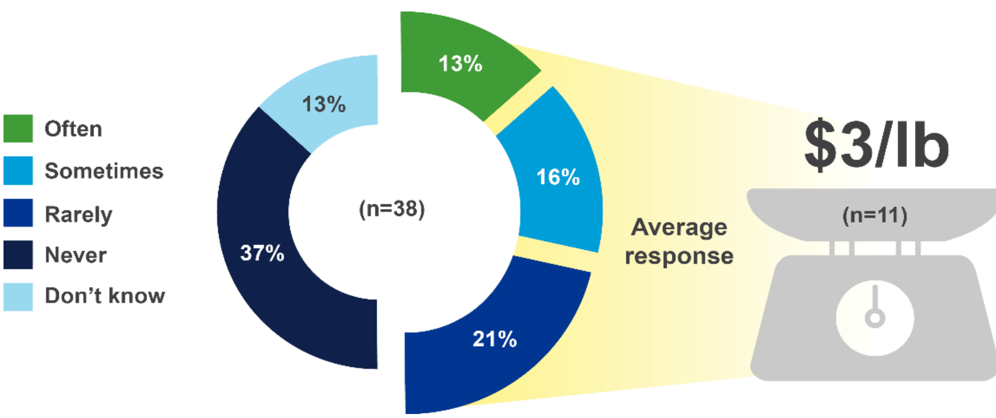
*17 respondents reported someone had received training but only 16 respondents provided an hours of training response.

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

1.4.3 Improved recovery

Refrigerants only cause environmental damage when released into the atmosphere. When equipment containing refrigerants is replaced it is especially important to collect and recover the remaining refrigerant carefully (through the process of recovery and reclamation). Technically, refrigerant recovery is the process of extracting refrigerant from one system to a refrigerant recovery tank or cylinder using a recovery machine.[9] Ideally, contractors and technicians do this every time they retire equipment containing refrigerant from service. Refrigerant reclamation is the process of returning used refrigerant to the same quality and chemical composition of new refrigerant. Throughout the study, the research team noted alarming rates of refrigerant emissions when equipment is decommissioned or replaced. Current CARB estimates show end-of-life emission rates are highest for smaller equipment (80%-99% for residential) with end-of-life emission rates decreasing as systems and charge sizes increase in the commercial and industrial sectors. Interviews with refrigerant policy SMEs and EPA-licensed reclaimers[10] support CARB's high end-of-life refrigerant emission estimates. In IDIs with licensed contractors, all six contractors reported they use recovery machines to pull the remaining refrigerant into recovery cylinders when retiring existing systems. The same group also openly acknowledged that many contractors do not do the same. Lack of enforcement of Section 608 of the US Clean Air Act prohibiting the intentional release of refrigerants into the atmosphere[11], the added time required for proper system recovery, lack of meaningful monetary incentives, and the need to complete jobs in a single day, were some of the key reasons for contractors to cut corners. Only half of survey respondents reported receiving payment for recovered refrigerant. Of those who reported receiving payment, the average payment received was only $3/pound of refrigerant, as shown in Figure 1-2. At that price, a contractor would receive about $21 for returning the remaining 7 lbs. of refrigerant recovered from a typical residential split-system. For comparison, the GHG impact of 7 lbs. of R-410A, the most common refrigerant found in residential HVAC systems, is equivalent to driving a passenger car 15,000 miles. Given all those barriers, it is little wonder recovery rates are so low.

Figure 1-2. Frequency performed and amount received for recovered refrigerant



In March 2024, DNV hosted representatives from two EPA-licensed reclaimers, two HVAC equipment distributors, the EPA, CARB, refrigerant policy SMEs, and four HVAC-R contractors for a virtual focus group. The group met to explore a path to enable energy efficiency programs to claim avoided GHG emissions for documented end-of-life refrigerant recovery and reclamation. Participating HVAC contractors each shared their process for recovering refrigerant at end-of-life. Three of the four reported they typically spend two hours performing end-of-life refrigerant recovery and receive virtually no payment for returning reclaimed refrigerant. One added that he sometimes gets charged because the reclaimer determines the recovered

[9] https://www.epa.gov/section608/refrigerant-recovery-and-recycling-equipment-certification

[10] Licensed facility that collects used refrigerant gas and reprocesses to meet the purity standards of new refrigerant gas or destroys the used refrigerant if unable to reprocess the used refrigerant to required standards.

[11] Section 608 – U.S. Clean Air Act, https://www.epa.gov/section608/stationary-refrigeration-prohibition-venting-refrigerants

refrigerant is too impure to reclaim. Another stated most contractors he knows do not reclaim, and that condensers with refrigerant often end up at the scrap yard never to be recovered. In contrast, the two EPA-licensed reclaimers both claimed they were surprised to hear that contractors do not get any value from reclaimed refrigerants. Both stated they buy back all used refrigerants, and that it is “a nightmare myth” that cylinders containing multiple recovered refrigerants cannot be reclaimed.

One of the contractors gave a virtual demonstration of the Visual Service[12] smartphone application his company’s technicians use when installing, servicing, and retiring equipment in the field. The Visual Service application’s ability to document the refrigerant recovery process impressed the attendees. The Visual Service application produces documentation that includes the following:

- A video of the contractor operating the recovery machine on the retired system
- A geographic pin showing the location
- A data tracker showing both the pressure of the refrigerant in the existing system decreasing
- The weight of the refrigerant being transferred to the recovery cylinder increasing
- The type and serial number of the recovery cylinder.

The focus group agreed that this level of documentation combined with a bill of lading[13] from an EPA-licensed refrigerant reclaimer showing the recovery cylinder was reclaimed, would effectively prove the refrigerant was reclaimed.

CARB estimates that the average end-of-life emission rate is 80% for central residential ACs and heat pumps. That is, 80% of the time all remaining refrigerant in removed systems is released into the atmosphere. When central ACs and heat pumps are removed today they predominantly contain the refrigerants R-22 or R-410A with R-410A becoming increasingly more common because R-22 was phased out of service for new systems in 2010. Using the 80% end-of-life emission rate estimated by CARB, the removal of a typical 2.5-Ton AC system with R-410A results in the release of 5.15 tonnes CO_2 GHG emissions. Correspondingly, the avoided emission credit that could be claimed if that 2.5 Ton AC’s remaining refrigerant was recovered, reclaimed and documented, would be over $700 in net present value dollars according to the RACC. Today, contractors and technicians who receive payment for reclaiming refrigerant only receive about $21 for that 2.5 Ton AC’s 7 lbs. of remaining refrigerant and half of all contractors surveyed don’t receive payment at all.

In the survey, participants were asked if compensation would motivate their business to perform and document end-of-life recovery. Knowing it may involve submitting photographic evidence of the recovery process through a mobile app, they were asked how much compensation they would need to fulfill end-of-life recovery/reclamation documentation requirements on a residential split-system. Figure 1-3 shows that $114 was the average amount provided by the 18 respondents (46%) who agreed to specify a dollar amount. In contrast, eight (21%) did not provide an amount and would not do it unless required by law, and three said they would do it without compensation.

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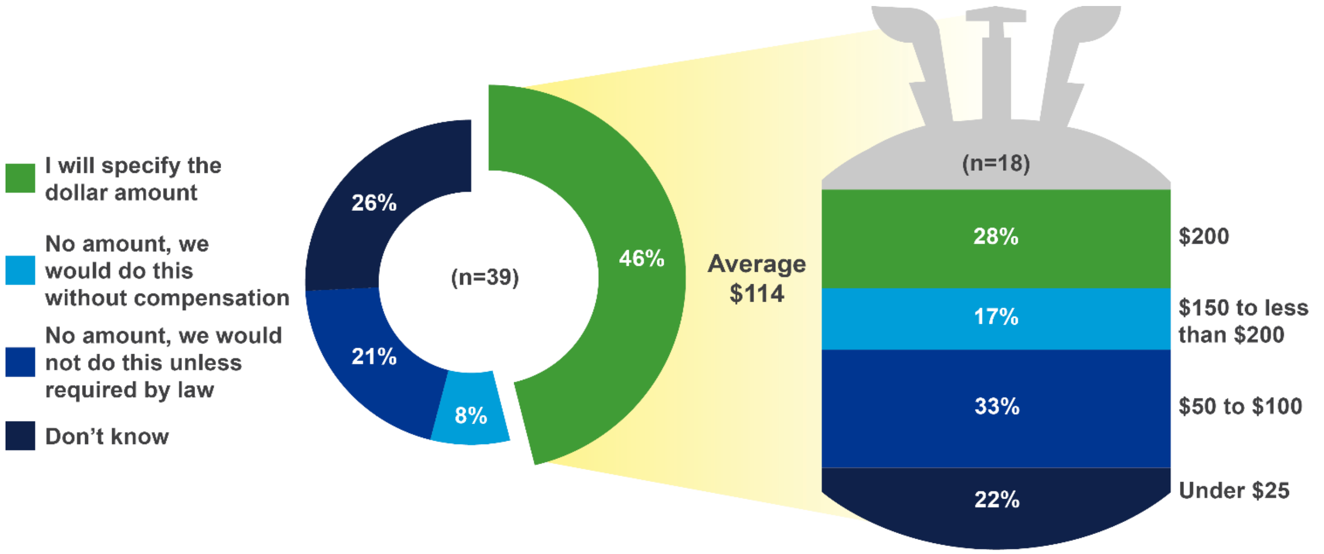
12 https://www.visualservice.com/

13 Bill of lading is a detailed list of a shipment of goods in the form of a receipt that is exchanged between parties carrying the goods.

Figure 1-3. What compensation would be required for documenting end-of-life refrigerant recovery and reclamation?



During the focus group, refrigerant policy SMEs from the EPA and the Yale Carbon Containment Lab shared concerns that the net benefits resulting from documented end-of-life recovery need to account for several regulatory and market effects. They shared an overarching market concern that reclaimed high-GWP refrigerant does not uniformly displace demand for virgin high-GWP refrigerant. The American Innovation and Manufacturing (AIM) Act subsection (h)[14] could dramatically expand demand for reclaimed gases and there may be a need to eventually sunset avoided GHG claims for documented recovery and reclamation depending on how the market reacts to that legislation. Other policy SMEs took a more practical approach reminding the group not to let perfect be the enemy of good and that end-of-life emissions are occurring at alarming rates every day. Those same policy SMEs suggested that with the right safeguards, this type of incentive or credit to key market actors could serve as a bridge to making recovery and reclamation standard practice in the workforce.

1.5 Key findings and recommendations

This section presents key findings and recommendations followed by considerations for next steps.

The Low-GWP HVAC refrigerant transition is still in the early stages.

The transition away from high-GWP refrigerant in HVAC is still in the early stages. High-GWP HVAC systems remain standard practice in 2024 and the next stage of lower-GWP HVAC refrigerants, R-454B and HFC-32, still have 100-year GWP levels of 466 to 675 respectively. Flammability, toxicity, and design challenges are preventing an immediate transition to natural refrigerant HVAC equipment in the U.S.

The Low-GWP transition for stationary refrigeration is further along but limited by workforce knowledge.

Residential, retail, and industrial refrigeration systems using some forms of natural refrigerant are available for most applications. The biggest barrier preventing the widespread adoption of natural refrigerants in new stationary refrigeration equipment is a trained workforce. Existing stationary refrigeration infrastructure remains a high GHG liability because of high operational leak rates, extended measure lives, and challenges retrofitting or replacing systems with low-GWP refrigerant.

[14] Technology Transitions Final Rule, October 2023, https://www.federalregister.gov/documents/2023/10/24/2023-22529/phasedown-of-hydrofluorocarbons-restrictions-on-the-use-of-certain-hydrofluorocarbons-under-the

Natural refrigerants are the essential solution.

Research findings and refrigerant SMEs agree that natural refrigerants in stationary refrigeration and HVAC sectors provide the best long-term solution for the environment. The three most common natural refrigerant categories — hydrocarbons, CO_2, and ammonia — all have zero ozone-depleting properties, GWP levels below 4, no forever chemicals like PFAS, and are proven to have equal to superior performance capabilities when safety, design, and toxicity barriers are addressed.

Fund and promote natural refrigerants where and when they are permitted.

PAs of stationary refrigeration incentive programs should support refrigeration systems containing natural refrigerants over lower-GWP synthetic refrigerants wherever natural refrigerants are permitted. PAs of heat pump appliances should use the RACC-FSC to weigh the TSB achieved with natural refrigerant heat pump appliances over HFC alternatives. Regulators should encourage all U.S. and California codes and standards to **rapidly** harmonize with those in Europe and Asia.

Performing end-of-life refrigerant recovery and reclamation comes with a heavy burden.

HVAC workforce respondents report that the typical residential AC refrigerant recovery process can take 30 minutes to more than 2 hours. Recovering and transporting the refrigerant to EPA-licensed reclaimers requires tanks and equipment technicians struggle to find. EPA laws prohibiting intentional emissions have existed for decades with virtually no enforcement. Interviewees who reported the prolonged lack of enforcement sent a clear message that it is ok to violate the rules. For many contractors, not following responsible recovery and disposal procedures is an embedded standard practice they follow to maintain profitability.

Over half of contractor survey respondents do not receive compensation when reclaiming refrigerant.

Surveys and interviews show only a small percentage of the workforce receives compensation for the refrigerant they recover and provide to reclaimers. Contractors who reported receiving payment only receive $3 per pound on average.

End-of-life refrigerant emission events from existing systems are enormous GHG liabilities and opportunities for GHG reduction and TSB attainment.

The RACC-FSC estimates the avoided cost resulting from end-of-life refrigerant emissions is over $300 per ton of residential AC cooling retired. This is a low-hanging/high-value fruit to reduce GHG emissions that will continue for decades until all current and future high-GWP equipment is replaced or retired.

Allow avoided emission credit to be claimed for documented end-of-life refrigerant recovery and reclamation.

California regulators should allow avoided end-of-life refrigerant emissions to be claimed when responsible end-of-life refrigerant recovery and reclamation is completed by a licensed EPA reclaimer. This act must be documented and performed when the retired system is replaced with a new high-efficiency system containing refrigerant. The Visual Service field application for smart phones and tablets is currently capable of documenting a refrigerant recovery process with excellent precision and authenticity. The Visual Service application or other means of documentation for this claim should include the following parameters to be deemed valid:

- Photographs of the existing equipment and the equipment nameplate with a geographic location tag
- Video of the existing equipment undergoing the recovery process
- Photo or video of the recovery cylinder on a scale after completion
- Photo or video showing the level of depressurization achieved at the end of the recovery process
- Bill of lading or comparable documentation proving recovered refrigerant was either reclaimed or destroyed by an EPA licensed reclaimer

Compensate contractors, technicians, and market actors who perform and document end-of-life refrigerant recovery/reclamation/disposal.

Web survey respondents reported they would willingly document end-of-life refrigerant recovery and reclamation on a standard size residential AC for $114. Performing this activity is worth over $700 in avoided emission TSBs.

Provide extra incentives to distributors who assist with refrigerant recovery and reclamation.

Distributors who participate in ratepayer funded high-efficiency equipment incentive programs often serve as transfer stations for recovered refrigerant between contractors and reclaimers. Web survey participants and interviewees report they currently receive little to no refrigerant recovery equipment support or monetary compensation from distributors they work with. Implementers of upstream programs should provide incentives to distributors who support refrigerant recovery and reclamation. This support could include offering contractors and technicians discounts or free access to high-quality refrigerant recovery equipment and cylinders capable of quick and well documented end-of-life refrigerant recovery. It could also include support in documenting refrigerant recovery and reclamation with new installations.

Compensate EPA licensed reclaimers who directly support contractors in performing end-of-life refrigerant recovery, reclamation, and equipment disposal.

Multiple EPA-licensed reclaimers report they will buy back any refrigerant cylinder, even mixed cylinders. These reclaimers play a critical role in reclaiming high-GWP refrigerant and offsetting the demand for new virgin high-GWP refrigerant. PAs and program implementers should provide additional compensation to reclaimers who support contractors and technicians in performing and documenting end-of-life refrigerant recovery, reclamation, and disposal.

Near-term avoided end-of-life emission credits could help transition workforce standard practice.

SMEs suggested that with the right documentation requirements, incentives to key market actors could serve as a bridge to where routine end-of-life recovery and reclamation is standard practice in the workforce. SMEs also noted there are current and future state and federal regulatory requirements trying to standardize the practice that must not be overlooked.

Closely monitor and eventually sunset documented avoided end-of-life emission claims.

Bad actors are found in every market and are known to exploit loopholes for financial gain. Any policy authorizing PAs or Implementers to incentivize reclamation must remain vigilant to appropriately validate all claims. Incentives should be sunset once CARB end-of-life emissions estimates show application-level recovery and reclamation rates exceed 50 percent.

DNV

2 INTRODUCTION

The California Public Utilities Commission (CPUC) contracted DNV to evaluate heating, ventilation, and air conditioning (HVAC) technologies under the Group A evaluation contract. In addition to conducting impact evaluations, the CPUC and program administrators (PAs) asked DNV to support forward-looking research on HVAC technologies via proposer-defined studies (PDS) as part of this contract. In 2021, DNV completed a forward-looking research study to accelerate the adoption of low-Global Warming Potential (GWP) refrigerants in HVAC equipment. This study builds on and expands the 2021 Low-GWP HVAC Study by helping the CPUC, PAs, and stakeholders navigate the transition to and quantify the impacts of low-GWP refrigerants in HVAC, commercial refrigeration, and heat pump water heating equipment.

2.1 Study purpose, objectives, and research questions

The purpose of this Forward-Looking Low-Global Warming Potential Refrigerant Transition Impacts Study was to assist the CPUC, PAs, and stakeholders' efforts to both accelerate the adoption of and quantify the impacts of low-GWP and natural refrigerant measures in HVAC, commercial refrigeration, and heat pump appliances. Its objectives were to:

1. Provide guidelines for developing baselines for deemed and custom measures, including refrigerant type by application, leakage rates, charge level, and suction and discharge pressure conditions.
2. Provide a Refrigerant Avoided Cost Calculator (RACC) technical guidance document for users claiming changes in Total System Benefits stemming from fuel substitution or low-GWP refrigerant related measures.
3. Provide recommendations to improve modeling tools to adequately capture the performance of various HVAC, commercial refrigeration, and water heating systems.
4. Summarize and recommend resources and forums available to market actors that provide the latest policy updates and required training for alternative refrigerants in terms of refrigerant handling, reclamation, safety, health, and installation.
5. Summarize the various recovery, reclamation, and disposal options available and explore ways to increase recovery rates and recovery documentation.

The study was designed to answer the following research questions:

1. What information or data is required to develop an adequate characterization of appropriate baselines for alternative low-GWP refrigerant measures?
2. Are existing performance modeling tools adequate? How could existing tools be improved to serve the various HVAC, commercial refrigeration, and water heating markets?
3. Does the existing refrigerant workforce know where to find the latest policies on alternative refrigerants, training requirements and available resources to safely deliver alternative low-GWP refrigerant technologies?
4. What's involved in effective refrigerant recovery, reclamation, and disposal, and what would it take to improve both the recovery rates and documentation of recovery?

