DNV·GL

Proposer Defined Study - A Roadmap for Accelerating the Adoption of Low-Global Warming Potential HVAC Refrigerants

EM&V Group A

California Public Utilities Commission

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SAFER, SMARTER, GREENER

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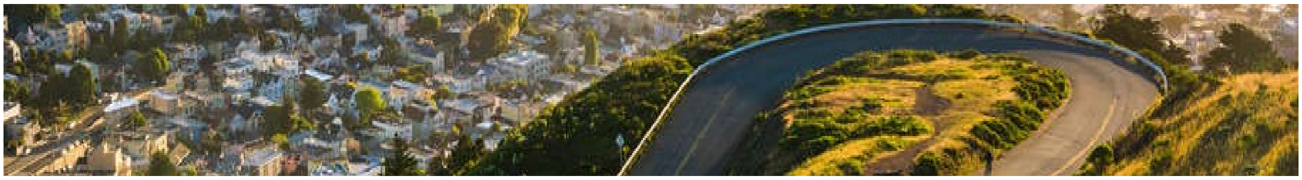

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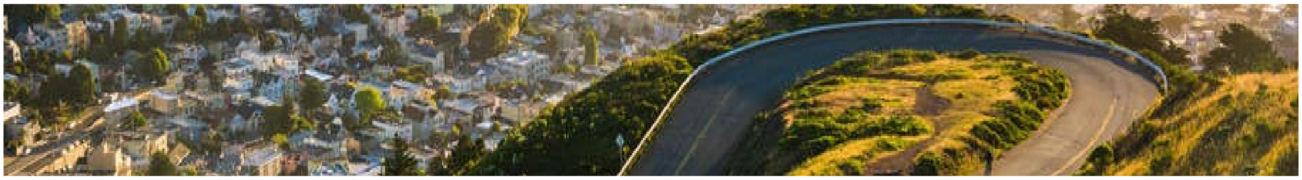

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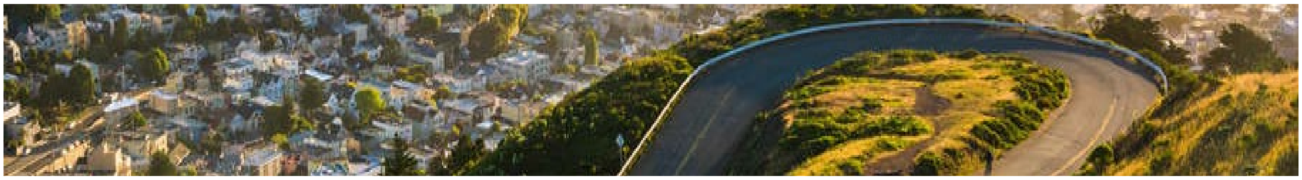

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1 EXECUTIVE SUMMARY

The focus of this study comes from California legislation directing the California Public Utilities Commission (CPUC) to develop a strategy for including low-global warming potential (GWP) HVAC refrigerants in incentivized energy-efficiency programs. The CPUC asked DNV GL to conduct forward-looking research on refrigerant markets and technologies for heating, ventilation, and air conditioning (HVAC) systems. This research study applies to both residential and commercial HVAC systems using refrigerants but excludes industrial-scale refrigeration. This research supports the CPUC and the following program administrators (PAs): San Diego Gas and Electric Company (SDG&E), Southern California Edison (SCE), Southern California Gas Company (SCG), Pacific Gas and Electric Company (PG&E), and Marin Clean Energy (MCE).

1.1 Background

All HVAC systems rely on chemicals known as refrigerants. Refrigerants are gases that allow for heat to be drawn from one place and transferred to another. Refrigerants are essential for HVAC systems, freezers in grocery stores, and refrigerators.[1] Over the last hundred-plus years, refrigerants used in HVAC equipment have evolved to address toxic impacts, ozone depletion, and now global warming. As California policies seek to shift from natural gas furnaces to heat pumps to take advantage of clean electricity, the need for refrigerants will grow.

Central to this study is the global warming potential (GWP) of refrigerants. GWP is a widely recognized method for measuring the harmful impact that refrigerants can have on our planet’s health. The GWP of a gas is measured by the heat trapping impacts (referred to as the greenhouse effect) on the atmosphere of one metric ton of the gas relative to the heat trapping impacts of one metric ton of carbon dioxide (CO2). The most common refrigerant class used in HVAC equipment today is hydrofluorocarbons (HFCs). HFCs are refrigerants that are not harmful to the ozone layer, however, their impact on global warming is very large.