2.2 Study background

Refrigerants allow heat to be drawn from one source and transferred to another. They are essential for HVAC systems, freezers in grocery stores, refrigerators, and countless other applications. Over the last century, refrigerants have evolved to address toxicity impacts and ozone depletion and are currently undergoing a transition to mitigate their impact on global warming. The most common refrigerant class used today is hydrofluorocarbons (HFCs). In the 1990s, HFCs emerged as the preferred refrigerant class because of their thermodynamic properties and their absence of ozone-depleting substances. When first introduced, HFCs' impact on global warming was not clearly recognized; however, it quickly became clear that the heat-trapping characteristics of HFCs pose a long-term problem. According to the California Air Resources Board (CARB), HFCs are the fastest growing source of greenhouse gas emissions in California and worldwide.[15] While global warming is increasing the global demand for air conditioning (AC), electrification efforts are rapidly increasing heat pump usage for both space and water heating. These trends are projected to continue well into the coming decades and beyond.

Central to this study is the global warming potential (GWP) of refrigerants. GWP is the most widely recognized method for measuring the warming impact refrigerants and other gases can have on the atmosphere. The GWP of a gas is measured by the heat-trapping impacts on the atmosphere one metric ton of the gas has relative to that of one metric ton of carbon dioxide (CO_2). Currently, the most referenced source for defining the GWP of a gas comes from the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) of 2021. In the report, GWP equivalent levels are defined two ways, as the 100-year and 20-year GWP. The 100-year GWP is the CO_2 equivalent energy absorbed by a gas over a 100-year timeframe, and the 20-year is the same over 20. For gases whose molecules break down faster, the 20-year GWP can be substantially higher than the 100-year, while the inverse is true for gases with molecules that take thousands of years to break down. As a point of reference, the most common refrigerant installed in HVAC equipment today is R-410A, with a 100-year GWP of 2,088 and a 20-year GWP of 4,340.

Global, national, and state laws and regulations involving refrigerant use are driving a transition toward alternative refrigerants with low to zero GWPs. The California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32, specifies California must be carbon neutral and achieve zero net greenhouse gas (GHG) emissions by 2045. Per California Senate Bill (SB) 1383, this mandate on short-lived climate pollutants (SLCP) requires a 40% reduction in emissions of synthetic gas hydrofluorocarbon (HFC) to achieve the GHG reduction goal set forth by AB 32. Furthermore, under SB 1013 the "California Cooling Act," the CPUC and other state regulatory agencies are called upon to assess the operational performance of refrigerants with low GWP and to develop a strategy to encourage the adoption of those low-GWP refrigerants in equipment funded by energy efficiency (EE) programs overseen by the CPUC. To that effect, in 2021 DNV completed a study with the CPUC for providing a roadmap for accelerating the adoption of low-GWP HVAC refrigerants. The 2021 study focused on HVAC systems and did not cover refrigeration or heat pump water heating equipment. The scope of this study was expanded to include HVAC, stationary refrigeration, and heat pump water heating equipment.

The CPUC oversees the Avoided Cost Calculator (ACC), which is a platform of tools and supporting documentation that includes the Refrigerant Avoided Cost Calculator (RACC) In 2024, the TSB metric replaced annual electricity, electric demand, and gas (kWh, kW, and therm) savings as the metric for setting goals and measuring the accomplishments of the California energy efficiency portfolio. TSB represents the lifecycle energy, capacity, and GHG benefits of an energy efficiency program, project, or measure.

TSB is defined as follows:[16]

TSB is an expression, in dollars, of the lifecycle energy, ancillary services, generation capacity, transmission and distribution capacity, and GHG benefits of energy efficiency activities, on an annual basis.[17] The 2021 Energy Efficiency Potential and Goals study states that TSB represents the total benefits, or "avoided costs," that a measure provides to the electric and natural gas systems.[18] The factors included in avoided costs are defined through the CPUC Integrated Distributed Energy Resources (IDER) proceeding.[19]

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15 https://ww2.arb.ca.gov/our-work/programs/slcp/about - HFCs

16 Total System Benefit Technical Guidance, Version 1.1, 08-16-2021

17 Assessment of Energy Efficiency Potential and Goals and Modification of Portfolio Approval and Oversight Process (2021) Decision (D.) 21-05-031, p. 9.

18 2021 Potential and Goals Study, p. 3

19 Integrated Distributed Energy Resources Proceeding, Rulemaking (R.) 14-10-003. This Rulemaking has since been superseded by R.22-11-013, Order Instituting Rulemaking to Consider Distributed Energy Resource Program Cost-Effectiveness Issues, Data Access and Use, and Equipment Performance Standards

The environmental impact of gases associated with the use of fossil fuel and changes in the amount or type of refrigerant resulting from projects funded by the energy efficiency portfolio are included in the TSB. The RACC is the tool used to quantify the contribution of refrigerants to the TSB. The FSC is required for projects where all or a portion of the existing energy use is converted from one CPUC-regulated fuel to another CPUC-regulated fuel[20]. The RACC yields a dollar value for either the costs associated with introducing refrigerant where there was none before (such as when a gas water heater is replaced with a heat pump water heater) and in cases where a project reduces the global warming potential of the refrigerants in-use by selecting a low-GWP refrigerant relative to standard practices in the market. While the RACC can be a transformative tool used to accelerate the adoption of low-GWP refrigerants, proper guidance is needed to ensure users are characterizing baselines and installing measures appropriately. This study provides comprehensive guidance to users of the RACC and explores strategies for minimizing ongoing refrigerant emissions.

[20] Fuel Substitution in Energy Efficiency, CPUC, https://www.cpuc.ca.gov/about-cpuc/divisions/energy-division/building-decarbonization/fuel-substitution-in-energy-efficiency

3 METHODOLOGY

This section details the approach DNV used for collecting the data, data processing, conducting the research, and analyzing the results of the research. Primarily, our research was comprised of six tasks:

- **Baseline characterization:** This task included a full review of all application types included in the latest version of the CPUC's RACC. The DNV team pooled internal and external SMEs from the DEER/Ex-Ante and Custom Program teams as part of this exercise. The task assessed and documented key baseline parameters for existing and emerging EE measures that involve alternative low-GWP refrigerants.
- **Modeling tools review:** This task identified performance modeling tools capable of simulating both alternative low-GWP and natural refrigerant measures and their relevant baselines. The focus of this task was to assess the modeling tools' ability to produce hourly load shapes for applications that utilize refrigerants with 100-year GWP levels below 750 both in full and part load conditions.
- **RACC technical guidance for retail refrigeration:** This task involved the development of a RACC technical guidance document to provide users guidance on how they can use the RACC to claim the costs or benefits associated with avoided refrigerant emissions for various projects. This document was initially developed for retail refrigeration applications since there was an immediate need for this guidance. However, this technical guidance document is not a static document, and will require periodic updates to incorporate new information.
- **Comprehensive RACC technical guidance document:** This task expanded the fast-tracked retail refrigeration technical guidance document to include additional applications. The comprehensive technical guidance document provided users guidance on how they can use the RACC to claim the cost and benefits associated with refrigerant emissions. This document leveraged information gathered during the baseline review and modeling tools review tasks. The team also incorporated technical guidance on how the RACC could be used to support refrigerator/freezer end-of-life recovery and reclamation best practices, and the impacts of heat pump refrigerant charge levels relative to equivalent cooling capacity air conditioners. The comprehensive guidance document is a living document and will require periodic updates with the most current information, regulations and data.
- **Workforce knowledge:** This task involved gathering information in workforce interviews and surveys to identify gaps and provide recommendations on how to bridge those gaps, specifically for the HVAC workforce.
- **Improved recovery:** This task summarized various recovery, reclamation, and disposal options available and explored ways to increase recovery rates and documentation.

3.1 Data sources and tools

The research team drew from an assortment of data sources that included:

Secondary research: The research team conducted an expansive research effort both prior to and while conducting interviews and analysis. The sources included California and national publications covering the low-GWP refrigerant transition, EPA regulations and webinars, CARB regulations and webinars, industry journal articles, manufacturer publications, North American Sustainable Refrigeration Council (NASRC) publications and webinars, and research findings for other refrigerant related studies funded by the California PAs.

RACC: The research team conducted a thorough review of the 2022 Avoided Cost Calculator Refrigerant Calculator (v1b updated) and prior versions of both the RACC and the other ACC tools. The team reviewed the technical guidance document for the ACC as well as the changes and reasoning for changes to the RACC since it was first released.

Stakeholder interviews: Program administrator representatives and supporting consultants were interviewed by the research team to better understand their experiences with the RACC to date and to identify any pain points encountered using the tool.

In-depth interviews (IDIs) with refrigerant policy SMEs: The research team conducted multiple interviews with representatives from CARB, as well as individual interviews with representatives from the EPA, Environmental Investigation Agency (EIA), the Carbon Containment Lab (formerly the Yale CCL), the Institute for Governance and Sustainable Development (IGSD), and the North American Sustainable Refrigeration Council (NASRC). Refrigerant policy and low-GWP transition timelines were the primary focus of these conversations. Policy SMEs also shared insights about emerging natural refrigerant applications globally, barriers preventing U.S. adoption, and strategies for improving refrigerant recovery and reclamation.

IDIs with HVAC-R SMEs: The research team interviewed six different California HVAC-R contractors about the ongoing transition to low-GWP refrigerants, training, and refrigerant recovery and reclamation. Each interviewee was asked about the following:

- General knowledge of current and future low-GWP refrigerants available in the market
- Training and guidance resources they use to stay informed about code changes
- End-of-life refrigerant recovery and reclamation

Existing tools review: The research team performed secondary research to assess the features and capabilities existing modelling tools have with regards to refrigerant impacts on energy efficiency, capacity, and load shapes. Researchers worked with DNV's ex-ante team to identify which measure types are in most need of simulation tools and prioritized the review for these measures.

Focus group: In March 2024, DNV led a 90-minute virtual focus group to explore strategies that may help reduce refrigerant emissions and improve end-of-life refrigerant recovery and reclamation. Participants of the focus group included SMEs who completed in-depth interviews and other key market actors who expressed interest in participating. The 23 attendees included four CA licensed HVAC-R contractors, representatives from the EPA, CARB, the Carbon Containment Lab, the Environmental Investigation Agency (EIA Global), two EPA licensed refrigerant reclaimers, two major HVAC distributors, and CPUC study leads. A detailed summary of the focus group discussion is included in Appendix C: Focus group discussion.

HVAC-R web survey: DNV conducted a brief web survey with 44 known HVAC-R contractors and technicians in April of 2024. The survey questions were derived using the findings from the HVAC-R in-depth interviews and the focus group. A full summary of the HVAC-R web survey can be found in Appendix B: Web survey.

3.1.1 Enhanced RACC

DNV reviewed and provided technical guidance to users of the 2022 Avoided Cost Calculator Refrigerant Calculator (RACC).[21] In conducting this task, we reviewed the equations and data provided in the workbook, we identified errors in the workbook, and then looked for improvement opportunities. We proposed a series of improvements to the RACC to streamline and ensure compliance with existing policy. The proposed changes address baseline GWP requirements, correct errors, and allow the document to be updated in a more fluid fashion. The proposed improvements for the "Enhanced RACC" are summarized in Appendix A: Updates to RACC and FSC.

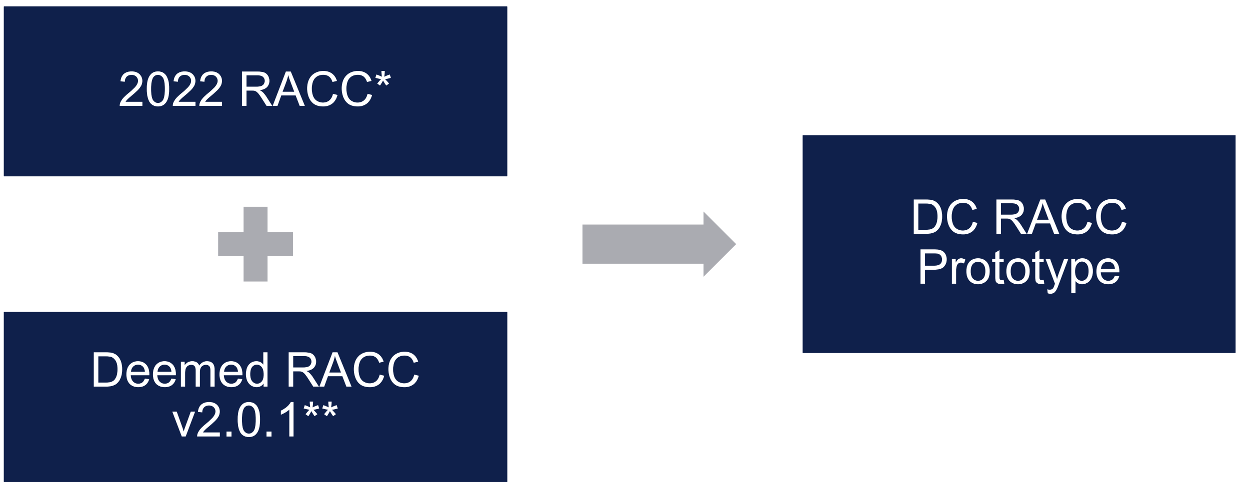
3.1.2 Combining of the Deemed and Enhanced RACC

While developing the enhanced version of the RACC, we were also asked to review an updated version of the Deemed RACC tool (DRACC) developed by Southern California Edison and Solaris Technical. In our review of the DRACC, we found several minor issues that warranted addressing, but overall, the DRACC included many features that streamlined the original RACC tool. However, the DRACC did not include DNV's latest proposed enhancements to the RACC. DNV developed a combined

[21] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/2022-acc-refrigerant-calculator-v1b-updated.xlsx

version of the RACC tool or Deemed/Custom RACC (DC RACC), merging DNV's recommended RACC enhancements with the DRACC (v2.0.1) from SCE and Solaris Technical, as shown in Figure 3-1.

Figure 3-1. Combine existing tools into a single workbook



*Enhanced version of the "2022 ACC Refrigerant Calculator v1b updated.xlsx"
**Deemed Measure RACC Workbook v2.0.1 xlsx

This task involved merging the enhanced changes DNV proposed to the "2022 ACC Refrigerant Calculator v1b updated" version of the RACC into the latest proposed Deemed RACC v2.0.1. These changes include integrating CARB regulations to establish evolving baselines, restricting the dropdown options to include only refrigerants that are legal to use in California based on project dates specified, and other improvements proposed in the "Enhanced RACC" (see Table 6-1 in Appendix A: Updates to RACC and FSC.

DNV's reviewed the Deemed RACC v2.0 and identified eleven recommendations that correct errors and improve the calculator's accuracy. Table 6-2 in Appendix A: Updates to RACC and FSC provides a list of recommended changes and revisions to the Deemed RACC v2.0.1 and the priority of the change.

Testing of the "DC RACC Prototype"

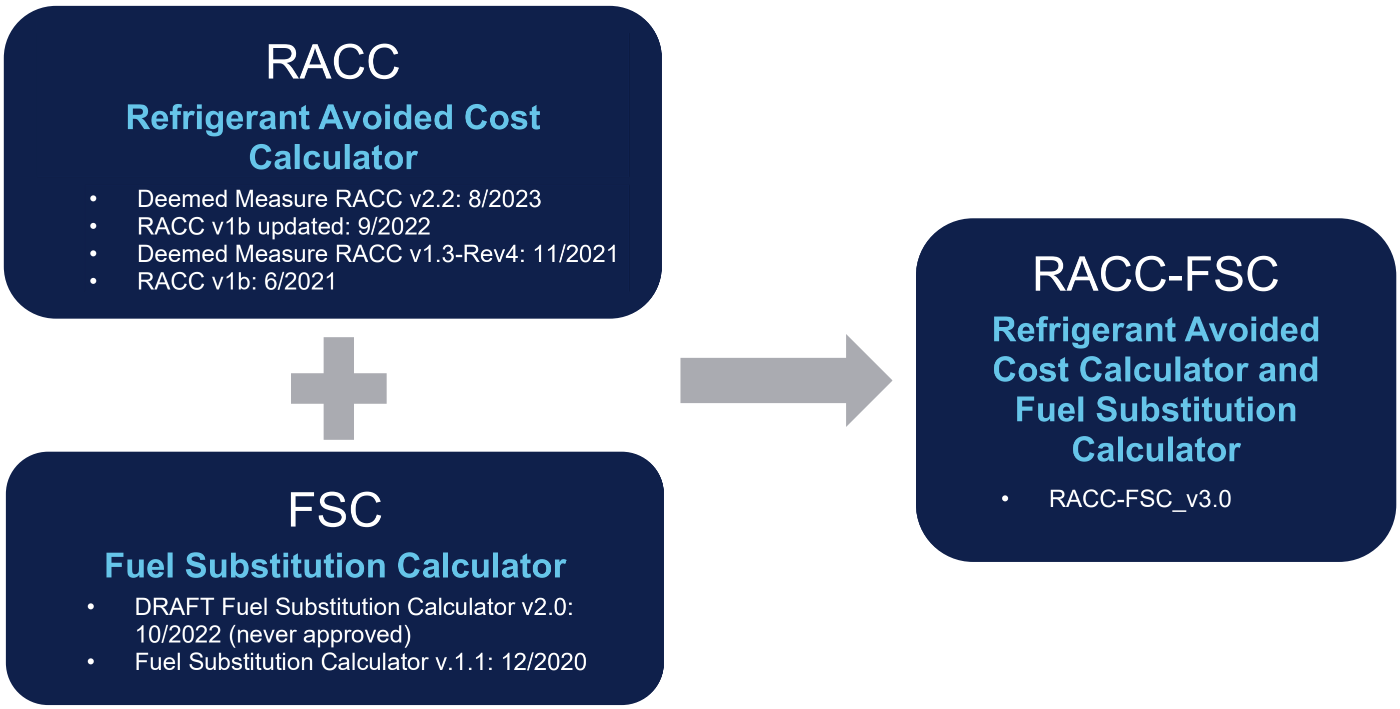
Once all changes were completed for this combined version of the RACC, DNV ran tests and example projects through the updated "DC RACC Prototype" tool with the goal to:

1. Ensure that the DC RACC Prototype is capable of handling both deemed and custom program use.
2. Adequately test the updated tool with example measures to make sure the results are in alignment with the previously approved tools. If there were changes made to fix errors in the tool, we will review and compare the outputs to ensure the updates produce reasonable results for all measure application types and device types.

3.1.3 Combining the DC RACC with the Fuel Substitution Calculator

During the work to develop the DC RACC Prototype, we discovered that many of the same inputs and assumptions are required for both the RACC and Fuel Substitution Calculator (FSC). To ensure that both use the same refrigerant baseline GWP assumptions the RACC and FSC, DNV proposed the merging of these two tools. DNV's recommended plan to combine the RACC and FSC is depicted in Figure 3-2.

Figure 3-2. Combine existing tools into a single workbook



The functionality of the FSC was integrated into the DC RACC Prototype. This integration reproduced the input fields and calculations performed in the Fuel Substitution Calculator v2.0.xlsx to assess whether each permutation of a given measure package or custom application passes all parts of the fuel substitution test and provides a summary of the results. The enhancements made to the DC RACC Prototype include the changes listed in Table 6-3 Appendix A: Updates to RACC and FSC.

3.1.3.1 Webinar and stakeholder feedback

To help stakeholders assess the updated tools, understand the underlying assumptions, and demonstrate highlights of the workbook updates and the technical guidance document, DNV held a webinar with stakeholders on March 6, 2024. The presentation slide deck was delivered to the CPUC for internal stakeholder review two weeks before the prestation. A draft version of the RACC-FSC and the companion technical guidance document was uploaded to Energy Division's Public Document Area (PDA) one week before the presentation, with the stakeholder comment period lasting two weeks.

3.1.3.2 Final RACC-FSC_v3.0 approval and posting

Following the webinar and stakeholder review and assessments, DNV addressed feedback and made updates to the final version. The updates included the following:

- **Improving workbook performance:** Improved workbook calculation performance time by reducing the quantity of named ranges with imbedded calculations, converted the RACC Excel table to normal range, added toggle for conditional formatting, and reduced number of rows in the RACC worksheet.
- **Creating additional DEER database table links to reference tables:** Added key parameters to the DEER database to allow for easy update of several key parameters used in the RACC and FSC calculations.
- **Eliminating EOL emissions pro-rating:** Eliminated the pro-rating of EOL emissions for existing and standard practice equipment, except in cases where the standard practice equipment needs to be installed multiple times to last until the end of the measure life. In such cases, the second EOL leakage event is pro-rated based on the extent to which the equipment coincides with the measure life.

- **Extending functionality for longer EULs:** Extended functionality to accommodate measure lives that exceed 20 years.

A summary of the updates can be found in Table 6-4 Appendix A: Updates to RACC and FSC.

4 RESULTS

In this section we present the study findings and results of our research. In the five detailed sub-sections we present the findings of our secondary research, review of the RACC, the feedback received during in-depth interviews (IDIs) and focus group discussions, and the results of the web survey.

4.1 Baseline characterization

This section presents an overview of the baseline conditions for energy efficiency projects containing refrigerants. The baseline parameters are defined by policies regulating refrigerant usage and emissions in California and the US. Key legislation or policy guidelines from CARB and the EPA were sourced to produce the accepted/prohibited refrigerant and GWP baseline definitions. Baseline definitions for measure application types, equipment measure life, and required documentation were sourced from the CA Custom Project Guidance Document, the CA Deemed Measure Package Rulebook, and through discussions with CPUC staff. Additionally, the document delineates the appropriate baselines for the following scenarios:

- Measure application type
- Measure life
- Refrigerant leakage rates
- Refrigerant charge levels
- Applicable state and federal regulations on approved and prohibited refrigerant types and GWP limits by application
- Required documentation

During the IDIs, stakeholders and measure package developers requested further clarification on modeling retail refrigeration and fuel-substitution measures. They expressed concerns that the custom project pathway is time-consuming and has numerous barriers, making it challenging to regularly pursue with retail refrigeration measures. As a result, they prefer deemed measures.

An overview of current and future refrigerant GWP limits by end-use or project type is presented in Table 4-1 End-use categories sometimes contain multiple GWP policy limits for a single year. For these instances, the values presented in each cell represent the most restrictive GWP limit or maximum approved refrigerant GWP value found on the CARB[22] or EPA[23] websites. For some end-use categories, no GWP restrictions exist for a given year at either the state or federal level. For these instances, the research team sourced the typical refrigerant type and GWP values from the certified Energy Star product finder website.[24]

[22] California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10 Climate Change, Article 4. Final Regulation Order. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hfc2020/frorevised.pdf

[23] Environmental Protection Agency. *Significant New Alternatives Policy (SNAP) Program*. https://www.epa.gov/snap/

[24] Energy Star Product Finder. https://www.energystar.gov/productfinder/

Table 4-1. Current and future refrigerant GWP limits by end use

Sector	End-Use	2024	2025	2026	2027	2030
Stationary Refrigeration	Existing Retail Refrigeration (<50 lb. refrigerant)	No regulation (Typical GWP: R-404A: 3,922)	→	EPA: GWP ≤300 (remote units only)	EPA: GWP ≤300	→
	Existing Retail Refrigeration (> 50 lbs., ≥ 20 stores)	No regulation (Typical GWP: R-404A: 3,922)	→	→	CARB GWP: <2,500 (avg. across all stores)	CARB GWP: <1,400 (avg. across all stores)
	New Retail Refrigeration (>50 lb.)	CARB GWP: <150	→	→	→	→
	New Stand-alone Refrigeration Units	No regulation (ENERGY STAR® GWP: 2)	EPA GWP: ≤ 150 (ENERGY STAR® GWP: 2)	→	→	→
Stationary Air-conditioning	HVAC Systems and Chillers	No regulation (Typical GWP: R-410A: 2,088)	EPA: GWP ≤700	→	→	→
	HVAC Products	CARB: GWP <750	EPA: GWP ≤700	→	→	→
	HVAC: Variable Refrigerant Flow	No regulation (Typical GWP: R-410A: 2,088)	→	EPA: GWP ≤700	→	→
Heat Pump Appliances	Heat Pump Water Heaters	No regulation (Typical GWP: HFC-134a: 1,430, R-410A: 2,088)	→	→	→	→
	Heat Pump Clothes Dryers	No regulation (Typical GWP: HFC-134a: 1,430)	→	→	→	→

Research and in-depth interview findings all pointed to natural refrigerants as the most environmentally friendly refrigerant solution the collective industries and regulating authorities should be working towards. The most common natural refrigerants include ammonia (R-717), propane (R-290), isobutane (R-600a), and carbon dioxide (R-744). These refrigerants all have GWP levels below 4, zero ozone depletion potential, meaning they do not contribute to the depletion of the ozone layer, and do not contain per and polyfluoroalkyl (PFAS) chemicals, which are persistent in the environment and can have negative health impacts to all living organisms. Natural refrigerants are often cheaper to produce and, under the right design conditions, have similar if not improved performance compared to traditional refrigerants.

Table 4-2. Natural refrigerant barriers to adoptions

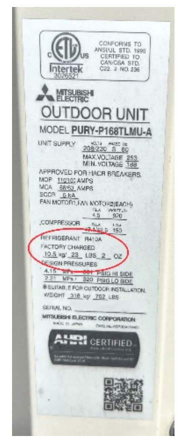
Natural Refrigerants	Barriers
Propane (R-290), isobutane (R-600a)	**Safety:** High flammability. Current 300-500 gram charge size restrictions in the U.S. limit effective hydrocarbon use to residential and smaller self-contained commercial refrigeration equipment.
Ammonia (R-717)	**Safety:** Toxic, mildly flammable. Limited use outside of industrial refrigeration.
Carbon dioxide (R-744)	**Design:** Higher system pressures due to gas properties increase system component costs, and design requirements compared to synthetic higher-GWP HFC alternatives.

Table 4-2 shows the primary barriers preventing the adoption of natural refrigerants is safety and design. R-290 propane and R-600a isobutane are classified as A3 (non-toxic, highly flammable). While R-717 ammonia is classified as a B2L (toxic, mildly-flammable) refrigerant. R-744 carbon dioxide is classified as an A1 (non-toxic, non-flammable) refrigerant like all HFCs; however, R-744 carbon dioxide does not behave like a traditional refrigerant. R-744 has much greater heat transfer efficiency, which can lead to smaller heat exchangers with lower temperature differentials compared to an HFC system. The downside to R-744 is that the pressures of the refrigerant are much larger than HFC systems leading to increased system component cost. Currently, natural refrigerants are found in many applications including retail refrigeration, industrial refrigeration, residential refrigerators, small heat pump and air-conditioning systems (internationally), and commercial ice machines.

In 2022, the International Electrotechnical Committee (IEC) approved standards for increased acceptable charge limits for hydrocarbons in various HVAC systems. As a result, R-290 systems are quickly gaining traction in parts of Europe and Asia. IEC standards have not yet been approved in the U.S. but there is a proposal under way to adopt the rule. If that proposal proceeds in a timely fashion, the U.S. could start to see these units and other smaller units become available in 2028.

4.1.1 Measure application types

Normal replacement measures require a standard practice baseline condition, which could either be equipment that meets code and regulation requirements or industry standard practice (ISP) equipment, whichever has greater energy efficiency. For refrigerant emissions the normal replacement baseline would be either code/regulation or ISP, whichever has a lower GWP. The normal replacement baseline is sometimes referred to as a “standard baseline.”



Measures may only be categorized as accelerated replacement (AR) if the existing equipment being replaced could and would remain in operation without program intervention. The baseline for the AR measure would be the existing system for the RUL period, and then a standard baseline (code/regulation, or ISP) for the remainder of the measure life. The default RUL is defined as one-third of the existing equipment’s EUL. However, the default RUL period may be replaced with a custom value in cases where credible evidence is provided to support an alternative RUL value that CPUC staff can reasonably deem more credible than of the adopted default value.[25]

4.1.2 EUL/RUL considerations

Generally, the EUL for RACC claims shall be based on default DEER database EULs where possible. These represent the median lifetimes. When the CARB average EUL does not align with DEER, a user-specified EUL in the RACC should be used to align with DEER.

However, when pursuing a custom project or site-level Normalized Metered Energy Consumption pathway, alternative EULs are allowed but are subject to PA review and require documentation supporting the claim. Alternative EUL and RUL should only be used if suitable EUL IDs in the DEER database do not exist. Sources must be provided for manual entries of EUL and RUL, and independently evaluated and assessed before using for claims. Sources may include project documentation, ASHRAE tables, workpapers, industry publications, etc. Alternative EULs can be used up to 20 years. Anything beyond 20 years is difficult to get approved, due to an existing CPUC rule that sets a max EUL of 20 years.

4.1.3 Leakage rate

Normally, users of the RACC will not deviate from the CARB average annual leakage rates, and EOL leakage values. Locally defined, system/site-specific leakage rates may be used only if the rate is less than the CARB average.

4.1.4 Refrigerant charge

For custom projects, site-specific charge level in pounds will be used in place of the CARB averages included in the RACC. If the measure is a normal replacement measure application type, the charge level will be determined by the manufacturer

[25] Decision 12-05-015, p.348. https://www.calmac.org/events/Decision_12-05-15.pdf

specification for the new equipment. With accelerated replacement measure application types with an existing system initial baseline condition, the site-specific refrigerant charge needs to be supported by adequate documentation.

4.1.4.1 Documentation requirements for charge level

If a retail food refrigeration facility is already registered in the CARB Refrigerant Management Program (RMP), then the normal operating charge should be defined and reported to CARB. This documentation can be used to support the charge levels of existing equipment for claims using the RACC.

If a retail food refrigeration facility is not already registered in the CARB RMP then the normal operating charge can be determined using one of the following methods:[26]

- Name plate
- Charge calculator program
- Midpoint of range
- Sum of refrigerant charged into system
- Calculated from design documents
- Equipment manual
- Recover full charge and weight back in system

To support the claimed charge from these methods, we recommend the following as example documentation:

- Photo of nameplate
- PDF or scan of equipment manual
- Screenshot of the design documents calculation

4.1.5 Refrigerant policy

California has consistently been at the forefront of the battle against climate change, establishing and adopting a series of policies specifically designed to regulate refrigerant emissions and expedite the phase-down of HFCs, a major contributor to global warming. California Senate Bill 1383 (SB1383), signed into law in 2016, targets the reduction of short-lived climate pollutants (SLCPs), which are pollutants that, despite their relatively short lifespan in the atmosphere, are much more potent than carbon dioxide in their capacity to trap heat. HFCs are one of the three main SLCPs identified in SB1383. The bill requires a 40% reduction of HFC emissions below 2013 levels by 2030.

In 2018, California passed the California Cooling Act (SB1013) and a new CARB HFC regulation to backstop the EPA Significant New Alternatives Policy (SNAP) prohibitions. Under SB1013, California adopted the U.S. Environmental Protection Agency's federal HFC regulations into state law. Following the direction set by SB1383, SB1013 established an HFC regulation by instituting multiple sector-specific measures to reduce HFC emissions. These measures apply to sectors like refrigeration and air conditioning and aim to transition these sectors to using substances with lower global warming potential.

In 2020, CARB updated its 2018 HFC regulation to enforce limits on the GWP of refrigerants used in new air conditioning and refrigeration equipment. This update encourages industries to not just move away from refrigerants with the highest GWP, but to rapidly adopt those with the lowest GWP that are still commercially viable and technologically feasible. In addition, the update mandates companies in the retail food sector that own existing systems containing more than 50 lb. of refrigerant to cut their overall HFC emissions. This can be achieved either by reducing the company-wide weighted-average GWP or, alternatively, by lowering their total potential to emit GHGs.

[26] California Environmental Protection Agency, CARB R3 Registration Checklist, https://ww2.arb.ca.gov/sites/default/files/2020-11/r3-registration-checklist_0.pdf

Therefore, refrigeration systems in California need to follow both the EPA and CARB rules on phasing down HFCs and adopting refrigerants with low-GWP values. Those policies affect how users should choose appropriate baselines to claim avoided emissions and costs using RACC.

Table/index of refrigerant emission regulations

The CARB HFC regulation has a sector-level regulation for facilities with more than 50 lb. of refrigerant as shown in Table 4-1. As shown in Table 4-3, new facilities in both retail food sector and cold storage are not allowed to use refrigerants with a GWP of 150 or greater since January 1, 2022. Existing retail food facilities with existing refrigeration systems will be required to achieve companywide HFC reductions.

Table 4-3. CARB HFC regulation for facilities with more than 50 lb. of refrigerant

Facility type	End-use	Company size	Compliance requirement	Effective date
New	Retail food refrigeration, cold storage	N/A	Refrigerants with a GWP of 150 or greater are prohibited	January 1, 2022
Existing	Retail food refrigeration	Companies owning or operating 20 or more retail food facilities in California, and national supermarket chains operating in California	Attain a company-wide weighted-average GWP of less than 2,500 or a 25% or greater reduction in GHGp below 2019 levels by December 31, 2026	December 31, 2026
			Attain a company-wide weighted-average GWP of less than 1,400 or a 55% or greater reduction in GHGp below 2019 levels	January 1, 2030
		Companies owning or operating fewer than 20 retail food facilities in California	Attain a company-wide weighted-average GWP of less than 1,400 or a 55% or greater reduction in GHGp below 2019 levels	January 1, 2030

In addition to the above-mentioned sector-level requirements, CARB HFC regulation also lists sector-specific prohibited refrigerants for retail food refrigeration, vending machines, and cold storage as shown in Table 4-4. These requirements apply to all refrigeration systems regardless of charge size.

Table 4-4. CARB HFC regulation for sector-specific prohibited refrigerants regardless of charge size[27]

Specific end-use	Prohibited substances	Effective date
Supermarket systems (new)	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Prohibited as of January 1, 2019
Supermarket systems (refrigerant retrofit)	R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Prohibited as of January 1, 2019
Remote condensing units (new)	HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Prohibited as of January 1, 2019
Remote condensing units (refrigerant retrofit)	R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A	Prohibited as of January 1, 2019
Stand-alone medium-temperature units with a compressor capacity below 2,200 Btu/hr and not containing a flooded evaporator (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	Prohibited as of January 1, 2019

[27] https://ww2.arb.ca.gov/our-work/programs/california-significant-new-alternatives-policy-snap/retail-food-refrigeration

Specific end-use	Prohibited substances	Effective date
Stand-alone medium-temperature units with a compressor capacity below 2,200 Btu/hr and containing a flooded evaporator (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	Prohibited as of January 1, 2020
Stand-alone medium-temperature units with a compressor capacity equal to or greater than 2,200 Btu/hr (new)	FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03	Prohibited as of January 1, 2020
Stand-alone low-temperature units (new)	HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)	Prohibited as of January 1, 2020
Stand-alone units (refrigerant retrofit)	R-404A, R-507A	Prohibited as of January 1, 2019
Refrigerated food processing and dispensing equipment (new)	HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)	Prohibited as of January 1, 2021
Vending machines (new)	FOR12A, FOR12B, HFC-134a, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C,	Prohibited as of January 1, 2019
Vending machines (refrigerant retrofit)	R-404A, R-507A	Prohibited as of January 1, 2019
Cold storage warehouses (new system)	HFC-227ea, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-423A, R-424A, R-428A, R-434A, R-438A, R-507A, and RS-44 (2003 composition)	Unacceptable as of January 1, 2023.
Cold Storage Warehouses (new), Refrigeration equipment (new), containing more than 50 lb. refrigerant	Refrigerants with a GWP of 150 or greater	Prohibited as of January 1, 2022

The EPA Phasedown of HFCs final ruling 40 CFR Part 84, Subpart B – 10-05-2023, also listed sector specific proposed GWP limits or prohibited substances for new systems. Table 4-5 shows the proposed HFC restrictions for stationary refrigeration.

Table 4-5. EPA proposed HFC restrictions for stationary refrigeration[28]

Sectors and subsectors	Proposed GWP limit or prohibited substance	Installation compliance date
Residential and light commercial air conditioning and heat pump systems	700	January 1, 2025
Variable refrigerant flow systems	700	January 1, 2026
Chillers, industrial process refrigeration with exiting fluid below -50°C (-58°F)	Not covered	Not covered

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

Sectors and subsectors	Proposed GWP limit or prohibited substance	Installation compliance date
Chillers, industrial process refrigeration with exiting fluid between -50°C (-58°F) and -30°C (-22°F)	700	January 1, 2028
Chillers, industrial process refrigeration with exiting fluid above -30°C (-22°F)	700	January 1, 2026
Chillers, comfort cooling	700	January 1, 2025
Ice rinks	700	January 1, 2025
Data centers, computer room air conditioning, and information technology equipment cooling	700	January 1, 2027
Industrial process refrigeration systems with refrigerant charge capacities of 200 lb. or greater, and refrigerant temperature entering evaporator above -30°C (-22°F), excluding high temperature cascade system	150	January 1, 2026
Industrial process refrigeration systems with refrigerant charge capacities less than 200 lb., and refrigerant temperature entering evaporator above -30°C (-22°F)	300	January 1, 2026
Industrial process refrigeration, high temperature side of cascade systems, and refrigerant temperature entering evaporator above -30°C (-22°F)	300	January 1, 2026
Industrial process refrigeration, and refrigerant temperature entering evaporator from -50°C (-58°F) to -30°C (-22°F)	700	January 1, 2028
Industrial process refrigeration, and refrigerant temperature entering evaporator below -50°C (-58°F)	Not covered	Not covered
Cold storage warehouse systems with refrigerant charge capacities of 200 lb. or greater, excluding high temperature side of cascade system	150	January 1, 2026
Cold storage warehouse systems with refrigerant charge capacities less than 200 lb.	300	January 1, 2026
Cold storage warehouse – high temperature side of cascade system	300	January 1, 2026
Retail food refrigeration – supermarket systems with refrigerant charge capacities of 200 lb. or greater, excluding high temperature side of cascade system	150	January 1, 2027
Retail food refrigeration – supermarket systems with refrigerant charge capacities less than 200 lb.	300	January 1, 2027
Retail food refrigeration – supermarket systems, high temperature side of cascade system	300	January 1, 2027
Retail food refrigeration – remote condensing units with refrigerant charge capacities or 200 lb. or greater, excluding high temperature side of cascade system	150	January 1, 2026
Retail food refrigeration – remote condensing units with refrigerant charge capacities less than 200 lb.	300	January 1, 2026

Sectors and subsectors	Proposed GWP limit or prohibited substance	Installation compliance date
Retail food refrigeration – remote condensing units, high temperature side of cascade system	300	January 1, 2026
Retail food – remote refrigerated food processing and dispensing equipment	R-402A, R-402B, R-404A, R-407B, R-408A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-438A, R-507A, R-125/290/134a/600a (55/1/42.5/1.5), RS-44 (2003 formulation), GHG-X5	January 1, 2027
Remote automatic commercial ice machines	R-402A, R-402B, R-404A, R-407B, R-408A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-438A, R-507A, R-125/290/134a/600a (55/1/42.5/1.5), RS-44 (2003 formulation), GHG-X5	January 1, 2027

As shown in Table 4-5, there is overlap between the EPA rule and the CARB rule, and the categorization of the sector is not the same. Given the wealth of details within these policies and the potential for misunderstandings and confusion, we present a selection of examples to assist in making sense of and navigating these regulations. For example, to navigate through the applicable requirement for a supermarket refrigeration system, users can follow the steps provided in Table 4-6. Supermarket refrigeration system falls under the retail food sector where the CARB HFC regulation has both sector level GWP requirements and sector-specific prohibited refrigerants. At the same time, the EPA also has listed GWP limits for new systems based on charge size.