Unfortunately, much of the refrigerant found in HVAC systems leak or are emitted into the atmosphere. Almost all refrigerants found in HVAC equipment today have high-GWP levels, which is why they are often called greenhouse gases (GHGs). The two most common refrigerants installed in new HVAC equipment today are R-410a and R-134a. Table 1-1 summarizes refrigerants that are commonly available and their GWP, flammability, and toxicity. For example, R-410a has a 100-year GWP of 2,088, meaning over a 100-year period, these HFCs will trap over 2,000 times more heat than CO2. All refrigerants will be referenced by their refrigerant name in this table throughout the executive summary and report.

Table 1-1. Current commonly available refrigerants and important properties including GWP

GWP Rating	Refrigerant Name	Refrigerant Type	100-year GWP	Flammability/Toxicity
High GWP	R-410a	Hydrofluorocarbon (HFC) Blend	2,088	No Flame Propagation/Low-Toxicity

[1] Refrigeration refers to the process of cooling a specific space or thing to a temperature below room temperature. Refrigeration equipment includes everything from household refrigerators and freezers to cold food display cases in grocery stores and industrial process refrigeration.

GWP Rating	Refrigerant Name	Refrigerant Type	100-year GWP	Flammability/Toxicity
High GWP	R-134a	Hydrofluorocarbon (HFC) Blend	1,430	No Flame Propagation/Low-Toxicity
Low-GWP	R-32	Hydrofluorocarbon (HFC)	675	Lower-Flammability/Low-Toxicity
Low-GWP	R-452B (DR-55)	Hydrofluorocarbon (HFC) Blend	698	Lower-Flammability/Low-Toxicity
Low-GWP	R-454B	Hydrofluorocarbon (HFC) Blend	466	Lower-Flammability/Low-Toxicity
Low-GWP	R-466A (Solstice® N41)	Hydrofluorocarbon (HFC) Blend	733	No Flame Propagation/Low-Toxicity
Ultra-Low-GWP	R-290 (propane)	Hydrocarbon/Natural Refrigerant	3	High flammability/Low-Toxicity
Ultra-Low-GWP	R-744 (CO_2)	Natural Refrigerant	1	No Flame Propagation/Low-Toxicity
Ultra-Low-GWP	R-717 (Ammonia)	Natural Refrigerant	0	Low Flammability/High Toxicity
Ultra-Low-GWP	HFO-1234ze (E)	Hydrofluoro-olefin (HFO)	1	Lower-Flammability/Low-Toxicity
Ultra-Low-GWP	HFO-1234yf	Hydrofluoro-olefin (HFO)	1	No Flame Propagation/Low-Toxicity

The use of HVAC equipment is expanding rapidly. Population growth and the increasing need for cooling caused by climate change are spiking the demand for cooling. In addition, increasing electrification efforts requires many more systems with refrigerants for space heating.

In California, GHG emissions from refrigerants in HVAC equipment is the fastest growing global warming pollutant.[2] Latest estimates by the California Air Resources Board (CARB) show that in 2019, California HVAC equipment accounted for approximately 11-million pounds of refrigerant emissions. That is equivalent to the average annual emissions from 1.5 million passenger cars.[3]

To address the growing climate threat from refrigerants, California State Senate Bill (SB) 1383 (Lara, 2016) calls for the emissions of HFCs to be reduced so that by 2030, California's HFC emissions will be 40% of what they were in 2013 based on GWP impact. California SB 1013 (Lara, 2018) was passed shortly after SB 1383 to help define the rules and create an incentive program to reduce HFC use needed to reach the 2030 HFC emissions reduction goal. When SB 1383 was written, it appeared the United States was also planning to phase down the use of HFCs.

After the passage of SB 1383, a 2017 US District Court ruling limited the US Environmental Protection Agency's (EPA) ability to regulate refrigerants based on GWP. The ruling effectively stalled national efforts to transition away from high-GWP refrigerants. Despite this, California is pursuing both the goals set by the Montreal Protocol[4] and moving forward with a state-led phasedown of HFCs. This

[2] California Air Resources Board, Technical Working Group Meeting, Proposed GWP Limit for New Stationary Air Conditioning Equipment, August 6, 2020.

[3] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[4] In October 2016, parties of the Montreal Protocol met in Kigali, Rwanda, and drafted an amendment to phase down the use of HFCs, now known as the Kigali Amendment. The United States contributed to the research and proposals that lead to the agreement, which was adopted by 197 countries at the time of signing. It became an official amendment in 2017 and entered into force in 2019. The prescribed phasedown of HFCs and other impacts of the Kigali Amendment are estimated to reduce potential global warming impacts by up to 0.5°C by 2100.

study provides the CPUC and the PAs with a roadmap for including low-GWP HVAC refrigerants in incentivized energy-efficiency programs.