The first step is to determine the facility type. If the facility type is new, and the charge size is more than 50 lb., it needs to follow the CARB GWP limit of 150. If the charge size is 50 lb. or less, it needs to meet the prohibited refrigerants requirement from CARB and the GWP limit of 300 from EPA rule. If it is an existing facility and the measure is refrigerant swap, for charge size 50 lb. or less, it only needs to follow the prohibited refrigerants list from CARB. If the charge size is more than 50 lb., it needs to follow the company wide GWP limit rule as well. Similarly, if the existing facility is installing new refrigeration equipment or system, depending on the charge size, it falls under different requirements from CARB and EPA.

Table 4-6. Example supermarket refrigeration system policy walkthrough

Facility type	Charge size	System	GWP limit or prohibited refrigerants
New	>50 lb.	New	GWP limit of 150 since 1/1/2022
	50 lb. or less	New	Prohibited refrigerants since 1/1/2019 GWP limit of 300 since 1/1/2025
Existing	50 lb. or less	Swap	Prohibited refrigerants since 1/1/2019
	>50 lb.	Swap	Companywide GWP limit Prohibited refrigerants since 1/1/2019
	200 lb. or greater	New	GWP limit of 150 since 1/1/2025
	>50 and <200 lb.	New	Companywide GWP limit Prohibited refrigerants since 1/1/2019
	50 lb. or less	New	Prohibited refrigerants since 1/1/2019 GWP limit of 300 since 1/1/2025

4.1.6 Alternative refrigerants

This section presents a summary of the likely low-GWP refrigerant candidates the greater HVAC-R and heat pump appliance industry will transition to in the coming decade.

4.1.6.1 Transition timeline to Low-GWP refrigerants

The transition timeline to low-GWP refrigerants in the U.S. is dependent on equipment end-use, current market standard practices, adoption of HFC phase-down regulations, and building fire code regulation updates. The Kigali Amendment to the Montreal Protocol and the 2021 American Innovation and Manufacturing Act will both serve pivotal roles in mitigating the global warming impact HFC refrigerants have. Both the Kigali Amendment and the American Innovation and Manufacturing (AIM) Act call for a gradual phase-down in HFC use. For the U.S. and other non-Article 5 countries, as defined by the Montreal Protocol, the phase down calls for an 85% reduction in HFC use by 2036. The EPA has begun enacting regulations to ensure the various industries that use HFCs will adhere to the 85% HFC reduction. In December 2023, the EPA issued a final ruling on the use of HFCs in the Residential and Light Commercial Air Conditioning and Heat Pump Sector that calls for a 700-GWP ceiling to be applied to new residential and light-commercial HVAC systems beginning in 2025 (EPA 2023a).

The Kigali Amendment and AIM Act will all make huge strides toward limiting new high-GWP refrigerants, but it will likely take decades before emissions really come down if more is not done. Most new HVAC equipment installed before 2025 will continue to emit high-GWP refrigerants for the lifetime of the equipment. The EPA issued a final rule in December 2023 that establishes a GWP limit of 700 for refrigerants used in new residential and light commercial air conditioning and heat pump systems starting in 2025. In contrast, the timeline for the transition abroad varies by country. Many countries, particularly in Europe, have already implemented stricter regulations and are ahead of the U.S. in transitioning to low-GWP refrigerants. For example, the European Union's F-Gas Regulation aims to reduce HFC use by 79% by 2030.

For HVAC equipment, HFC phase down regulation appears to be driving the adoption of alternative refrigerants in the near-term in the form of A2L or mildly flammable refrigerants. Many original equipment manufacturers (OEMs) have committed to using one of two A2L alternative refrigerants, R-32 or R-454B by 2025. However, A2L refrigerants may just be a midterm solution where the end-goal will be natural refrigerants, such as propane or isobutane. Propane and isobutane refrigerants are already used for certain end-uses including small commercial ice machines, and residential refrigerators where refrigerant charge levels are limited. The primary barrier to wider adoption of propane and isobutane natural refrigerants is their classification as A3 flammable refrigerants and limited allowable refrigerant charge levels in building fire and mechanical codes.

In the context of retail refrigeration applications, such as those found in grocery stores, the transition to low-GWP refrigerants is currently underway, especially for new construction. “Grocers are actively talking about how to meet the upcoming requirements. This is a focus in the sector.” Through interviews with retail refrigeration contractors, the consensus was that natural refrigerant systems containing CO_2 refrigerant were a “no brainer as this point” for new stores. Several contractors interviewed also indicated that retrofit of refrigeration systems within existing stores is possible with careful coordination. Modular solution approaches are available allowing the replacement of small sections of a grocery store refrigeration system over time. One contractor pointed out, “Modular approaches will be more and more appealing because it will minimize stranded assets, be a more manageable project undertaking, and address upgrades as they are needed.”

4.1.6.2 A2L refrigerants in HVAC

In the U.S., the current near-term solution to high-GWP HFC refrigerants like R-410A and R-134a is the transition to A2L HFC refrigerants such as R-32 and R-454B. Nearly all major R-32 and R-454B are both lower-GWP refrigerants that have emerged as interim options for new light-commercial and residential HVAC equipment. They represent a significant improvement over R-410A in terms of GWP, but both come with tradeoffs. Table 4-7 shows a summary of the pros and cons of R-32 vs R-454B.

Table 4-7. R-32 and R-454B comparison across residential and small commercial HVAC applications

Refrigerant	Pros	Cons
HFC-32 aka R-32*	• Single-component refrigerant • No Per and polyfluoroalkyl (PFAS) chemicals • Improved cooling capacity** • Improved heating capacity** • Similar EER cooling efficiency** • Similar COP heating efficiency** • Lower charge requirements**	• Mildly flammable • 100-year GWP 675
R-454B	• 100-year GWP 466 • Slightly improved cooling efficiency** • Slightly improved heating efficiency** • Lower charge requirements**	• Contains PFAS • Blended refrigerant • Slightly lower cooling capacity** • Lower heating capacity** • Mildly flammable

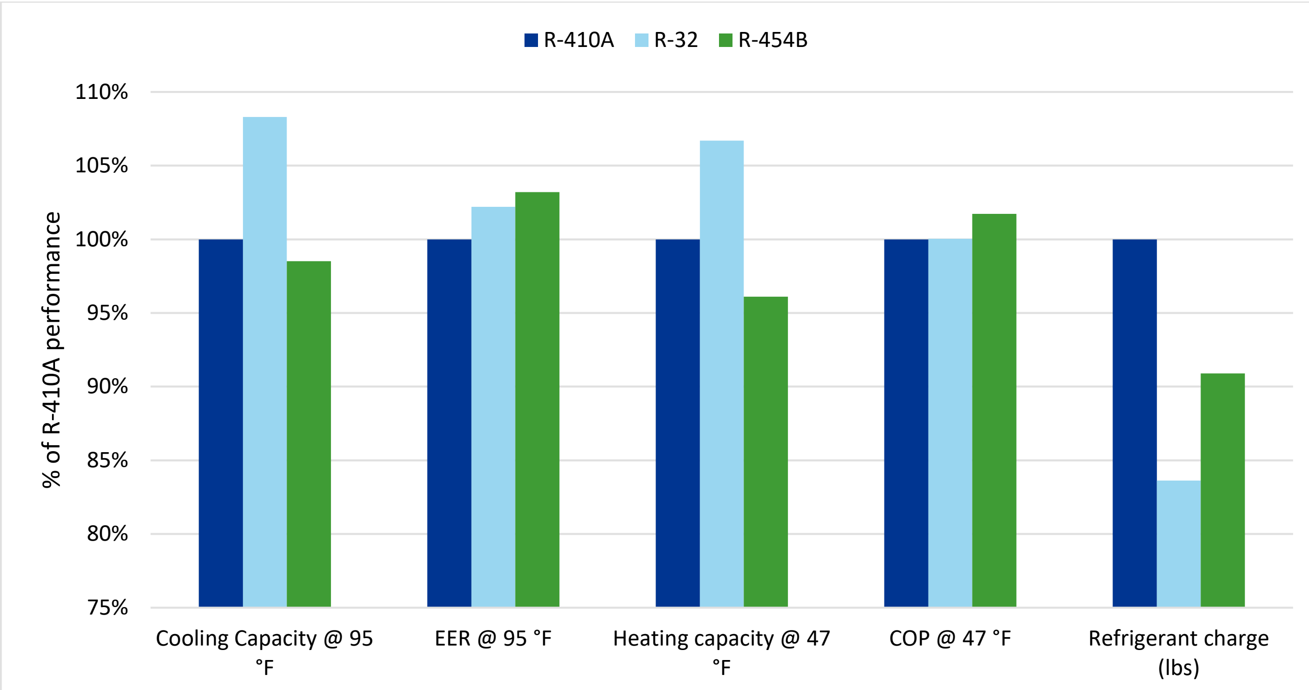
*Because R-32 is comprised of a single refrigerant and not a blend of different refrigerants it is technically HFC-32 but is more commonly referred to as R-32.

**Performance metrics compare an R-410 system with drop-in refrigerant testing of R-32 and R-454B at 95°F cooling and 47°F heating conditions.

Single component vs. blend. R-32 is a single-component refrigerant, meaning that it consists of only one chemical compound. R-454B, on the other hand, is a refrigerant blend, meaning that it is a mixture of two or more chemical compounds. The difference between single component and refrigerant blend has implications for the design, operation, and maintenance of heat pump systems. A blended refrigerant will have glide, meaning the different compounds in the refrigerant blend will have different saturation temperatures at the same pressure. When a refrigerant with glide enters a condenser, the one component will condense into a liquid before the other component. This results in a higher condensing temperature at the beginning of the condenser and a lower temperature at the end. This can reduce the heat transfer performance of the condensing coils in a system. Likewise, a glide refrigerant can impact evaporator temperature in a similar manner.

Efficiency performance. Numerous studies exist touting the performance benefits of R-32 and R-454B over R-410A. In many cases, these studies were conducted directly by refrigerant manufacturers or OEMs who have publicly committed to using one of the two mildly flammable refrigerants which presents a conflict of interest. Most of the independent lab studies comparing the various A2L refrigerants' performance were conducted on systems originally designed for R-410A, sometimes with and sometimes without system controls adjustments designed to optimize performance for the test case refrigerant. One study from 2023 analyzed the performance characteristics of optimal heat pumps for R-410A alternative refrigerants, including R-32 and R-454B. The study used the DOE/Oak Ridge National Laboratory Heat Pump Design Model (HPDM) to model the performance of heat pumps with R-32 and R-454B. Figure 4-1 shows drop-in performance modeling of cooling capacity and EER at 95 °F, heating capacity and coefficient of performance (COP) at 47 °F, and the optimum refrigerant charge for R-32 and R-454B relative to an R-410A heat pump system.

Figure 4-1. Drop-in performance modeling of R-32 and R-454B



Based on the modeling performed in this 2023 study, the R-32 outperforms R-410A and R-454B in cooling capacity and heating capacity (Zhenning 2023). R-32 showed an 8% increase in cooling capacity over R-410A and a 7% increase in heating capacity. R-454B performed slightly worse in terms of capacity than R-410A, with a 1% reduction in cooling capacity and 4% reduction in heating capacity. With EER and COP efficiencies, R-454B outperforms both R-410A and R-32, with a 3% increase in EER performance compared to R-410A and a 2% increase in COP compared to R-410A. R-32 performed similarly to R-410A or slightly improved, with a 2% increase in EER, and no change in performance for COP. Both R-32 and R-454B show a decrease in the required system refrigerant charge relative to an R-410A heat pump system. R-32 outperforms R-454B in this regard, with a 16% reduction in required charge compared to R-454B's 9% reduction in required charge.

These tests assume no change in the system and component design to optimize the performance for the new refrigerants. It is up to the OEMs to design their systems to be optimized for the working refrigerant. Additional performance can be gained through adjustments to the design. One example is to reduce the suction line diameter to 5 mm from a baseline size of 7.95 mm. Modeling showed that this one change could increase the EER of an R-32 heat pump system from 2% better than an R-410A system to 14% better. This change showed similar improvements for COP, with an R-32 heat pump system COP improving from the same performance as a R-410A system to 13% better. Time will tell what impact the different A2Ls have on heat pumps delivered to the market.

PFAS. Per and polyfluoroalkyl (PFAS) chemicals are a category of contaminates found in various industrial and consumer products since the 1950s. PFAS chemicals are sometimes called "forever chemicals" as they are very persistent in the environment and break down very slowly over time. PFAS chemicals have been detected in water, air, fish, and soil across the world (EPA PFAS 2023). PFAS chemicals are found within several single-component refrigerants used in blends, such as R-134a, and many HFO refrigerants like R-1234yf. R-454B also contains PFAS chemicals because it is a blend of R-32 and R-1234yf. Currently, five countries in Europe are proposing a ban on refrigerants containing PFAS which would ban R-454B from use (Cooling Post 2023). R-32 on the other hand does not contain any PFAS chemicals and would be excluded from this ban.

Training and code requirements for A2Ls. The HVAC industry needs to be trained and educated on the proper installation, maintenance, and servicing of A2L refrigerant systems. The EPA's Technology Transitions Program provides guidance and resources for the safe and efficient use of A2L refrigerants, such as online courses, webinars, videos, and manuals.

A2L refrigerants are classified as mildly flammable and require special precautions and handling to avoid ignition and combustion risks. Modifications to the building code, fire code, and mechanical code are required to allow the use of A2L refrigerants. The 2024 International Building Code, International Fire Code, and International Mechanical Code allow the commercial and residential use of A2L refrigerants with certain restrictions and requirements, such as charge limits, leak detection, ventilation, and labeling (ICC 2024).

4.1.6.3 HFO refrigerants

Hydrofluoroolefin (HFO) is a type of refrigerant that has a low GWP and is being used as an alternative to high-GWP refrigerants such as HFCs. HFOs are considered fourth-generation refrigerants and are being used in various applications such as air conditioning, refrigeration, and heat pumps. Some common HFO refrigerants include R-1234yf, R-1234ze, and R-1233zd. Several HFO refrigerants contain PFAS chemicals and may have unknown deleterious impacts on the environment. Lab tests have shown that HFOs are prone to refrigerant glide which can cause performance to decrease when leaks occur and can also require a complete evacuation of the system prior to charging activities.

4.1.6.4 Natural refrigerants

Natural refrigerants are an ultra-low GWP alternative with GWPs much lower than traditional refrigerants, making them a more environmentally friendly option. Some common natural refrigerants in use today include ammonia (R-717), propane (R-290), isobutane (R-600a), and carbon dioxide (R-744). These refrigerants all have very low GWP levels. Of the common natural refrigerants listed R-290 (propane) has the highest GWP of 4, and R-717 (ammonia) has the lowest GWP of 0. Natural refrigerants have zero ozone depletion potential, meaning they do not contribute to the depletion of the ozone layer. Natural refrigerants do not contain per and polyfluoroalkyl (PFAS) chemicals, which are persistent in the environment and can have negative impacts.

All natural refrigerants are single-element chemicals, meaning there are no temperature glide issues for any of the natural refrigerants available. Natural refrigerants are often cheaper than traditional refrigerants. Many natural refrigerants have similar if not improved performance compared to traditional refrigerants. For example, R-290 propane refrigerant has similar performance characteristics to R-22, R-404A, and R-134a. However, propane can achieve this performance with lower pressure drop and with less mass flow rate through the system.

The primary drawback of many natural refrigerants is either flammability or toxicity. R-290 propane and R-600a isobutane are classified as A3 (non-toxic, highly flammable). While R-717 ammonia is classified as a B2L (toxic, mildly-flammable) refrigerant. R-744 carbon dioxide refrigerant is classified as an A1 (non-toxic, non-flammable) refrigerant like all HFCs. However, R-744 carbon dioxide does not behave like a traditional refrigerant. Where traditional refrigerant gases dissipate heat by condensing into a liquid, R-744 sometimes operates above the critical point, a thermodynamic state where the properties of liquid and vapor become identical. R-744 is unable to condense and requires a gas cooler to dissipate heat instead of a traditional condenser. R-744 has much greater heat transfer efficiency, which can lead to smaller heat exchangers with lower temperature differentials compared to an HFC system. The downside to R-744 is that the pressures of the refrigerant are much larger than HFC systems leading to increased system component cost. Currently, natural refrigerants are in use in many applications including industrial refrigeration, residential refrigerators, small heat pump and air-conditioning systems, and commercial ice machines.

Propane is a clear choice for residential and light-commercial HVAC applications in the future. The limiting factor is in building, fire, and mechanical code to increase the charge limits for the use of an A3 flammable refrigerant. In 2022, the International

Electrotechnical Committee (IEC) increased allowable charge limits for R-290 in residential heat pumps and air conditioners. At the ISH 2023 in Germany, a world leading trade fair for HVAC and Water, close to 40 manufacturers were showing R-290 heat pumps (Hydrocarbons21 2023). Air-to-water monobloc heat pump systems where all the refrigerant is hermetically sealed and contained in the outdoor unit allows for the safe and successful use of propane in these systems. This allows for easier use of propane as a refrigerant than in the air-to-air systems in the U.S. where refrigerant lines are inside the building. U.S. agencies will take time to authorize charge levels approved internationally, which can slow down the adoption of natural refrigerants. Christina Starr, a refrigerant policy subject matter expert at the EIA, was interviewed by the authors of this report and shared the following about the timeline for natural refrigerant adoption in the U.S.

“Propane is one of the most promising natural refrigerant solutions in HVAC. IEC standards for increased charge limits have not been approved in the U.S. yet but there is a proposal under ASHRAE 15, to allow for a 5-kilogram charge in an outdoor indirect monobloc unit. If that proposal proceeds in a timely fashion, then gets adopted by Underwriters Laboratories, UL LLC (UL), and then later by EPA SNAP, the U.S. could start to see these units become available in 2028. Most states now have legislation in place that say once EPA SNAP approval is completed, no state or local level building code can prevent the EPA SNAP ruling. California, however, does not have that EPA SNAP clause, so it would still require an update to state and local codes before increase charge sizes are allowed.”

For other air-to-air systems, no immediate efforts to harmonize with increased IEC charge sizes exist. Unless immediate efforts are made to accelerate the approval process, it may be another five to ten years before natural refrigerants are widely available for heat pump applications in the U.S. market.

4.1.7 Hybrid system measures

For hybrid measures, where systems use two different refrigerants, such as cascade refrigeration systems where the loads (low-temperature and medium-temperature) can be served by one or more systems with one refrigerant all served by a high-temperature system with another refrigerant that rejects heat through an exterior condenser. Since the current version of the RACC-FSC workbook calculates a different set of parameters on each row of the RACC worksheet, a hybrid system can be split into two separate calculation rows. Each row would represent one portion of the hybrid system. For example, a hybrid propane (high temperature side) and CO_2 (medium and low temperature side) system could be modeled with one row for the high temperature side using propane as the refrigerant, and the medium/low temperature side would be modeled by selecting CO_2 as the refrigerant. In the case of an accelerated replacement scenario with a hybrid system with two refrigerants. For the existing system baseline, the original system charge needs to be allocated proportionally to the high temperature and medium/low temperature systems.