1.1.1 Project objectives

The primary objectives of this research study were to:

- Provide the CPUC and PAs a roadmap for accelerating the adoption of low-GWP HVAC refrigerants.
- Identify emerging HVAC refrigerant options that meet near-term and long-term California emissions goals.
- Identify barriers and challenges preventing the adoption of low-GWP HVAC refrigerants and provide recommendations on how best to overcome those barriers.
- Analyze and report on the potential impacts low-GWP HVAC refrigerants will have on energy performance and long-term GHG emissions.
- Provide recommendations on how to improve the CPUCs recently developed tool used to calculate lifetime carbon dioxide equivalent emissions impacts from refrigerants.

1.1.2 Approach

The study sought to collect and examine the most relevant information and expertise currently available about HVAC refrigerants.

The objectives for this research study were pursued through the following tasks:

- Conducting secondary research using existing data
- Conducting interviews with 21 known HVAC refrigerant-related experts
- Administering a web survey with feedback from 55 identified subject matter experts in HVAC refrigerants
- Analysis of alternative refrigerants' lifetime GWP and theoretical energy efficiency and capacity performance
- Coordination of all research and analysis activities to generate recommendations to improve the CPUC's Refrigerant Avoided Cost Calculator (ACC) tool for refrigerants
- Developing a prototype lifetime GWP impact calculator tool as a means of improving the existing CPUC's Refrigerant ACC using data gathered through this research study

1.2 Summary of key findings

The key findings and corresponding recommendations are presented in this section.

Key findings: Highlight interesting trends and findings from the body of the report. Key findings are noted with the key symbol. Not all key findings have recommendations.

Recommendations: These are provided directly in response to key findings and their implications. Recommendations are noted with the gear symbol.

Flammability is the problem.

The single biggest current barrier of adopting low-GWP refrigerants is the issue of flammability.

Virtually all low-GWP alternative refrigerants with cooling capacity and energy-efficiency performance characteristics similar to refrigerants currently in use are mild to highly flammable. All the HVAC experts we spoke with emphasized the fact that they are not currently permitted to install mildly flammable refrigerants in most common HVAC equipment today. Lab testing performed by one of the experts we interviewed shows mildly-flammable refrigerants being considered for near-term adoption are only flammable in conditions where high rates of leakage occur in a confined space.[5] Mechanical, fire, and building codes are currently being modified to allow for mildly flammable refrigerants given appropriate measures to minimize risk are in place.

Refrigerant transitions take time.

Our secondary research and interviews with HVAC-refrigerant experts revealed an extensive list of national organizations, state and local codes, and other authorities required to approve the use of new refrigerants in the United States. Any increase in flammability or change in toxicity for a refrigerant extends the length of time for its approval. The United States is a safety-focused society relative to some other industrialized countries. For instance, Europe and Asia are already moving quickly ahead in using mildly flammable refrigerants and to some degree natural refrigerants in HVAC equipment. The proposed HFC reduction timeline and the recent passing of the American Innovation and Manufacturing Act of 2020[6] ensures the transition will happen in California and the rest of the United States eventually.

Figure 1-1. Web survey: Minimum lead time needed to transition to <750 GWP refrigerants following code finalization

*The distribution presented above does not include the 19% of "don't know" respondents.

The refrigerant evolution continues.

The current transition away from high-GWP HFCs towards HFCs with GWP levels <750 is rife with challenges and the likely outcome is still pending. All 10 of the HVAC manufacturers and contractors we spoke with agree the preferred near-term refrigerant candidates are all mildly flammable HFCs. There is one technically viable refrigerant, R-466a (Solstice® N41), that is not flammable under normal conditions and has a GWP just below 750. On the surface, these characteristics would make R-466a the preferred option, but it has drawbacks. In terms of performance, it falls short of the other leading <750 GWP candidates, and it's relatively unproven. It also contains a molecule not traditionally used in refrigeration that is concerning because of its slight ozone-depleting potential. Six experts we spoke with at length about R-466a see it as a step in the wrong direction. All experts we talked to said manufacturers are transitioning to mildly flammable refrigerants to meet the low-GWP phasedown requirements.

The Refrigerant Avoided Cost Calculator is a valuable tool.

The CPUC Refrigerant ACC is a relatively new tool that holds a lot of value. The tool provides users a

[5] https://www.osti.gov/servlets/purl/1465066

[6] https://www.congress.gov/bill/116th-congress/senate-bill/2754/text

simple yet informative option for calculating refrigerant carbon-equivalent emission impacts. The tool's approach is based on a well vetted methodology by the Intergovernmental Panel on Climate Changes (IPCC). Using the IPCC methodology and leveraging CARB emissions estimates, the tool predicts refrigerant impact in a dollar equivalent value. Our review of the tool and based on the findings of this research study, the outputs of the tool are very noteworthy but can be further improved. For example, the current CPUC Refrigerant ACC tool does not consider the energy performance or refrigerant charge required of alternative refrigerants.

Explore DNV GL's prototype lifetime GWP calculator.

The CPUC should consider using the DNV GL prototype lifetime GWP calculator to update the current CPUC Refrigerant ACC. The research findings of this study provide the data needed to expand the outputs of the current CPUC Refrigerant ACC tool. Using our evaluation approach, we defined variables impacting equipment energy operation and refrigerant emissions. Using the sourced variables, we developed a prototype add-on tool that calculates energy impacts from alternative refrigerants as well as required charge-level impacts on emissions. The framework of the tool can be extended to measures beyond HVAC refrigerants.

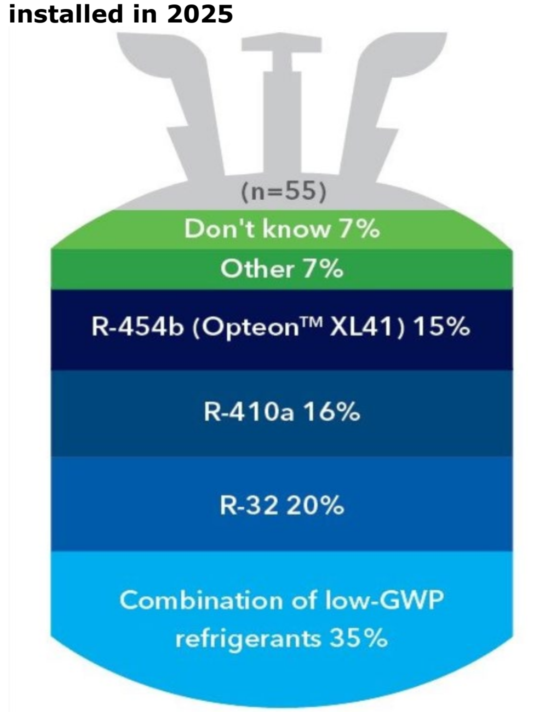
Accurate outputs rely on accurate inputs.

Many of the estimates both the CPUC and our add-on tools produce are based on CARB emission inventories. Our discussion with CARB determined annual inventories take a year or more to summarize and become available for use. It is important to incorporate the latest findings when estimating future impacts. Some operational leakage rates found in current estimates track higher than our outside research indicates. End-of-life emissions could also be tracked better for the purposes of this tool. The outputs of both tools are significant and noteworthy. Minimizing the uncertainties in the tool are that much more important given the significance of the findings.

Mildly flammable HFCs are the near-term solution.

Currently, HVAC contractors are not permitted to install mildly flammable refrigerants in most common HVAC equipment today. The leading mildly flammable HFC candidates for the most common residential and commercial HVAC applications include R-32, R-454B, and R-452B. However, state fire marshal delays now indicate building and fire codes most likely won't be updated to allow these mildly flammable refrigerants for use in most California HVAC equipment until January 1, 2024. Web survey responses indicate the HVAC supply chain will likely take around two years from when building and fire code requirements are finalized to have a representative selection of <750 GWP HVAC refrigerant equipment offerings.

Figure 1-2. Web survey: Anticipated most common HVAC refrigerant installed in 2025



Promote mildly flammable HFCs in the near-term.

PAs should begin including a requirement for the use of mildly flammable HFCs into their HVAC incentive programs where these refrigerants are currently permitted. The mildly flammable HFC refrigerants are currently allowed in portable, window and smaller air-conditioners as well as in some larger commercial settings. As more mildly flammable HFCs become viable with updated building codes, the PAs should provide incentives for those options as well.

The goalposts are still moving.

CARB's latest proposed amendment to regulations on HFCs will delay the transition timing from the current 2023 <750 GWP HFC reduction timeline, to 2025.[7] A public hearing was held on December 10, 2020, with the board voting in favor of adopting the amendment, but the bill is still undergoing approval and likely won't receive final approval until October 2021. HVAC experts we spoke with point to updates in the next cycle of California Building and Fire Codes that will include revised policies and guidelines to allow for the use of mildly flammable HFC refrigerants in most major HVAC equipment. Until those updates are released, the goalposts are not set, and the timing of the transition remains uncertain. Once the building and fire codes get finalized, most likely not until the interim code update is published in January 2024, the policy and timing of California's transition, will be more certain.

Closely follow CARB, California building and fire code updates.

The CPUC and PAs should follow the timing of the building and fire code updates. As soon as the building and fire codes allow mildly-flammable HFCs, the PAs should promote these HFCs via their HVAC incentive programs. In the near-term, the PAs should provide incentives for the use of reclaimed high-GWP refrigerants in HVAC equipment.

Natural refrigerants are the long-term solution.

The refrigerant evolution will not stop with mildly flammable HFCs. The HFC reduction goals mean that in the next 10-20 years, HVAC equipment will need to push past <750 GWP HFCs towards refrigerants with GWP levels below 150. Findings from literature reviews and interviews with HVAC experts all indicate the long-term goal is refrigerants with GWP levels close to 1. Natural refrigerants like pure CO2, R-290 (propane), and ammonia have GWP levels below 10, but also require significant HVAC system redesigns before they can be made widely available.