4.1.8 Residential heat pumps that replace natural gas furnaces without cooling

When developing fuel-substitution permutations for residential heat pumps that replace existing natural gas heating systems without either room/window air conditioning or central air conditioning, the standard practice baseline shall use an imputed cooling baseline. The imputed cooling baseline is based on the weighted proportion of homes that would have added cooling equipment when there was none before. This proportion is derived from the comparison of 2009 and 2019 RASS data and is used to interpolate between the electric energy usage for the permutation without cooling and with cooling to produce a weighted baseline for fuel-substitution calculations.

4.1.9 Refrigerant retrofit measures

A common and lower cost option to reduce a systems GWP is to retrofit the existing system by replacing the current refrigerant with a compatible lower-GWP refrigerant. This type of project is commonly referred to as a refrigerant/gas replacement, refrigerant/gas swap, or a drop-in refrigerant replacement project.

4.1.9.1 Refrigerant retrofit, >50 lb. charge

Existing retail food refrigeration facilities with systems containing more than 50 lb. of refrigerant must adhere to CARB regulations limited to the company-wide weighted average GWP, down to 1400 GWP by the year 2030, see Table 4-1. A common strategy to achieve this is to replace the refrigerant to a low-GWP alternative as a low-cost option that does not require a full system retrofit. Current systems use a refrigerant with an A1 safety classification (no flame propagation, lower toxicity). A compatible replacement refrigerant must be an A1 classified refrigerant. Common alternative refrigerants that are A1 classified, such as R-448A or R-449A, have GWP levels at 1386 and 1396, respectively. The GWP levels of these alternative refrigerants are just able to meet the regulation requirements in 2030, but do not measurably exceed 2030 requirements. Lower GWP alternative refrigerants often have an A2L safety classification, which is a mildly flammable, lower toxicity refrigerant. A2L refrigerants cannot be used in refrigerant retrofits for existing equipment that was rated for a non-flammable, A1, refrigerant. The use of A2L refrigerants requires a new system with components rated for mildly flammable characteristics.

Given that the available drop-in refrigerant replacements are just meeting the future regulation, this type of project represents something retail food facilities will need to do regardless of program influence. Retail food facilities should not claim this type of measure as it would not pass the free ridership screening.

4.1.9.2 Refrigerant retrofit, ≤50 lb. charge

For existing retail food refrigeration systems with less than 50 lb. of refrigerant, there is no CARB GWP requirement, and the EPA only regulates new systems. Without a proven energy efficiency benefit associated with a refrigerant gas replacement project, there is currently no means to claim any refrigerant emissions benefits from this application. If a pathway to claim these benefits does get established, the duration of this measure be limited to the lesser of the RUL of the host equipment (typically 5-year RUL for retail food refrigeration) or the EUL of any companion energy efficiency activities bundled with the refrigerant replacement, such as leak repair or retro-commissioning (up to 3 years).

4.2 Comprehensive RACC Technical Guidance Document

DNV developed the RACC-FSC Technical Guidance Document in conjunction with the RACC-FSC to help users understand how to use the RACC-FSC to claim cost benefits associated with avoided refrigerant emissions and run the fuel-substitution tests for various measures all in one workbook. This document leveraged information from the baseline characteristics research task to provide best practices for baseline input for a wide assortment of end-use applications. The RACC-FSC Technical Guidance Document is posted on CEDARS alongside the RACC-FSC_v3.0 workbook.[29] The RACC-FSC Technical Guidance Document includes the following sections:

Introduction: Provides background information on the policy and regulations leading to the creation of the RACC and the FSC.

RACC-FSC overview: Provides a detailed description of the workbook calculations and overall functionality of the combined tools.

Baseline guidance: Details the baseline guidance related to RACC and FSC applications researched as part of this study described in the prior section.

Example walkthroughs: Included within the technical guidance document is a series of step-by-step walkthrough examples for various measures that involve refrigerants.

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[29] California Energy Data and Reporting System (CEDARS), Supporting Files. https://cedars.sound-data.com/deer-resources/tools/supporting-files/

Stationary refrigeration: This set of walkthroughs includes several refrigeration system examples such as retail refrigeration replacement with natural refrigerant system. A list of the included examples is as follows:

- Complete system replacement with natural refrigerant system, >50 lb. charge (accelerated replacement and normal replacement examples)
- Cascade retail food partial system replacement with hybrid refrigerant system, >50 lb. charge systems (accelerated replacement and normal replacement examples)
- Commercial ice machines (normal replacement only)
- Stand-alone units
- Refrigerated food processing and dispensing equipment (normal replacement only)
- Cold storage warehouse system, 50-200 lb. (accelerated replacement and normal replacement examples).

Stationary air-conditioning: This set of example walkthroughs includes several stationary air-conditioning systems such as air-cooled chillers for air conditioning, and residential heat pump systems. A list of the included examples is as follows:

- Air-cooled HVAC chiller (accelerated replacement and normal replacement examples)
- Unitary air-cooled AC and gas furnace, RTU with R-32, commercial (accelerated replacement and normal replacement examples)
- Central heat pump replacing residential gas furnace weighted baseline AC cooling, fuel substitution (accelerated replacement and normal replacement examples)
- Ductless heat pump replacing residential gas furnace and weighted baseline AC cooling, fuel substitution (normal replacement only)

Appliances: This set of example walkthroughs includes several residential appliance systems that include refrigerant such as heat pump water heaters. A list of the included examples is as follows:

- Heat pump water heater, residential, fuel-substitution (accelerated replacement and normal replacement examples)
- Heat pump clothes dryer, residential, fuel-substitution (normal replacement only)
- Residential refrigerator, freezer (accelerated replacement and normal replacement examples)

4.3 Modeling tools review

The existing modeling tools for refrigeration system performance can be categorized into two classes: system simulation tools and whole building simulation tools. Both types of tools are capable of modeling most of the existing refrigeration system configurations in the market. System-level modeling tool models the refrigeration cycles of the refrigeration system and does not include components like building spaces and HVAC system.

Whole building simulation engine can capture the interactions between the refrigeration system and the HVAC or ambient space but requires a steeper learning curve. The whole building simulation tool also demands a large number of inputs along with knowledge in refrigeration, HVAC, building science, and modeling tool itself. Therefore, even though the whole building tool is more capable in detailed simulation, it is difficult to use and generate reliable results without sufficient knowledge or pre-defined system and refrigerant templates.

In this work, we also sought to investigate if the existing tools can capture the performance of not only predominant system configurations and refrigerants in the market, but also potential low-GWP alternatives and emerging system configurations that accommodates those low-GWP refrigerant alternatives.

4.3.1.1 Whole building simulation tools

eQuest/DOE 2.2R

DOE 2.2R stands as a specialized, whole-building energy analysis software, devised with a primary emphasis on modeling refrigeration component subsystems. Born as a companion program to eQUEST, it offers a platform to construct intricate systems from individual components, catering to a diverse array of building types. eQUEST, in tandem, operates as a more user-centric interface, built atop the foundational DOE2 engine. This unique blend ensures that while users gain access to a graphical and intuitive environment via eQUEST, they are simultaneously harnessing the depth and robustness of DOE 2.2R's detailed modeling capabilities.

Pros: DOE2.2R and eQUEST are widely recognized tools in the building energy modeling domain, each with their own distinctive features tailored to diverse project needs. DOE2.2R stands out for its modular design that allows systems to be constructed from individual components. This flexibility can be instrumental when modeling both simple and intricate energy systems. Additionally, the tool offers detailed energy consumption and cost analyses for a wide array of building types, ensuring comprehensive insights for various projects. Recognizing the challenges of building accurate models, DOE2.2R incorporates default refrigeration system templates. These templates not only aid in streamlining the modeling process but also ensure that users have a reliable starting point.

On the other hand, eQUEST, building on the foundational DOE2 simulation engine, offers a user-friendly interface complemented by a suite of modeling capabilities. Notably, eQUEST allows users to develop model wizards tailored to specific building envelopes, lighting, and HVAC requirements. One of its notable features is the provision for parametric runs. This capability facilitates nuanced scenario analyses, providing deeper insights into potential system performances under varied conditions. Further aiding interpretation, eQUEST's graphical results display ensures data is presented in an intuitive manner, aiding swift and informed decision-making.

Both tools incorporate advanced rate treatment mechanisms, reflecting real-world utility scenarios. From time-of-use rates to demand charges, users have the tools at their disposal to simulate realistic billing conditions. Moreover, with fluid property data spanning 15 different refrigerants, DOE2.2R ensures broad compatibility across various refrigeration systems.

Cons: Both DOE2.2R and eQUEST offer a range of valuable features but come with certain limitations that users should be aware of. Notably, DOE 2.2R has not been as widely adopted as some other industry-standard tools, and its documentation is relatively sparse. This lack of extensive documentation can pose challenges when troubleshooting or trying to gain a deeper understanding of specific functionalities. eQUEST, with its user-centric design, leans heavily on the DOE2 engine. As a result, certain modeling tasks can become intricate.

One significant challenge in DOE 2.2R is the requirement to manually create and edit component-based refrigeration systems using a text editor. This approach can be prone to errors and may not be the most efficient. Additionally, as of the current version of the tool (version 3.65 build 7175), the platform does not support the modeling of CO_2 transcritical systems, although there is potential for this to change with future updates. Another consideration is the recency of the tool's updates; with the latest public version dating back to 2017, questions arise about its ongoing relevance. Lastly, potential users should be prepared for a learning curve, as substantial training may be required to harness the full capabilities of these tools.

EnergyPlus

EnergyPlus is a leading-edge whole-building energy simulation software that was developed by the U.S. Department of Energy (DOE) in collaboration with various partners. It is an integration of some of the best features of its predecessors, DOE-2 and BLAST, with added functionalities and improvements. Primarily utilized for modeling energy consumption and indoor environmental quality, EnergyPlus covers a range of building systems, including HVAC, lighting, and refrigeration.

The software stands out for its capability to simulate interactions among building systems in different weather conditions, offering an hour-by-hour simulation to provide detailed results. Its versatility makes it suitable for modeling everything from individual rooms to large complexes or even district energy systems.

Refrigeration system modeling

Pros: EnergyPlus provides an intricate framework for modeling diverse refrigeration systems. The software can accurately represent their operational intricacies of walk-in coolers, display cases, secondary cooling loops, or cascading systems, among other system types. This capability aids designers in optimizing system design for both performance and energy efficiency.

A hallmark feature of EnergyPlus is its adeptness in modeling refrigeration equipment under a gamut of operational conditions. For instance, users can simulate the performance of variable-speed compressors, subcoolers, and other high-end components, leading to an in-depth understanding of equipment behavior under real-world scenarios. A distinguishing strength of EnergyPlus is its integrated approach, allowing for a holistic analysis of how a refrigeration system interacts with other facets of a building, such as HVAC or lighting systems. For example, opportunities like reusing waste heat from a refrigeration unit for space or water heating can be explored and quantified.

Beyond standard operational modeling, EnergyPlus extends support for advanced control strategies. These might encompass demand-response controls, fine-tuned start/stop cycles, or synchronizations with renewable energy sources, granting users the leeway to push the boundaries of energy efficiency. The tool offers a dual approach in its simulation runs. On one hand, design day simulations assist engineers in appropriately sizing equipment based on peak load scenarios. On the other hand, annual simulations furnish projections on yearly energy consumption, costs, and performance metrics, enabling long-term planning and optimization.

Cons: While EnergyPlus is equipped with extensive libraries for various building systems, its resources for refrigeration systems and equipment are notably limited. This poses a challenge for professionals who may need to gather external performance data or lean on manufacturer-specific details to enrich their simulations. Modeling refrigeration systems in EnergyPlus demands a solid grasp not only of the software itself but also foundational knowledge in building science, HVAC, and refrigeration systems. The intricate relationships and interdependencies among these domains require users to possess a multi-disciplinary understanding, which can be daunting for newcomers or those specialized in only one field.

Potential: Recognizing these challenges, there's significant potential for the future enhancement of EnergyPlus in the realm of refrigeration. The introduction of prototype buildings or auxiliary tools that can parametrize settings to cater to custom requirements could streamline the modeling process. Additionally, the development and inclusion of comprehensive libraries or datasets tailored for refrigeration systems and equipment could substantially elevate the software's capability and user-friendliness in this area.

4.3.1.2 System simulation tools

Cycle D-HX

Developed by the National Institute of Standards and Technology (NIST), CYCLE_D-HX stands out as a pivotal tool in the realm of thermodynamics, specifically tailored for vapor compression cycle modeling. The tool’s foundation rests upon its consideration of refrigerant thermodynamic and transport properties, ensuring simulations’ precision and accuracy. CYCLE_D-HX simulates the performance of single-compound refrigerants and refrigerant blends in subcritical vapor-compression refrigeration cycles. The basic system simulated by CYCLE_D-HX consists of a compressor, discharge line, condenser, expansion device, evaporator, compressor suction line, and an optional liquid-line/suction-line heat exchanger. The other cycles may contain a second compressor, one or two economizers, or an intercooler.

Pros: One of CYCLE_D-HX's most notable features is its expansive refrigerant database, offering users the flexibility to simulate the performance of over 160 distinct refrigerant types. This comprehensive assortment not only enables a deep dive into each refrigerant's intricacies but also allows for performance comparisons across a broad spectrum. Beyond its refrigerant selection, CYCLE_D-HX excels in its adaptability. The tool provides users with the autonomy to tweak HVAC cycles and parameters as needed. Such versatility ensures that users can craft simulations that closely mirror the desired conditions. At the heart of any simulation is the quest for actionable metrics, and CYCLE_D-HX delivers on this front. The tool efficiently computes the Coefficient of Performance (COP) and unit capacity, making it invaluable for those aiming to gauge the efficiency and potential output of various equipment types.

Cons: Depending on the version and user feedback, there might be a learning curve associated with mastering all the functionalities of the tool. While CYCLE_D-HX includes a wide array of system types, there might be specific, niche systems or configurations that the tool might not fully encompass. The ease of integrating CYCLE_D-HX outputs with other modeling or analytical platforms can be an area of limitation. This tool is also limited in generating detailed annual simulation results.

Genetron Properties

Genetron Properties stands as a system-focused modeling software, provided at no cost by Honeywell, a prominent manufacturer and distributor of refrigerants. The tool grants users the flexibility to select from a roster of 11 predefined system architectures, including the likes of CO_2 transcritical, CO_2 booster, and cascade configurations. Furthermore, it supports a rich array of refrigerants such as ammonia, propane, and R-448A — the latter being a product of Honeywell's Solstice N40 brand. However, it is worth noting the absence of R-449A, which Chemours markets under the Opteon XP40 brand.

In comparison to its counterparts, Genetron Properties opts for a more streamlined approach, primarily resorting to a default input set for its elementary functions. Nevertheless, it does offer a "multicase" feature, enabling users to project annual performances. This mode allows for diverse input conditions, yet the transition from multicase runs to a bin-type approximation of annual performance demands a considerable amount of post-processing. A noticeable omission from the tool's capabilities is an integrated economic analysis module.

Other industry giants, such as Chemours (Chemours Refrigerant Expert), also present comparable modeling tools. While each tool brings its unique features to the table, many share analogous constraints, underscoring the industry's collective areas for potential enhancement.

Pack Calculation Pro

Pack Calculation Pro, commonly referred to as "Pack Calc Pro", is a specialized system-only modeling program tailored for the simulation of refrigeration systems. The program hinges on leveraging specific compressor model data from various manufacturers to precisely compute refrigeration system and heat pump annual performance metrics. Developed by two adept thermodynamics and energy technology engineers hailing from Denmark, Pack Calc Pro stands out in its segment for its wide-ranging capabilities.

The tool's design allows users to harness default templates for a diverse array of 18 refrigerant cycles. These encompass refrigeration and heat pump transcritical booster and cascade systems, offering flexibility in terms of refrigerant choices. A total of 143 available refrigerants, including popular ones like R-448A and R1234yf, can be selected. However, the latter isn't natively incorporated within the program. A notable strength of the software lies in its vast compressor performance database, consolidating data from five major manufacturers in the industry with around 13,500 commercially available compressors.

Additionally, the software seamlessly integrates annual weather data files from across the globe, specifically targeting 21 key cities in California. Even though the tool incorporates a basic economic analysis framework, it does require users to make some simplified assumptions about energy costs. Regular updates, underlining the developers' commitment to staying with industry trends, ensure that the tool remains relevant. As of the official website indicates, the last significant version update was registered in November 2023[30].

Pros: Calc Pro excels in conducting comprehensive annual simulations, distilling results across varied climates. The program remains independent from commercial influences, ensuring unbiased results pertinent to different refrigeration technologies. It features multiple CO_2 transcritical and booster systems. Regular software updates ensure it remains current and in line with industry advancements. With a broad spectrum of annual weather data files from across the globe, it is particularly beneficial for those focused on conditions in California. Although basic, the inclusion of an economic analysis feature adds another layer of utility for users.

Cons: The software does not natively cater to the explicit modeling of fixtures and loads, which might necessitate supplementary tools or manual computations for some users. To harness the full breadth of the tool's capabilities, users are mandated to have a system license, which could be a barrier for casual or infrequent users.

4.3.2 Summary

In the dynamic and complex realm of refrigeration and building energy modeling, it is evident that no single tool can encompass all the features and capabilities to meet every specific need of the user community. Several factors contribute to this observation:

Ease of use: Most comprehensive tools come with intricate interfaces and functionalities, requiring significant effort and time to master.

Simulation capabilities: While some tools are proficient in simulating existing systems, they may fall short when it comes to potential emerging systems or equipment.

Refrigerant support: With the increasing diversity of refrigerants used in the industry, not all tools offer comprehensive support or updates for them.

Interactive effects: The capability to simulate the interactive effects of a refrigeration system with other building systems or components is a pivotal feature, yet not all tools are equipped to perform this complex task seamlessly.

Updates and maintenance: Continuous development, maintenance, and updates are vital for a tool's relevance in an ever-evolving industry. Not every tool receives regular updates or has a dedicated team for maintenance.

Of the tools evaluated, EnergyPlus and Pack Calculation Pro are prominent contenders in the field. However, they too come with their set of constraints. Both tools have the capability of generating and exporting hourly results. However, manual analysis of the exported hourly data is required to generate system load shapes. While EnergyPlus boasts robust capabilities and is versatile, newcomers often face a steep learning curve. The depth and breadth of knowledge required can sometimes be overwhelming. Addressing these challenges would necessitate augmented support from refrigeration system/equipment libraries and datasets in the future. Pack Calculation Pro is adept in refrigeration system simulations and offers regular updates, ensuring its applicability in contemporary scenarios. However, its limitation lies in simulating the interactive effects of the refrigeration system within the broader context of building systems. In conclusion, while many tools offer diverse strengths, a holistic tool meeting all industry requirements remains elusive. Users need to judiciously select a tool based on their specific project needs and be aware of its limitations.

30 https://www.ipu.dk/products/pack-calculation-pro/

4.4 Workforce knowledge

The market transition to low-GWP and natural refrigerants is contingent on a skilled workforce with the resources and training to both install and service emerging low-GWP applications. For grocery stores and other stationary refrigeration projects, the North American Sustainable Refrigerant Council (NASRC) provides a growing workforce development and policy arena. While ample training and development is still needed, the transition to low-GWP and natural refrigerants in stationary refrigeration is well ahead of the HVAC refrigerant transition. For these reasons, HVAC workforce knowledge was the primary focus of this task.

The research team attended dozens of refrigerant-related trainings targeting HVAC-R service professionals. Some of the trainings focused on the low-GWP refrigerant transition while others focused on detecting leaks and other best practices for minimizing refrigerant emissions. Additionally, six different California HVAC-R contractors were interviewed about refrigerants between September 2023 and January 2024. Four of the six contractors participated in a March 2024 focus group to discuss refrigerant emissions and strategies to improve end-of-life recovery and reclamation. After completing the focus group, the research team conducted a 13-question web survey seeking feedback from HVAC technicians and contractors who have participated in prior PA sponsored energy efficiency HVAC projects. In total, 44 contractors and technicians responded to the survey in April 2024. The web survey responses helped inform the findings of both the workforce knowledge and improved recovery sections of this report.

4.4.1 Training resources

Each contractor we spoke with is aware of the pending residential and light commercial HVAC transition to one of two mildly flammable refrigerants that include HFC-32 (100-year GWP 675) and R-454B (100-year GWP 466). All interviewees reported receiving less than 4 hours in training specific to either refrigerant. The interviewees shared the various training and policy resources they utilize. Those sources included 1-2-hour classroom trainings provided by equipment manufacturers via the contractors preferred distributor, webinars or virtual classes taken through trade association websites, or in-person training workshops. Two of the interviewees touted the International Heating and Air Conditioning Institute (IHACI) for the free classroom trainings the organization provides. Table 4-8 summarizes the more notable training and policy platforms shared by interviewees or utilized to support secondary research.

Table 4-8. HVAC-R Policy and workforce knowledge resources

Organization	Summary	Sectors served	Supporting activities
North American Sustainable Refrigeration Council	A network of supermarket industry stakeholders working to remove barriers preventing the adoption of climate-friendly natural refrigerants.[31]	Retail refrigeration	Workforce development Funding Resources library Policy advocacy HFC Policy Tracker

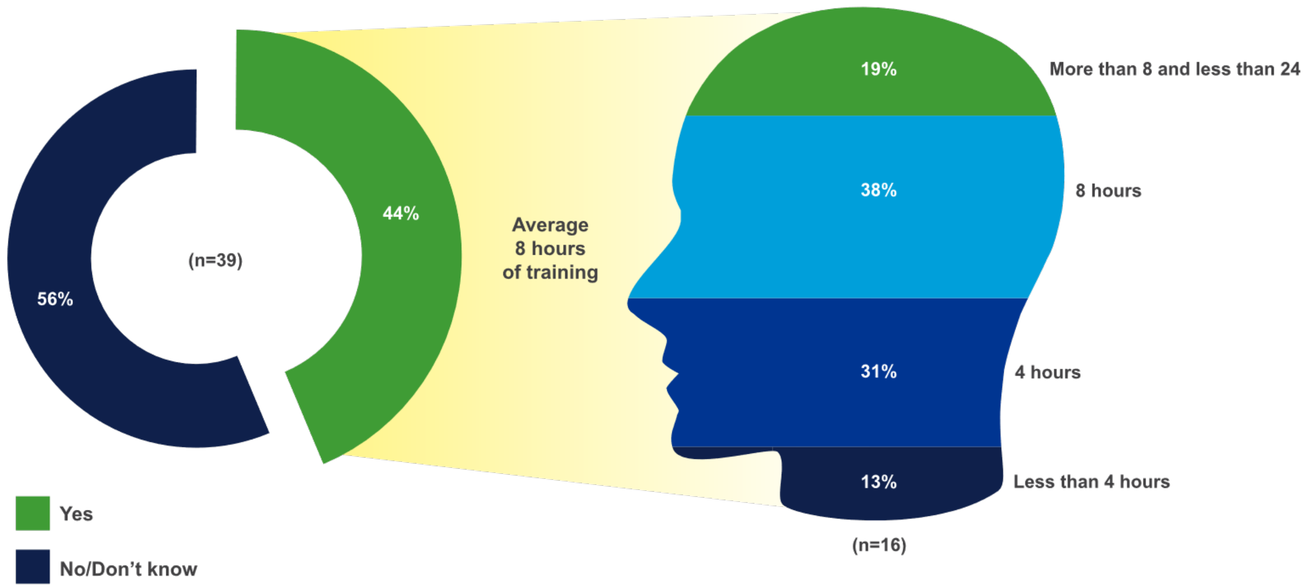
[31] https://nasrc.org/

Organization	Summary	Sectors served	Supporting activities
Air Conditioning Contractors of America	National trade association that provides members networking opportunities, education, and advocacy services while championing the national health of the HVAC-R industry.[32]	Residential HVAC Commercial HVAC Stationary Refrigeration	Workforce development A2L Safety Training Quality certifications Policy advocacy Industry standards
The Air-Conditioning, Heating, and Refrigeration Institute	Trade association representing manufacturers of heating, ventilation, air conditioning, commercial refrigeration, and water heating equipment.	Residential HVAC Commercial HVAC Stationary Refrigeration Water Heating	Performance rating standards Equipment certifications Policy advocacy
The Institute of Heating and Air Conditioning Industries, Inc.	Trade association of contractors, manufacturers, distributors, utilities, and businesses actively engaged in the HVAC-R, and sheet metal industries.	Residential HVAC Commercial HVAC Stationary Refrigeration	Workforce development North American Technical Excellence Certifications
Pacific Gas and Electric Energy Center	Energy efficiency, decarbonization, and electrification workforce training	Residential HVAC Commercial HVAC Stationary Refrigeration Water Heating	Workforce development

Web survey respondents were asked whether they or anyone at their company had received training on A2L mildly flammable refrigerants. As shown in Figure 4-2, only 44% of those respondents reported someone from their company having received training with eight hours of training being the average across those who reported receiving training.

32 https://www.acca.org/about-acca

Figure 4-2. Web survey responses who received training, and how many hours they received



Most survey respondents who reported receiving training on A2L refrigerants reported they had received training on both HFC-32 and R-454B (63%), while smaller subgroups reported receiving training on just one of the two as shown in Table 4-9.

Table 4-9. Refrigerant-specific training responses

Was the training specific to R-32, R-454B, or both?	(n=16)
R-32 refrigerant	6%
R-454B refrigerant	31%
Both R-32 and R-454B refrigerant	63%

4.4.2 Workforce needs

In-depth interviews and web survey results both show a clear need for additional HVAC workforce training for the transition to lower-GWP A2L refrigerants to be successful.

Additional equipment: The most frequent concern brought up by contractors is the need carry additional refrigerant cylinders with different storage requirements because of the mild flame propagation hazard present with HFC-32 and R-454B. While current HVAC contractors typically carry R-410A and HFC-22 cylinders and hoses with them, starting in 2025, they will need to carry up to four different sets of tanks and hoses to charge and service existing and new systems.

Operational leakage: Another major concern brought up is around operational leakage that stems from poor installs and inconsistent training. The founder and lead technician for an HVAC company that primarily serves rural customers and specializes in heat pumps brought up several points regarding operational leakage.

"Operational leakage is a major concern. The industry lacks quality standards around refrigerant line set tightness. Current standards allow enough greyness, so contractors have a low bar to reach to call an install complete. Most HVAC field technicians have a limited understanding about what they are doing and struggle to diagnose and fix issues they encounter. There is a significant lack in proper trainings on how to interpret the results. The new A2L procedures create a bigger need for testing and troubleshooting. Often technicians are not trained to do a proper vacuum test. One community college teacher said he doesn't teach his students to use a torque wrench when using flare fittings. Somebody needs to come up with a clearly defined set of standards to make sure best practices are put in place."

Heat pumps increase charge: Current CARB emission estimates show heat pumps typically contain a 9% greater refrigerant charge than the air conditioners of the same capacity they replace. A 2021 New York State Energy Research and Development Authority (NYSERDA) funded study on HFC Emissions Inventory and Mitigation Potential for NY State presented nine different residential heat pumps across three different efficiencies, which concluded that manufacturers increase charge by an average of 40%–69% (Guidehouse, NYSERDA 2021). The same study showed commercial RTU HP refrigerant charge sizes increased by an average of 18%-50% across three different efficiency ranges and three different manufacturers. It remains to be seen how much variation the emerging A2L refrigerants HFC-32 and R-454B will impact heat pump charge size increases since these products are just starting to come onto the market as this study is being published in 2024. Contractors interviewed said existing refrigerant lines will often need to be replaced. They also added that the mechanical fittings and connections required with A2Ls are new to some of the workforce and may potentially result in additional leaks.

Natural refrigerants: One Southern California-based contractor shared that he retrofitted an older R-22[33] system at his home to operate using R-290 Propane. He said while he knows it is a violation of many building and fire codes, he went ahead with the drop-in retrofit because it's more efficient and far better for the environment if it leaks. When asked if he had safety concerns, he brought up the fact that it is becoming more and more common for smaller systems in Europe and that nobody seems to be concerned about the 20 lb. propane cylinders they have attached to the BBQs.

4.5 Improved recovery

Throughout the study the research team noted alarming rates of EOL refrigerant emissions. Current CARB estimates show EOL emission rates are highest for smaller equipment (80-99% for residential) with EOL emission rates continually decreasing as systems and charge sizes increase in the commercial and industrial sectors. SMEs and EPA licensed reclaimers agree with CARB's estimates for EOL emission rates and some suggested that it could be even worse than CARB's estimates. A whitepaper published by the Yale Carbon Containment Lab looked at EPA's annual reclamation volume reports in combination with data reported by reclaimers and estimates, "that refrigerant recovery rates in the U.S. hover between 8 and 20 percent."

4.5.1 Current refrigerant recovery practices

During IDIs with HVAC-R contractors, all six of the contractors we interviewed reported that they use recovery machines to pull remaining refrigerant into recovery cylinders when retiring existing HVAC systems. The same group also willingly acknowledged many contractors in the workforce do not always go to the trouble of recovering EOL refrigerant. Lack of enforcement of Section 608 of the US Clean Air Act prohibiting intentional venting of refrigerants, the added time required for proper system recovery, the lack of meaningful monetary incentives, and the need to complete jobs in one day only, were some of the key reasons interviewees shared. Like the contractors we interviewed, Figure 4-3 shows most web survey respondents reported they perform EOL recovery most or every time, but the time they spend doing so ranged between 30 minutes to over two and a half hours for a typical split-system residential AC unit. It is worth noting that while DNV circulated the web survey via email to over 750 HVAC-R contractors, only 44 participated in the survey. Given the survey email subject heading, "Help the CPUC Shape Refrigerant Recovery Programs for HVAC-R," these responses may include a bias towards contractors and technicians who want to see refrigerant recovery improve. The survey was only circulated to contractors or technicians who have participated in some prior ratepayer funded program or spoke directly with the authors of this paper.

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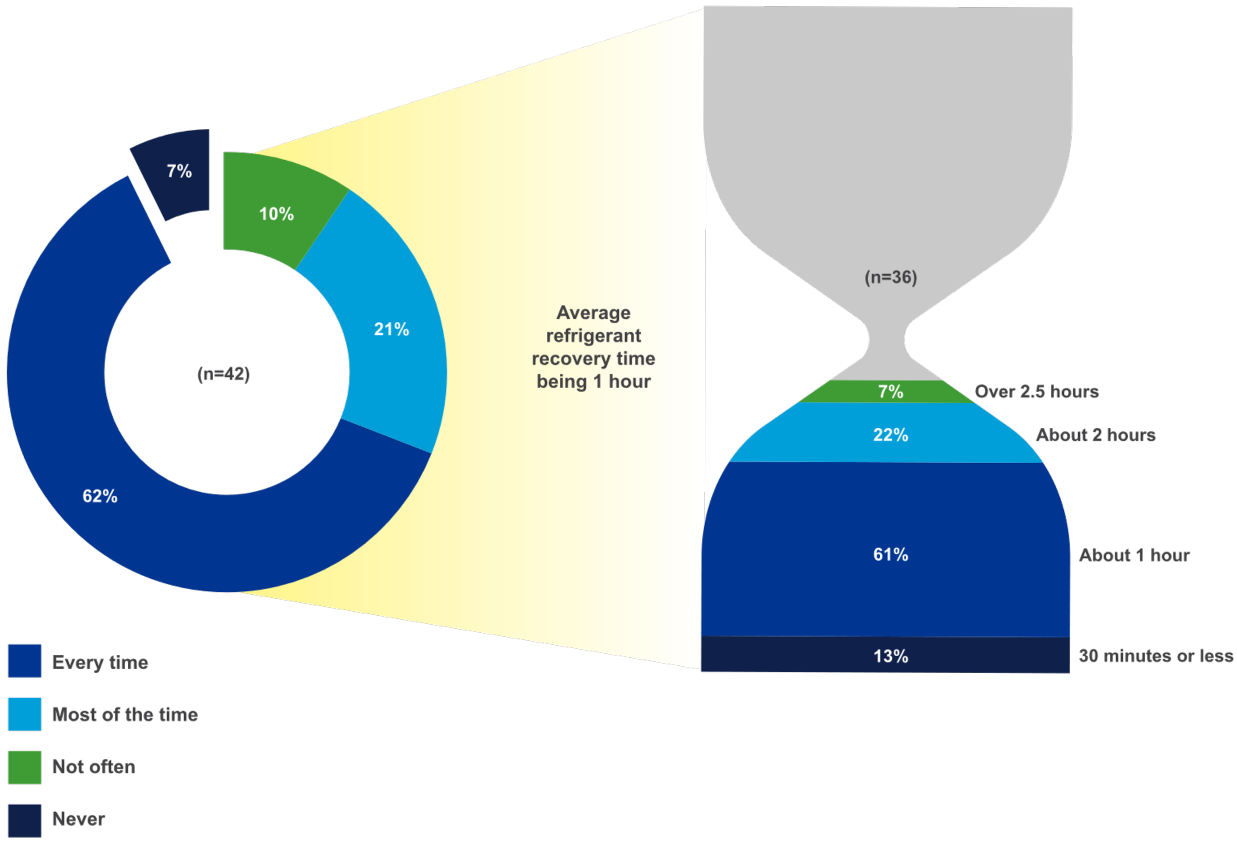
[33] R-22: a Hydrochlorofluorocarbon HCFC refrigerant with ozone-depleting substances that was banned for new HVAC installations in 2010

Figure 4-3. Web survey EOL recovery and average recovery time for a 2.5-Ton residential AC



Each contractor described the process they take when retiring an existing system and if they receive any incentives for recovered refrigerant. All six acknowledged that many contractors in the workforce do not use recovery machines to draw any remaining charge into a recovery cylinder. The time they spend performing recovery varied considerably as did the level to which they depressurized the retired systems when removing refrigerant. As shown in Table 4-10, the variation in responses seen for this depressurization question further illustrates the lack of consistent protocols used across the workforce.

Table 4-10. Depressurization levels used during refrigerant recovery process

When HVAC technicians at your company perform refrigerant recovery, to what pressure do they pull to?	(n=38)
Atmospheric pressure	16%
Negative 5 inches of mercury	34%
Negative 10 inches of mercury or less	16%
Don't know	32%

One HVAC contractor who works for a medium sized heating and cooling company operating out of the San Francisco Bay Area shared the process he believes contractors who cut corners with recovery use most. Often, he believes contractors are not directly venting at the unit but instead drawing refrigerant into the compressor cylinder of the outdoor condensing unit. They then disconnect the compressor from the rest of the system. The compressor either then gets serviced somewhere by a refrigerant reclaimer to recover and reclaim the remaining refrigerant or it goes directly to a scrap yard for processing where it will slowly leak until the compressor is compacted and processed for scrap resulting in the release of all remaining refrigerant into the atmosphere. It should be noted this same contractor said his company always follows proper EOL recovery when retiring systems and Rapid Recovery (a subsidiary of the EPA-licensed A-GAS) collects the recovered cylinders for reclamation on a regular basis.

One contractor we spoke with shared that nobody will accept his filled recovery cylinders where he operates. As a result, he saves most recovered refrigerant in recovery cylinders for future use. Web survey respondents were asked to allocate where they or their technicians typically take or store the refrigerant they recover (Table 4-11). Respondents were allowed to answer with percentages across multiple answer choice options. Returning the refrigerant to their equipment distributor or local supply house was the most common response (46%).

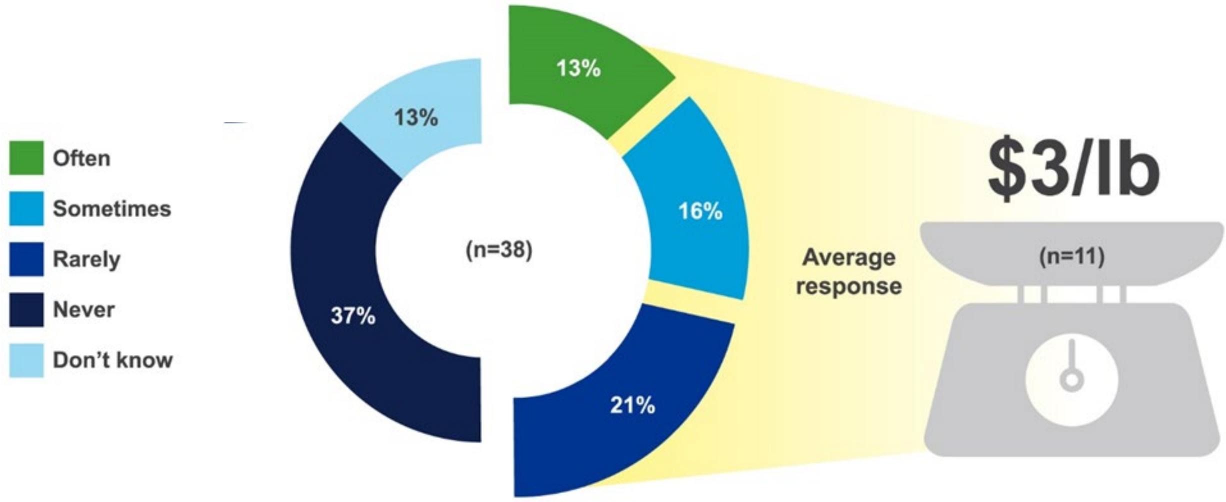
Table 4-11. Recovered refrigerant destination results

Where do HVAC technicians at your company typically take or store the recovered refrigerant?	(n=36)
Store it for future use	4%
Return to local supply house	46%
Licensed reclaimer collects recovery cylinders periodically	38%
Pull refrigerant into condenser and take to recycling center/scrap yard	9%
Other	0%
Don't know	3%

Only half of web survey respondents reported ever receiving payment for recovered refrigerant. Of the respondents who reported receiving payment, the average payment received was only $3/pound of refrigerant, as shown in Figure 4-4. At that price, a contractor would receive about $21 for returning the remaining 7 lbs. of refrigerant recovered from a typical residential split-system. Another barrier brought up was access to empty cylinders. Several of the contractors we spoke with shared frustrations about how particular the distributors they work with can be when it comes to exchanging recovery cylinders. They reported getting charged if the refrigerant they returned was deemed too impure to be reclaimable or even getting charged if the cylinder they returned wasn't filled to the maximum level with refrigerant.

The web survey included one open ended question asking contractors and technicians if there is anything else they would like to share on the topic of EOL refrigerant recovery and reclamation. It's worth noting that two of the open-ended comments received were directed at recycling or scrap yards. One contractor said; "Attention should be paid to tracking scrap yards that take machines with refrigerant in them." While a different contractor said; "If there was compensation for returned refrigerant even "scrappers" would be more inclined to do proper recovery instead of releasing the refrigerant."