Promote natural refrigerants.

The CPUC should recommend the PAs promote the use of natural refrigerants wherever code permits. Incentives should be directed towards accelerating the use of natural HVAC refrigerants over HFCs and HFOs. We recommend the PAs promote natural refrigerants either through the emerging technology program, under custom programs, or any other HVAC program.

Significant barriers limit refrigerant-only retrofits.

In all 12 interviews with HVAC experts in which we discussed refrigerant only change-outs, the interviewees reported extensive challenges to changing refrigerants in most existing HVAC equipment. A refrigerant-only changeout would include simply replacing the existing refrigerant with a low-GWP alternative refrigerant with only minimal alterations to the equipment. The list of barriers includes various code violations including mechanical, fire and building codes, the need for partial system

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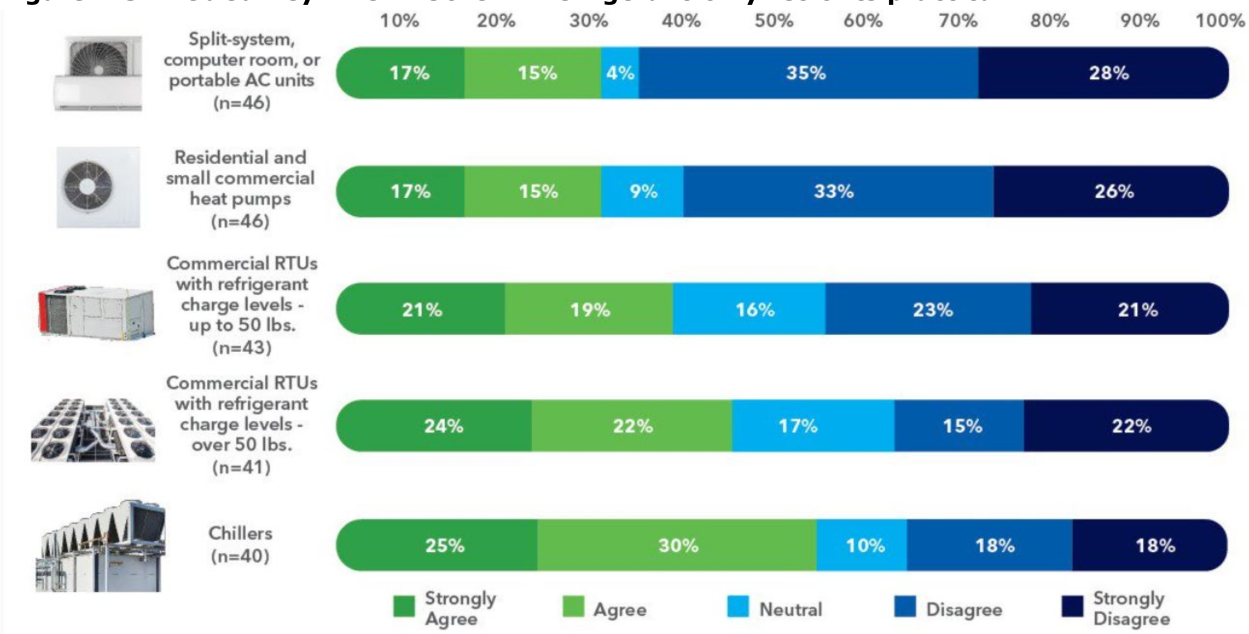
7 https://ww2.arb.ca.gov/rulemaking/2020/hfc2020

redesign once codes permit mildly flammable refrigerants, authorization from the manufacturer, authorization from the owner, and the need for the action to be cost-effective. Web-survey responses show increased feasibility for refrigerant-only retrofits on commercial HVAC equipment and chillers.

Figure 1-3. Web survey: Are <750-GWP refrigerant-only retrofits practical?



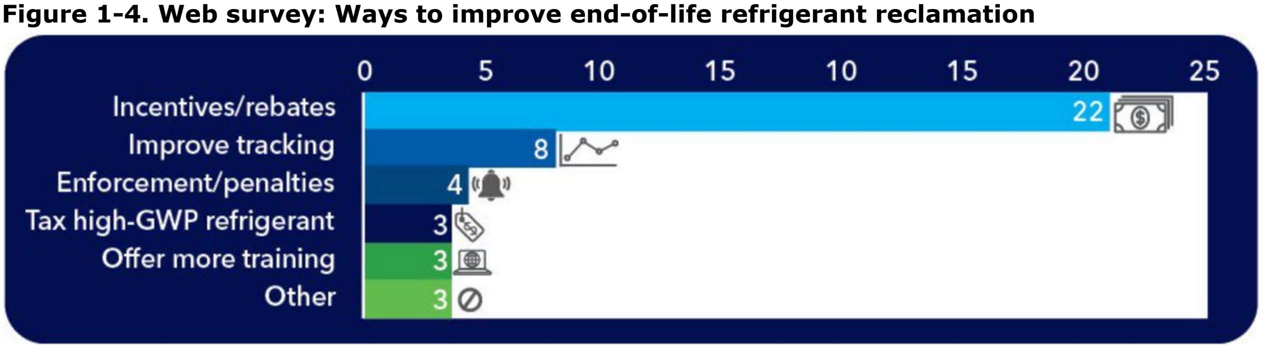
Direct drop-in of the refrigerants only viable for larger HVAC equipment.

PAs should only consider the option of refrigerant-only changeouts in larger HVAC equipment like chillers and commercial roof-top units. The cost of replacing larger existing HVAC equipment is substantially higher than the cost and challenges of a refrigerant only change-out.

End-of-life emissions are alarming.

Our research on CARB and EPA emission estimates show emissions either from intentional venting, improper disposal, or leaks during transport, are highest for residential and small commercial HVAC equipment. Everyone we spoke with said there is little to no incentive for contractors to recover and reclaim existing refrigerant in smaller equipment. All contractors we spoke with said the laws regulating intentional venting come with virtually zero enforcement. Among the people we spoke with and surveyed about refrigerant emissions, the most common solution shared is to offer incentives.

Figure 1-4. Web survey: Ways to improve end-of-life refrigerant reclamation



Provide incentives for safe and documented end-of-life refrigerant recovery.

PAs should require the safe and documented recovery of remaining end-of-life refrigerant a prerequisite for any HVAC system change-out incentive. Providing incentives to promote end-of-life refrigerant recovery would not only reduce emissions but it will help track the rate of end-of-life emissions and improve future estimates.

Refrigerant charge adjustments cause emissions to increase.

Our research on CARB and EPA emissions estimates shows operational refrigerant leakage stems from system leakage and incidental leaks when servicing the system. These types of emissions increase every time refrigerant is added to a system. Whenever hoses and gauges are attached to a unit, some minor leakage will occur. Significant leakage can occur because of a temperamental valve or a system getting overcharged. Feedback from HVAC contractors indicates that the standard practice is to avoid even checking the refrigerant charge unless all other common issues are ruled out, but this was not standard practice until just recently. Historical evaluated energy efficiency performance for air-conditioner maintenance programs focusing on refrigerant charge adjustments demonstrate these activities often provide minimal energy performance improvements.

Stop funding refrigerant charge adjustments.

PAs should consider discontinuing any HVAC maintenance programs that promote refrigerant charge adjustments. PAs should educate HVAC contractors about the problems associated with pro-active refrigerant charge adjustments and promote best practices for assessing charge levels without tapping refrigerant lines.

2 LIST OF DEFINITIONS

Key terms in this report are defined below. When possible, we used industry-accepted terminology.

Annual leak rate. Average annual rate of emissions from equipment operation and servicing (expressed as a percentage of the total chemical charge of the equipment). For example, a refrigeration unit containing 100 lb of refrigerant that leaked 15 lb of refrigerant during a year had an annual leak rate of 15%.

ASHRAE Standard 34 Ratings. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard that assigns refrigerant safety group classifications (ratings) for flammability and toxicity.

Avoided cost calculator (ACC). Used by CPUC for calculating the avoided costs related to generation and distribution of energy.

Azeotropic (refrigerant blend). An azeotrope or a constant boiling mixture is a mixture of two or more refrigerants with the same or very similar boiling points, and where the original proportion of components is not changed by distillation or boiling. The vapor of the azeotropic blend has the same proportions of constituents as the un-boiled mixture.

Charge size. Total quantity by weight, of a specific chemical that represents the full, normal, or optimal operating amount that is used in existing and new equipment. For example, a residential central AC system typically contains 5 lb to 7 lb of refrigerant, giving it a charge size of 5 lb to 7 lb.

Chlorofluorocarbons (CFCs). CFCs are refrigerants that contain chlorine. They have been banned since the beginning of the 90s because of their negative environmental impacts.

CO2e: Carbon dioxide equivalent is a standard unit for measuring carbon footprints. The idea is to express the impact of each different greenhouse gas in terms of the amount of CO2 that would create the same amount of warming.

Coefficient of performance (COP). The ratio between the useful heating or cooling provided to electricity required.

De Minimis. This Latin phrase translates into "about minimal things," but in the HVAC industry refers to quantities of refrigerant released while making good faith attempts to recapture and recycle or safely dispose of refrigerant. This includes unavoidable refrigerant releases that occur when connecting or disconnecting hoses to charge or service appliances.

End-of-life loss rate. Average percent of chemical charge amount that is vented to the atmosphere at the end-of-life when equipment is discarded or recycled.

EUL. Effective useful life of equipment.