Figure 4-4. Frequency performed and amount received for recovered refrigerant



4.5.2 Strategies for improvement

In March 2024, DNV hosted representatives from two EPA licensed reclaimers, two HVAC equipment distributors, the EPA, CARB, refrigerant policy SMEs, CPUC study leads, and four HVAC-R contractors for a virtual focus group. The group met to explore a path to enable energy efficiency programs to claim avoided greenhouse gas emissions for documented end-of-life (EOL) refrigerant recovery and reclamation. The participating HVAC contractors each shared the process they follow when recovering refrigerant at EOL. Three of the four contractors reported they typically spend a couple hours performing EOL refrigerant recovery and receive virtually no payment for returning reclaimed refrigerant. One added he will sometimes get charged because the reclaimer determines the recovered refrigerant is too impure to reclaim. Another stated most contractors he knows do not reclaim and condensers with refrigerant often end of at the scrap yard never to be recovered. In contrast, the two EPA licensed reclaimers in attendance both claimed they were surprised to hear contractors do not get any value from the reclaimed refrigerant. Both reclaimers stated they buy back all used refrigerants, and that it is "a nightmare myth" that mixed refrigerant cylinders cannot be reclaimed.

One of the contractors gave a virtual demonstration of the Visual Service smartphone application his company's technicians use when installing, servicing, and retiring equipment in the field. The Visual Service application's ability to document the refrigerant recovery process impressed the attendees. The Visual Service application produces documentation that includes the following:

- A video of the contractor operating the recovery machine on the retired system
- A geographic pin showing the location
- A data tracker showing both the pressure of the refrigerant in the existing system decreasing
- The weight of the refrigerant being transferred to the recovery cylinder increasing
- The type and serial number of the recovery cylinder

The focus group agreed that this level of documentation combined with a bill of lading[34] from an EPA-licensed refrigerant reclaimer showing the recovery cylinder was reclaimed, would effectively prove the refrigerant was reclaimed.

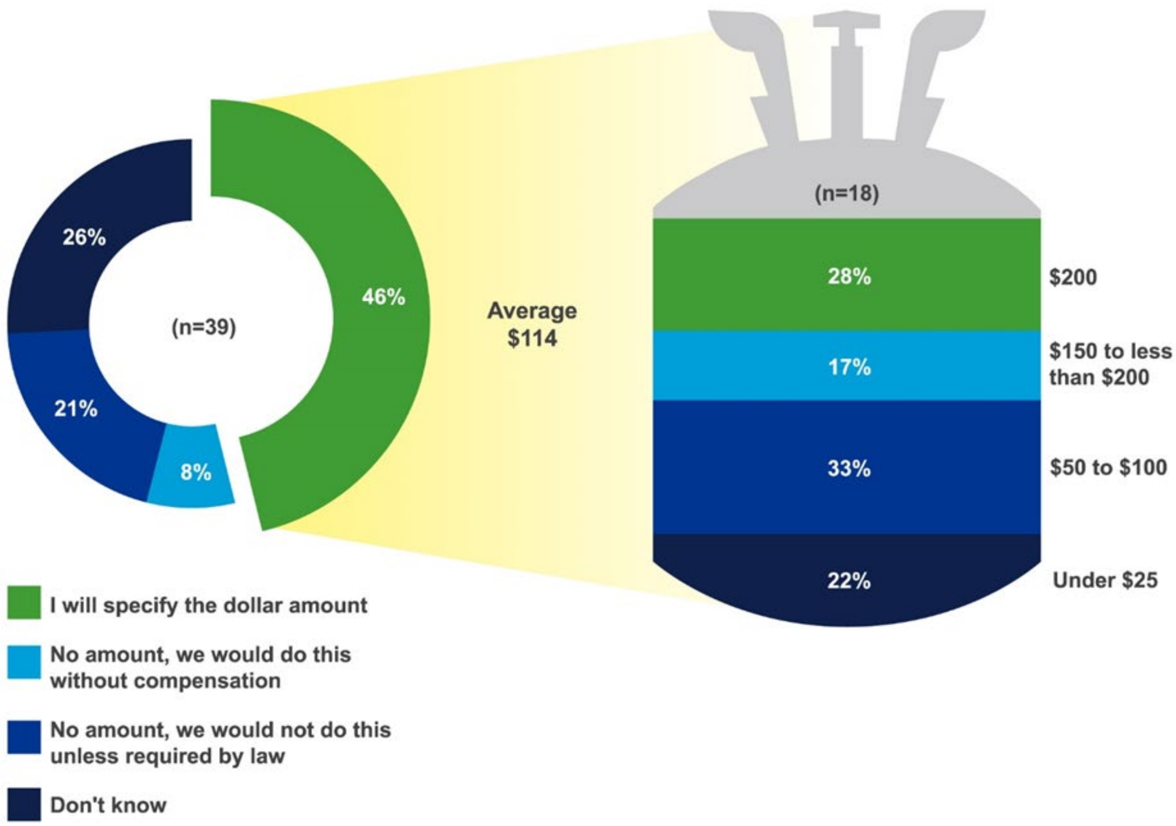
CARB estimates that the average end-of-life emission rate is 80% for central residential ACs and heat pumps. That is, 80% of the time all remaining refrigerant in removed systems is vented into the atmosphere. Correspondingly, the avoided emission

[34] Bill of lading is a detailed list of a shipment of goods in the form of a receipt that is exchanged between parties carrying the goods.

credit that can be claimed when remaining refrigerant is not emitted when retiring a system containing R-410A is 2.06 tonnes CO_2 equivalent per ton of cooling capacity. For a typical 2.5-Ton system retired in 2024, that equates to over $700 in net present value dollars.

In the survey, participants were asked if compensation would motivate their business to perform and document end-of-life recovery. Knowing it may involve submitting photographic evidence of the recovery process through a mobile app, they were asked how much compensation they would need to fulfill end-of-life recovery/reclamation documentation requirements on a residential split-system. Figure 4-5 shows that $114 was the average amount provided by the 18 respondents (46%) who agreed to specify a dollar amount. In contrast, eight (21%) did not provide an amount and would not do it unless required by law, and three said they would do it without compensation.

Figure 4-5. Compensation required for documenting EOL refrigerant recovery and reclamation?



One contractor suggested alternative incentive offerings that could have the potential to significantly improve EOL recovery rates and overall quality of work. He observed that lots of contractors buy their technicians the cheapest gauges they can find. They also struggle to spend a lot of time training technicians. Poor gauges and recovery machines invariably result in increased recovery times and less certainty about the quality of installed work. This contractor suggested providing contractors and technicians higher quality equipment that will be compatible with Visual Service and other more advanced service technology applications. Potentially a business would be given the higher quality equipment with the agreement that they would not be charged if they performed X-number of documented EOL recovery and reclamation in the first 6 months of receiving the equipment.

While the Visual Service app provides outstanding EOL recovery documentation capabilities, a minimum set of EOL documentation requirements is needed for this type of avoided GHG claim to be approves. The proposed set of requirements for claiming avoided EOL refrigerant GHG emissions when replacing an existing system with a new high efficiency system includes:

- A Photograph of the existing equipment and equipment nameplate with a geo tag
- A video of the existing equipment undergoing the recovery process
- A photo of the recovery cylinder on a scale after completion
- A photo of the pressure gauge showing the level of depressurization the contractor took the retired equipment's refrigerant lines to during the recovery process
- Bill of lading or comparable documentation proving recovered refrigerant was processed by EPA-licensed reclaimer

During the focus group, refrigerant policy SMEs from the EPA and the Yale Carbon Containment Lab shared concerns that the net benefits resulting from documented end-of-life recovery need to account for several regulatory and market effects. They shared an overarching market concern that reclaimed high-GWP refrigerant does not uniformly displace demand for virgin high-GWP refrigerant. The American Innovation and Manufacturing (AIM) Act subsection (h)[35] could dramatically expand demand for reclaimed gases and there may be a need to eventually sunset avoided GHG claims for documented recovery and reclamation depending on how the market reacts to that legislation. Other policy SMEs took a more practical approach reminding the group not to let perfect be the enemy of good and that end-of-life emissions are occurring at alarming rates every day. Those same policy SMEs suggested that with the right safeguards, this type of incentive or credit to key market actors could serve as a bridge to making recovery and reclamation standard practice in the workforce.

[35] Technology Transitions Final Rule, October 2023, https://www.federalregister.gov/documents/2023/10/24/2023-22529/phasedown-of-hydrofluorocarbons-restrictions-on-the-use-of-certain-hydrofluorocarbons-under-the

5 KEY FINDINGS AND RECOMMENDATIONS

This section presents key findings and recommendations followed by considerations for next steps.

The Low-GWP HVAC refrigerant transition is still in the early stages.

The transition away from high-GWP refrigerant in HVAC is still in the early stages. High-GWP HVAC systems remain standard practice in 2024 and the next stage of lower-GWP HVAC refrigerants, R-454B and HFC-32, still have 100-year GWP levels of 466 to 675 respectively. Flammability, toxicity, and design challenges are preventing an immediate transition to natural refrigerant HVAC equipment in the U.S.

The Low-GWP transition for stationary refrigeration is further along but limited by workforce knowledge.

Residential, retail, and industrial refrigeration systems using some forms of natural refrigerant are available for most applications. The biggest barrier preventing the widespread adoption of natural refrigerants in new stationary refrigeration equipment is a trained workforce. Existing stationary refrigeration infrastructure remains a high GHG liability because of high operational leak rates, extended measure lives, and challenges retrofitting or replacing systems with low-GWP refrigerant.

Natural refrigerants are the essential solution.

Research findings and refrigerant SMEs agree that natural refrigerants in stationary refrigeration and HVAC sectors provide the best long-term solution for the environment. The three most common natural refrigerant categories — hydrocarbons, CO_2, and ammonia — all have zero ozone-depleting properties, GWP levels below 4, no forever chemicals like PFAS, and are proven to have equal to superior performance capabilities when safety, design, and toxicity barriers are addressed.

Fund and promote natural refrigerants where and when they are permitted.

PAs of stationary refrigeration incentive programs should support refrigeration systems containing natural refrigerants over ones containing HFCs and HFOs wherever natural refrigerants are permitted. PAs of heat pump appliances should use the RACC-FSC to weigh the TSB achieved with natural refrigerant heat pump appliances over HFC alternatives. Regulators should encourage all U.S. and California codes and standards to **rapidly** harmonize with those in Europe and Asia.

Performing end-of-life refrigerant recovery and reclamation comes with a heavy burden.

HVAC workforce respondents report that the typical residential AC refrigerant recovery process can take 30 minutes to more than 2 hours. Recovering and transporting the refrigerant to EPA-licensed reclaimers requires tanks and equipment technicians struggle to find and pay dearly for. EPA laws prohibiting intentional emissions have existed for decades with virtually no enforcement. Interviewees who reported the prolonged lack of enforcement sent a clear message that it is ok to violate the rules. For many contractors, not following responsible recovery and disposal procedures is an embedded standard practice they follow to maintain profitability.

Over half of contractor survey respondents do not receive compensation when reclaiming refrigerant.

Surveys and interviews show only a small percentage of the workforce receives compensation for the refrigerant they recover and provide to reclaimers. Contractors who reported receiving payment only receive $3 per pound on average.

End-of-life refrigerant emission events from existing systems are enormous GHG liabilities and opportunities for GHG reduction and TSB attainment.

The RACC-FSC estimates the gross avoided cost resulting from end-of-life refrigerant emissions is over $300 per ton of residential AC cooling retired. This is a low-hanging/high-value fruit to reduce GHG emissions that will continue for decades until all current and future high-GWP equipment is replaced or retired.

Allow avoided emission credit to be claimed for documented end-of-life refrigerant recovery and reclamation.

California regulators should allow avoided end-of-life refrigerant emissions to be claimed when responsible end-of-life refrigerant recovery and reclamation is completed by a licensed EPA reclaimer. This act must be documented and performed when the retired system is replaced with a new high-efficiency system containing refrigerant. The Visual Service field application for smart phones and tablets is currently capable of documenting a refrigerant recovery process with excellent precision and authenticity. The Visual Service application or other means of documentation for this claim should include the following parameters to be deemed valid:

- Photographs of the existing equipment and the equipment nameplate with a geographic location tag
- Video of the existing equipment undergoing the recovery process
- Photo or video of the recovery cylinder on a scale after completion
- Photo or video showing the level of depressurization achieved at the end of the recovery process
- Bill of lading or comparable documentation proving recovered refrigerant was either reclaimed or destroyed by an EPA licensed reclaimer

Compensate contractors, technicians, and market actors who perform and document end-of-life refrigerant recovery/reclamation/disposal.

Web survey respondents reported they would willingly document end-of-life refrigerant recovery and reclamation on a standard size residential AC for $114. Performing this activity is worth $700 or more in gross avoided emission TSBs according to the RACC.

Provide extra incentives to distributors who assist with refrigerant recovery and reclamation.

Distributors who participate in ratepayer funded high-efficiency equipment incentive programs often serve as transfer stations for recovered refrigerant between contractors and reclaimers. Web survey participants and interviewees report they currently receive little to no refrigerant recovery equipment support or monetary compensation from distributors they work with. Implementers of upstream programs should provide incentives to distributors who support refrigerant recovery and reclamation. This support could include offering contractors and technicians discounts or free access to high-quality refrigerant recovery equipment and cylinders capable of quick and well documented end-of-life refrigerant recovery. It could also include support in documenting refrigerant recovery and reclamation with new installations.

Compensate EPA licensed reclaimers who directly support contractors in performing end-of-life refrigerant recovery, reclamation, and equipment disposal.

Multiple EPA-licensed reclaimers report they will buy back any refrigerant cylinder, even mixed cylinders. These reclaimers play a critical role in reclaiming high-GWP refrigerant and offsetting the demand for new virgin high-GWP refrigerant. PAs and program implementers should provide additional compensation to reclaimers who support contractors and technicians in performing and documenting end-of-life refrigerant recovery, reclamation, and disposal.

Near-term avoided end-of-life emission credits could help transition workforce standard practice.

SMEs suggested that the right documentation requirements and safeguards, incentives, or credits to key market actors could serve as a bridge to where routine end-of-life recovery and reclamation is standard practice in the workforce. SMEs also noted there are current and future state and federal regulatory requirements trying to standardize the practice that must not be overlooked.

Closely monitor and eventually sunset documented avoided end-of-life emission claims.

Bad actors are found in every market and are known to exploit loopholes for financial gain. PAs and third-party implementers who provide incentives to market actors for documented end-of-life recovery and reclamation must validate all claims and prohibit known bad actors from participating in ratepayer funded programs. Incentives should be sunset once CARB end-of-life emissions estimates show application-level recovery and reclamation rates exceed 50%.

Replace on burnout will lead to diminished performance, negative GHG impacts, and dissatisfied customers.

Far more often existing gas/AC systems are replaced when they break versus pre-emptive planning and replacement. Customers in immediate need of a new HVAC system will often prioritize getting a new system up and running quickly over other important factors. Assessing and correcting the existing HVAC ductwork, properly sizing a system to heating and cooling loads, and ensuring refrigerant line sets hold a vacuum will inevitably take more than one day. Performance will suffer and same day installed systems will inevitably be less reliable when urgency is prioritized over quality. Customers who opt for rushed heat pump electrification retrofits may regret embracing a newer technology that's more expensive and less reliable.

Target accelerated replacement heat pump retrofits and combine measures.

When heat pump retrofits are combined with additional energy efficiency measures and incentives everyone benefits. Fuel substitution retrofits that also include weatherization measures, airflow optimization, and emphasize proper refrigerant line installation and testing will yield the highest combination of lifecycle energy and GHG savings. SME interviews, contractor trainings, and referenced studies categorically warn about the performance and reliability issues that plague same day electrification retrofits. Targeted accelerated replacement projects will ensure customer decisions are not driven by desperation and will allow time to pursue the best combination of measures. Time is critical for combined measure projects to identify and secure all available incentives. Because accelerated replacement measures also claim savings using a one-third existing and two-thirds standard practice baseline, avoided operational refrigerant emissions from existing high-GWP systems will further add to total GHG benefits.

Existing modeling tools offer diverse strengths, but all come with limitations.

EnergyPlus, Pack Calculation Pro, Cycle D-HX, and Gnetron Properties each offer diverse strengths, yet none meet all industry requirements. Users need to judiciously select a tool based on their specific project needs and be aware of its limitations.

6 APPENDICES

6.1 Appendix A: Updates to RACC and FSC

The proposed improvements for the “Enhanced RACC” are summarized in Table 6-1.

Table 6-1. Proposed recommendations for the “Enhanced RACC”

No.	Worksheet and/or cell(s)	Recommendation	Comment, if any	Priority
1	Dashboard (Mod.), E123	Formula uses I74 instead of I7 for the annual inflation rate. DNV changed this to a named range, "Inflation_Rate".	This error caused the inflation rate to be zero	1
2	Dashboard (Mod.), C25 & ACC Inputs (Mod.), B6	Refer to "Measure Type" as "Measure Application Type" to avoid confusion with "Measure Impact Type".	Subtle error that may cause confusion for those more familiar with DEER-approved labels and definitions	1
3	General	Delete all named ranges that reference remote SharePoint site. Instead, list the location on the added "Sources (New)" worksheet.	Instead, provide a link to where the current avoided costs can be found	1
4	Refrigerant GWPs (Mod.)	Add natural refrigerants (ammonia, propane, isobutane, butane)	These refrigerants have low GWPs and should be available for consideration	1
5	Dashboard (Mod.)	Limit future year GWP avoided costs to reflect CARB baseline for each year.	Without considering the ever-decreasing GWP limits for refrigerants, the avoided costs of refrigerant replacements may be significantly overstated.	1
6	Refrigerant Leakage (Mod.), $K:$AO	Populate added columns (2022 to 2052) to indicate GWP baseline in future years according to CARB regulations.		1
7	See ACC Inputs (Mod.)	Consider adding more "Sector" options since it is not intuitive to think of heat pump clothes dryers as part of "Stationary Refrigeration". DNV added "Appliance" as a sector.	Ultimately, it may make sense to create another “Sector” for water-heating equipment.	2
8	ACC Inputs (Mod.)	Add weighted average of PA WACC rates for deemed measures that are offered statewide.	Given that deemed measures are often delivered across multiple service territories.	2
9	Dashboard (Mod.), D49	Enable ability to insert a site-specific annual refrigerant leakage rate. This value should be capped at the CARB average annual refrigerant leakage rate.	CARB recommends against allowing user to cite a leakage rate greater than the CARB average value.	2
10	Dashboard (Mod.), D53	Enable ability to insert a site-specific end-of-life refrigerant leakage rate. This value should be capped at the CARB average end-of-life refrigerant leakage rate.	CARB recommends against allowing user to cite a leakage rate greater than the CARB average value.	2
11	Refrigerant Leakage (Mod.), C1	Consider replacing CARB EUL list with CA eTRM's EUL list and, where there is none, clarify source of "Average lifetime (years)" on "Refrigerant Leakage" worksheet. (Alternative: Direct users to CAeTRM.com for approved DEER EULs.)	For deemed and custom energy-efficiency measures, DEER EUL values are typically used.	2
12	ACC Inputs (Mod.)	Explain why "GHG Value from Natural Gas ACC" is used.		2

No.	Worksheet and/or cell(s)	Recommendation	Comment, if any	Priority
13	Dashboard (Mod.) & ACC Inputs (Mod.)	Please provide example of add-on equipment that contains refrigerant. (DNV is unconvinced that MAT = AOE should be offered as an option and should not be bundled with Normal Replacement.)	The inclusion of Add-on Equipment may stem from a misunderstanding of the definition of this measure application type.	2
14	General	Assigned names to many of the variables that are used to calculate the refrigerant ACs.	This was done to make the Excel formulas easier to read and understand.	3
15	General	Create a separate "Sources" worksheet or column to allow reference worksheets--Refrigerant Leakage (Mod.) and Refrigerant Leakage (Mod.)--to be more consistently formatted.		3
16	Dashboard (Mod.)	Improve readability by showing $ in all fields that contain costs (format as currency).		3
17	Refrigerant GWPs (Mod.)	Populate added columns to indicate which refrigerants could be used for each sector category (see columns $I:$L).	This would allow further culling of the dropdown list of available refrigerants based upon the sector of the measure device(s).	3

Table 6-2 provides a list of recommended changes and revisions to the Deemed RACC v2.0.1 and the severity of the change.