Flame propagation. Flame propagation refers to the propagation of the reaction zone or "combustion wave" through a combustible mixture. When the transport of heat and active species (free radicals) have initiated chemical reaction in the adjacent layer of the combustible mixture, the layer itself becomes the source of heat and radicals and is then capable of initiating reaction in the next layer.

Greenhouse gas (GHG). Gas that absorbs and emits radiant energy within the thermal infrared range, causing the greenhouse effect.

Global warming potential (GWP). The heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO2).

High GWP. As used in this methodology, this means a refrigerant, F-gas, or any compound or blend of compounds that has a 100-year global warming potential value of 750 or greater.

HVAC. Heating, ventilation, and air conditioning.

Hydrocarbons (HCs). HCs are a very limited solution to the environmental problems associated with refrigerants. They are harmless to the ozone layer (ODP = 0) and have hardly any direct greenhouse effect (GWP <5), but they are highly flammable.

Hydrofluoro-olefins (HFOs). HFOs are unsaturated organic compounds composed of hydrogen, fluorine and carbon. HFO refrigerants are categorized as having zero ozone-depletion potential (ODP) and low global warming potential (GWP) and so offer a more environmentally friendly alternative to CFC, HCFC, and HFC refrigerants.

Hydrochlorofluorocarbons (HCFCs). HCFCs are inert compounds of carbon, hydrogen, hydrocarbons, chlorine, and fluorine, and contain less chlorine than CFCs, which means a lower ODP.

Hydrofluorocarbons (HFCs). HFCs are refrigerants that contain no chlorine and are not harmful to the ozone layer. However, their impact on global warming is very large compared with traditional refrigerants.

In-depth interview (IDI). A type of interview with an individual that aims to collect detailed information beyond what binary (e.g., yes/no, agree/disagree) or simple (e.g., selecting from a dropdown menu) answers provide.

Kigali Amendment. Agreement by more than 140 countries to phase down the production and consumption of HFCs globally, adopted October 2016 as an amendment to the existing Montreal Protocol on Substances that Deplete the Ozone Layer (see "Montreal Protocol").

Leakage (of emissions). Not to be confused with refrigerant leaks from equipment, "leakage" in the greenhouse gas emissions field is defined by CARB: "A reduction in emissions of greenhouse gases within the state that is offset by an increase in emissions of greenhouse gases outside the state."

Low-GWP. In this methodology, "Low-GWP" means a refrigerant, F-gas, or any compound or blend of compounds that has a 100-year global warming potential value of less than 750, Common low-GWP refrigerants include HFOs, carbon dioxide, ammonia, and hydrocarbons. Note that low-GWP is a relative term used for this methodology and CARB does not formally define low-GWP.

Montreal Protocol. The Montreal Protocol, first signed in 1987, is the international treaty governing the protection of stratospheric ozone. The Montreal Protocol on Substances That Deplete the Ozone Layer and its amendments control the phase-out of ozone-depleting substance (ODS) production and use.

Natural refrigerant. Natural refrigerants are naturally occurring, non-synthetic substances that can be used as cooling agents in refrigerators and air conditioners. These substances include hydrocarbons (propane, butane, isobutane, and propylene), carbon dioxide, ammonia, water, and air. Note that natural refrigerants can be derived from petrochemicals and industrial processing. All the natural refrigerants listed are considered ultra-low-GWP, with GWPs ranging from zero (ammonia, water, air) to one (carbon dioxide), and three to ten (hydrocarbons).

Non-azeotropic, or zeotropic (refrigerant blend). A non-azeotropic mixture is a mixture of components with different boiling points where the original proportion of components.

Ozone depleting potential (ODP). The relative amount of degradation to the ozone layer it can cause, with trichlorofluoromethane (R-11 or CFC-11) being fixed at an ODP of 1.0.

Refrigerant. The fluid used for heat transfer in a refrigerating system.

Refrigerant recovery. A recovered refrigerant is one that was removed from refrigeration or air conditioning equipment and stored in an external container without necessarily being tested or processed in any way. Reuse is restricted to the system that it was recovered from, or in any other system owned by the same equipment owner.

Refrigerant reclamation. Refrigerant reclamation is the act of processing used refrigerant gas that has previously been used in some type of refrigeration loop such that it meets specifications for new refrigerant gas. A reclaimed refrigerant has been reprocessed using specialized machinery and tested to meet AHRI Standard 700 purity specifications.

Retrofit. The replacement of the refrigerant used in a refrigeration or air-conditioning system with an alternative refrigerant.

Self-contained. For refrigeration systems, often called "stand alone," and used to describe small refrigeration systems with hermetically sealed refrigeration units that contain all refrigerating components within their structure. For example, a refrigerated vending machine is a self-contained refrigeration system.