Table 6-2. Recommendations on record for the Deemed RACC v2.0.1

No.	Worksheet and starting cell	Recommendation	Priority	Notes
1	Deemed Dashboard'!$CP:$CP	EOL NPV formula for standard case fails to multiply by ([@[Std % of device lifetime during measure years]]+[@[Std % of device lifetime retired early]]).	1	
2	Deemed Dashboard'!$CV:$CV	Refrigerant NPVCosts Net should subtract the measure case from the counterfactual case (rather than the other way around).	1	
3	'Predefined Device Types'!E18	This value seems too high compared to the per-unit weight in the "2022 ACC Refrigerant Calculator v2b updated.xlsx." It's expected that the room/window ACs would contain significantly less refrigerant per kBtu/h than typical split AC systems. Using "2022 ACC Refrigerant Calculator v2b updated.xlsx," a window/room/wall AC unit is estimated to contain an average of 1.54 lb of refrigerant; if we assume an average of 1 ton of cooling capacity, this calculator uses 3.20 lb. This results in just over a doubling of the refrigerant benefits per NormUnit. See screenshot shown in column F.	1	
4	Deemed Dashboard'!$DB:$DC	Swapped the logic since revising how column CV is calculated	2	(See 2.)
5	Deemed Dashboard'!$S:$CB	Use conditional formatting to highlight cells that override default lookups (a.k.a. user-specified). This was done within this workbook.	2	
6	Named Variable Corrupted:	=FILTER(TechGroup_NormUnit_Table[DropdownRefrigTech],#REF!#REF!="Msr")	2	

No.	Worksheet and starting cell	Recommendation	Priority	Notes
7	Dropdown_RefrigTechMsr	Consider adding 100-yr GWP column to TechGroup_NormUnit_Table to enhance user awareness of effects of various refrigerant types.	2	
8	'Predefined Device Types'!$D:$D	Surround formulae with =IFERROR(formula,"") to minimize confusion for users. This was done within this workbook.	2	
9	'Predefined Device Types'!Q12	Populate alternatives to common refrigerants (e.g., alternatives for R-410A in residential AC/HP units include R-32, R-454B, R-454C, R-452B, R-466A, etc.).	2	
10	'Refrig Type Research 2021'!B2	Formulae only exist in rows 40 through 49; the rest of the table rows in columns I and J are blank and do not populate with TGIndex and TGRows values. These were fixed within this workbook.	3	"Deemed Measure RACC Workbook v2.0.1.xlsx" file (stored at) has repaired this error.

The enhancements made to the DC RACC Prototype include the changes listed in Table 6-3.

Table 6-3. Enhancements in RACC-FuelSub Calculator v1.0

No.	Enhancement	Description
1	Create FuelSub worksheet	Insert a new worksheet that will contain the necessary input columns to perform the fuel substitution tests. This worksheet would only need to be populated for fuel substitution measures.
2	Import necessary reference tables	Import the tables from which the emissions rate by fuel and by year are drawn.
3	Perform calculations for and present Test Part 1 results	For every permutation within a given measure package, the lifecycle primary energy savings (in MMBtu per NormUnit) will be calculated and the Test Part 1 outcome clearly presented.
5	Perform calculations for and present Test Part 2 results	For every permutation within a given measure package, the lifecycle emissions avoided for each emissions source (electric, natural gas, and refrigerant) (in metric tCO2 per NormUnit) will be added together and the Test Part 2 outcome clearly presented. The refrigerant emissions calculations will be drawn from the RACC component/worksheet of the workbook.
6	Provide a summary of the fuel substitution test results in a pivot table	This enhancement will provide a color-coded building type by climate zone grid to present the results of fuel substitution tests in an easy to digest format. It will also use DEER building weights to estimate the weighted average of the climate-zone specific avoided emissions using the DEER-approved building weights.
7	Add flag to indicate whether existing equipment refrigerant reclamation documentation is to be provided	Since California has an opportunity to avoid the end-of-life emissions of existing equipment that contains refrigerants through each relevant measure implementation, this flag can be used to enable the RACC-FuelSub Calculator to account for these avoided refrigerant emissions in both the RACC and the FuelSub components.
8	Add field(s) to FuelSub component to accommodate blended baselines	When a fuel substitution measure offers space cooling where none was previously installed, a field(s) will be added that contains a scalar value that represents the proportion of installations where—without the program—it is presumed that the participant would have installed equipment that provided space cooling.[36]
9	Update GWP limits table per U.S. EPA update to rules	On 2023-10-06, the EPA finalized updates to the rules for the phasedown of hydrofluorocarbons under Subsection (i) of the AIM Act of 2020.

[36] As a placeholder for the residential scalar value, DNV has proposed the use of the 2019 RASS to inform these by building type and climate zone until a better source can be identified.

Following the webinar and stakeholder review and assessments, DNV addressed the feedback and made all updates deemed appropriate by the CPUC to the final version. A summary of the updates can be found in Table 6-4.

Table 6-4. Final enhancements to finalize the RACC-FSC v3.0

No.	Enhancement	Description
1	Improving workbook performance	Improved workbook calculation time by reducing named ranges, converting the RACC Excel table to normal range, adding a flag to turn off conditional formatting, and reduced number of records in the RACC worksheet from 100 to 25 rows.
2	Create additional DEER database table link to reference tables	Added key parameters to the DEER database to allow for easy update of the following parameters, ACC values, a list of refrigerants with associated GWPs, CARB refrigerant leakage rates, and CARB and EPA GWP limits. Added ability to compare DEER tables loaded into RACC_FSC with those in the actual DEER database to see whether any updates have occurred since the workbook was submitted for measure package review.
3	Eliminate EOL emissions pro-rating, unless multiple Std equipment needs to be installed.	Eliminated the pro-rating of EOL emissions for existing and standard practice equipment, except in cases where the standard practice equipment needs to be installed multiple times to last until the end of the measure life. In such cases, the second EOL leakage event is pro-rated based on the extent to which the equipment coincides with the measure life.
4	Extend functionality for longer EULs	Extended functionality to accommodate measure lives that exceed 20 years (but are capped at 30 years).

6.2 Appendix B: Web survey

Web Survey Questions:

1. Which sectors do you service? Please select all that apply.
    a. Residential HVAC
    b. Commercial HVAC
    c. Refrigeration
    d. None of these [Skip to Q19/End]
    e. Other

2. How often do technicians at your company recover the refrigerant remaining in systems you retire and replace?
    a. Every time
    b. Most of the time
    c. When it contains more than 15 lbs. of refrigerant
    d. Never [skip to Q9]
    e. Not applicable, as we only work on new construction projects
    f. Other, please specify:
    g. Don’t know
    h. Prefer not to answer

3. Approximately how long, on average, do technicians at your company spend recovering the remaining refrigerant found in a typical 2.5-ton split-system AC?
    a. Less than thirty minutes
    b. About an hour
    c. About two hours
    d. Over two and a half hours
    e. We do not work on systems of that type/size
    f. Don’t know
    g. Prefer not to answer
    h. Other, please specify:

4. When HVAC technicians at your company perform refrigerant recovery, to what pressure do they pull to?
    a. Atmospheric pressure
    b. Negative 5 inches of mercury
    c. Negative 10 inches of mercury or less
    d. Don’t know
    e. Prefer not to answer
    f. Other, please specify:

5. Where do HVAC technicians at your company typically take or store the recovered refrigerant? Please allocate the percentage of recovered refrigerant to each option:
    Total percentage must equal 100%
    a. Store it for future use ___%
    b. Return to local supply house ___%
    c. Licensed reclaimer collects recovery cylinders periodically ___%
    d. Pull refrigerant into condenser and take to recycling center/scrap yard ___%
    e. Other ___%
    f. Don’t know ___%

6. In the past two years, how often has your company received payment for the recovered refrigerant?
    a. Often
    b. Sometimes
    c. Rarely
    d. Never [Skip to Q9]
    e. Don’t know [Skip to Q9]
    f. Prefer not to answer [Skip to Q9]

7. [If Q6=A, B, C then ask otherwise skip] What is the typical value you receive for returned R-410A in pounds?
   a. Less than $1 per pound
   b. Between $1 and $4 a pound
   c. Between $4 and $6 a pound
   d. Between $6 and $10 a pound
   e. Over $10 a pound
   f. Other, please specify:
   g. Don’t know
   h. Prefer not to answer

8. [If Q6= a, b, or c then ask otherwise skip] What is the average waiting period between returning the cylinder and receiving payment?
   a. Less than two days
   b. Less than one week
   c. 2-4 weeks
   d. A month or more
   e. Variable/inconsistent
   f. Don’t know
   g. Prefer not to answer
   h. Other, please specify:

9. To increase end-of-life (EOL) recovery and reclamation, we are seeking feedback to determine whether compensation would motivate your business to perform and document end-of-life recovery. This may involve submitting photographic evidence through a mobile app of the recovery process. How much compensation would technicians need to fulfill these end-of-life recovery/reclamation documentation requirements on a residential split-system?
   a. I will specify the dollar amount
   b. No amount, we would not do this unless required by law
   c. No amount, we would do this without compensation.
   d. Don’t know

10. [Show if Q9= a1= How much compensation would technicians need to fulfill these end-of-life recovery/reclamation documentation requirements on a residential split-system?
   a. Dollar amount: ___

11. Has anyone in your company received training for handling and use of mildly flammable A2L refrigerants?
   a. Yes
   b. No
   c. Don’t know
   d. Prefer not to answer

12. [Ask if Q10 = yes] Was the training specific to R-32, R-454B, or both?
   a. R-32 refrigerant
   b. R-454B refrigerant
   c. Both R-32 and R-454B refrigerant
   d. Don’t know
   e. Prefer not to answer

13. [Ask if Q10 = yes] How many hours of training has been provided to your company for the mildly flammable A2L refrigerants?

   [Text box]

14. Do you know another California based HVAC-R contractor(s) that would be willing to participate in this survey? If yes, please provide their name and email address below:
    a. Yes, I will provide a name(s) and email(s)
    b. No
15. [Show if Q14=a] Please provide names and emails of other HVAC-R contactors what may be interested in this survey.

16. Is there anything else you would like to share on the topic of end-of-life (EOL) refrigerant recovery and reclamation. If yes, please describe below.
    [Text box]

6.3 Appendix C: Focus group discussion

CPUC Refrigerant Recovery and Emissions Reduction Focus Group, hosted by DNV on March 26, 2024.

Focus Group Objectives

- Reduce lifecycle refrigerant emissions
- Improve end-of-life recovery and reclamation
- Provide a forum for diverse stakeholders to discuss and debate potential strategies
- Define and document potential end-of-life recovery/reclamation claim requirements
- Document and report on discussion

Attendance

The 23 attendees included four CA licensed HVAC-R contractors, representatives from the EPA, CARB, the Carbon Containment Lab, the Environmental Investigation Agency (EIA Global), two EPA licensed refrigerant reclaimers, two major HVAC distributors, and CPUC study leads.

Discussion Notes

HVAC Equipment Retirement

Question 1: How long do you spend recovering refrigerant from an existing system being replaced?

- **Contractor 1:** 2 to 3 hours per system, using standard recovery tank set (equipment). Systems include residential 2 to 5 ton split systems, occasional packaged unit.
- **Contractor 2:** 1 day for large commercial/retail refrigeration systems.
- **Contractor 3:** A couple of hours to reclaim the refrigerant. Type of systems include R-22/R-410A, residential – 1.5 to 5 ton systems.

Question 2: What type of equipment do you use?

- **Contractor 2:** Appion recovery machine typically. Recovery equipment depends on size of system (and time to recover).

Question 3: Where do you take or store the recovery cylinder?

- **Contractor 1:** Storage facility, no handy place to recover refrigerant, in rural area.
- **Contractor 2:** Torpedo storage tanks, for taking or storing refrigerant.
- **Contractor 3:** Store in local tanks.

Question 4: How much do you typically receive per/pound of R-22 and R-410A?

- **Contractor 1:** Normally get next to nothing for the refrigerant.
- **Contractor 2:** Typically, negative per pound – refrigerant is wrecked.
- **Contractor 3:** Not getting paid anything typically, sometimes distributor charges for refrigerant, cents on the dollar for contaminated refrigerant.
- **Contractor 3:** Most contractors they know do not reclaim – condensers with refrigerant end of at scrap yard.

Additional comments

- **Contractor 2:** Why do contractors not reclaim? – makes you less competitive as a contractor, takes time, is painful, sometimes I feel like a sucker doing it, but it's the right thing to do.
- **Reclaimer/distributor 1:** It's surprising to hear that contractors don't get any value from the reclaimed refrigerant.

- **Reclaimer/distributor 1:** At Hudson they have a reclaim plant in Ontario, CA, they provide cylinders and pay for reclaimed refrigerant.
- **Reclaimer/distributor 2:** Nightmare myth, that mixed refrigerant cylinders can't be reclaimed.
- **Reclaimer/distributor 3:** There is a lot of money being paid by reclaimers for refrigerants, helping with trainings to improve recovery and reduce recovery time.

Visual Service Demonstration

The Institute of Heating and Air Conditioning Industries (IHACI), a nonprofit trade association of contractors, manufacturers, distributors, utilities, and related businesses actively engaged in the heating, ventilation, air conditioning, refrigeration, and sheet metal industries, developed the Visual Service tool. Visual Service is a video-enabled field service application for HVAC contractors. The software allows a remote master technician to supervise and assist the work of multiple field technicians in real-time.

Bob Wiseman (President, IHACI) demonstrated how contractors could use Visual Service to aid in refrigerant recovery. During the demonstration, Bob showed how Visual Service pared with measurement tools could be used to document and record the weight of a refrigerant cylinder during the recovery process.

Some key points discussed during demonstration:

- IHACI – notices a lack of tools available for contractors to provide quality installation and servicing.
- Refrigerant reclamation – is an important part of the system that's missing.
- Currently, no way to bring refrigerant from cradle to grave.

EOL Recovery/Reclaim Documentation

Tentative EOL documentation requirements:

1. Photograph of the existing equipment and equipment nameplate
2. Photograph of the existing equipment undergoing the recovery process
3. Photo of cylinder on a scale after completion*
4. Bill of lading or comparable documentation proving recovered refrigerant was processed by EPA licensed reclaimer.

Discussion from contractors:

- **Contractor 1:** "for typical residential size equipment" its realistically a 2-3 hour process to get the refrigerant out. Have to pull the top off and heat up reservoir to get the refrigerant out.
- **Contractor 4:** For us, the average time in a residential system is 45 minutes, to recover refrigerant down to atmospheric and they are done.
- **Contractor 4:** 20 minutes or more once evacuation machine starts, additional time is for prep for evacuation.
- **Contractor 2:** How perfect a recovery do you want, recovery weight is always more than nameplate (because of oil mixed in), if tank already has a bunch of refrigerant/hard to get more refrigerant in there. We do the best we can, we don't have ideal conditions, never have ideal conditions, tanks are never empty.
- **Contractor 3:** 20 min to 3 hours "recovery time".
- **Contractor 3:** "based-on" 30-years of experience, "these steps" adds to the time "of recovery". It's like a city permit, a lot of companies don't pull permits because it adds to the time. If state or Fed says we'll reward you, then you have to pull permits.
- **Contractor 3:** Using something like visual service, that is documenting the info needed to give to the State. If they ("State, regulators, etc."?) say they want to see it, contractors would do it.

- **Contractor 3:** "Contractors would recover" If they had a program (like Visual Service), without additional added steps to make the process seamless.
- **Contractor 4:** All these steps are doable, but photo of cylinder on a scale is easily faked.
- **Contractor 1:** There needs to be a target reclaim level (pressure/vacuum level).
- **Contractor 4:** A lot of recovery machines will shut off at atmospheric pressure.
- **Contractor 1:** $100/lb (of refrigerant) contractors may take action.

Avoided GHG Claim Viability

- **Policy/regulator 1:** One thing that would be helpful, on CARB perspective, is there kind of a stick approach that could be added to prevent loopholes. What else could be added. What would be a reasonable requirement.
- **Policy/regulator 1:** It seems like the app (VS) is a great way to track that, make sure it is tried and tested before implemented.
- **Policy/regulator 2:** Some think reclamation can be claimed as an emissions reduction. Reclaimed gas goes back into the market and eventually leaks to the atmosphere. A deferred emission.
- **Policy/regulator 2:** Counter argument – displaces virgin refrigerant demand. When markets are in phase-down, and demand for phased down refrigerants is high. Recovered refrigerant will serve increased phase-down refrigerant demand.
- **Policy/regulator 3:** Similar to carbon offset methodologies, were working with changing regulatory landscape with emissions. How do you justify claiming/giving credits. Concerns of double counting emissions claims in the future if the chemical continues to be produced.
- **Policy/regulator 4:** There is an issue of claiming a permanent emissions reduction from reclaimed refrigerant gas.
- **Policy/regulator 4:** Emissions are occurring in reality, and not being addressed by policies and regulations, applications like Visual Services could help.
- **Policy/regulator 4:** Make sure any incentives have the right balance, too much – taking gas out of people's systems when they don't need to and selling more refrigerant gas to them. Perverse incentive to pull more refrigerant gas then needed.
- **Policy/regulator 4:** CA recommendation – some of these issues of carbon accounting, can be paid not for emissions, but for system benefit.
- **Policy/regulator 4:** Could see a program by CPUC as a bridge.
- **Reclaimer/distributor 1:** real world scenario – credits for HFC refrigerants – we do belief that while every pound reclaimed is a pound that does not need to be manufactured.
- **Reclaimer/distributor 1:** Always looking for ways people could take advantage of programs like this.
- **Reclaimer/distributor 4:** I think for us, recovery is always the right answer at EOL. Are we trying to be perfect and be great (to cut the time to recover). I hear the concerns about double counting.
- **Reclaimer/distributor 2:** One of the things to cycle back to, energy efficiency – 2018 if the people at CARB remember FRIP, equipment for disadvantaged communities. When you look at energy efficiency, don't forget to get the gas. Need to hand that gas to a certified reclaimer before you get the energy efficiency incentives.
- **Reclaimer/distributor 2:** Carrot – start with the energy efficiency program – pot of money that creates incentive.
- **Reclaimer/distributor 2:** Creates opportunities in disadvantaged communities.
- **Reclaimer/distributor 2:** Stick – is that if you vent that refrigerant gas you don't get the carrot.
- **Contractor 1:** If that's the path contractors are taking (take whole unit with refrigerant in to recycling center/scrap-yard), are we incentivizing the recycling center to recover.

Other Strategies

- **Policy/regulator 2:** Wanted to make sure we don't lose this idea. When contractors hand over cylinder, it is a net payment, not benefit.
- **Reclaimer/distributor 4:** There is disconnect between what reclaimers are paying and what contractors are receiving.
- **Contractor 4:** There is a big difference between recyclers and what they pay.
- **Reclaimer/distributor 3:** Possibly what we are starting to see is that as the Aim Act starts to take hold, Recylers/Reclaimers are ramping up, need to figure out that "middle man", what's happening (related to the disconnect from previous comment).

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6.5 Appendix [X]: Comment matrix (final report only)

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