Senate Bill (SB) 1383. California Senate Bill 1383, Lara, 2016 "Short-lived climate pollutants: methane emissions: dairy and livestock: organic waste: landfills." SB 1383 requires a 40% reduction in HFC emissions below 2013 levels by the year 2030.

Servicing demand. The amount of refrigerant required by existing equipment to refill refrigerant lost from leaks.

Significant New Alternatives Policy (SNAP) Program. SNAP was established under Section 612 of the Clean Air Act to identify and evaluate substitutes for ozone-depleting substances.

Stationary AC equipment. Stationary air conditioning systems are non-portable systems used to provide cooling for indoor occupants for their thermal comfort at a suitable indoor air quality.[8]

Temperature glide (glide): The absolute value of the difference between the starting and ending temperature of a phase change process by a refrigerant within a component of a refrigerating system, exclusive of any subcooling or superheating. This term usually describes condensation or evaporation of a zeotrope.

Transcritical CO2 refrigeration. Refrigeration using only CO2 as the heat transfer fluid or gas. Transcritical simply means that the refrigerant passes across the critical point of temperature and pressure of a refrigerant from liquid to vapor. In a sub-critical CO2 system, generally referred to as "cascade," "hybrid," or "secondary loop," a secondary cooling system containing liquid CO2 is cooled by

[8] Under CARB 2019 HFC Emissions Estimates, this includes the following equipment types: Large Chiller 2,000 lbs. +, Medium Chiller 200-2,000 lbs., Commercial Unitary AC 50-200 lbs., > 135,000 BTUh size, Commercial Unitary AC, < 50-lbs., < 135,000 BTUh size (includes smaller "residential-type" central AC and heat pumps), Window/Room AC and PTAC Units, commercial, Residential Unitary AC, Residential Heat Pumps, Window/Room/Wall AC and Packaged Terminal AC (PTAC) Units, residential, Portable AC, and Dehumidifiers.

a primary refrigeration unit that may use HFCs, ammonia, or other refrigerants. Sub-critical refers to the CO_2 remaining in liquid form without crossing the critical point to vapor.

Trifluoroacetic acid (TFA). TFA is a decomposition byproduct formed when HFC and HFO gases enter the atmosphere and break down. HFO-1234yf produces five to ten times more TFA than HFC-134a.

Ultra-Low-GWP. In this methodology, "ultra-low-GWP" means a refrigerant, F-gas, or any compound or blend of compounds that has a 100-year global warming potential value less than 10. Note that ultra-low-GWP is a relative term used for this methodology and CARB does not formally define low-GWP.

Unit capacity. The cooling or heating capacity can be provided per unit mass of refrigerant. Common unit is BTUh/lbs.

Vintage. The equipment or HFC-containing material that entered into use in a given year. Also called a production year.

Vapor compression cycle. A thermodynamic cycle in which the refrigerant undergoes phase changes to transfer heat from low temperature to high temperature.

Zeotropic. Blends comprising multiple components of different volatiles that, when used in refrigeration cycles, change volumetric composition and saturation temperatures as they evaporate or condense at constant pressure.

3 INTRODUCTION

The focus of this study comes from California legislation directing the CPUC to develop a strategy for including low-global warming potential (GWP) HVAC refrigerants in energy efficiency programs. The California Public Utilities Commission (CPUC) asked DNV GL to conduct forward-looking research on HVAC markets and technologies via proposer-defined studies under the HVAC Roadmap group. This research supports CPUC and the following program administrators (PAs): San Diego Gas and Electric Company (SDG&E), Southern California Edison (SCE), Southern California Gas Company (SCG), Pacific Gas and Electric Company (PG&E), and Marin Clean Energy (MCE).

3.1 Background

Greenhouse gas (GHG) emissions from refrigerants in stationary HVAC equipment is the fastest growing global warming pollutant in California.[9] The average refrigerant charge in a 4-ton residential air conditioner (AC) when emitted into the atmosphere is the equal to the pollution from driving an average passenger car 16,450 miles.[10] The California Air Resources Board (CARB) estimates that the combined annual refrigerant emissions from all California stationary HVAC equipment (i.e., non-mobile HVAC equipment as opposed to those in cars, for instance)[11] was approximately 11,000,000 lb in 2019.

HVAC refrigerant emissions occur at three different stages of a unit's lifetime. A small percent of emissions occurs during the delivery and installation of HVAC equipment. A sizeable portion of leaks occurs during the lifetime operation, both from the equipment itself leaking and through de minimis leaks stemming from refrigerant charge adjustments (RCAs). Finally, a significant portion of emissions occur at the end-of-life (EOL), either through direct venting, improper disposal, and/or de minimis leaks that occur during recovery and reclamation.

Depending on the equipment, some larger HVAC types like chillers are estimated to emit more refrigerant during their operational life than at their EOL. For the smaller HVAC equipment types, the single biggest source of emissions comes at the EOL. The current estimated success rate for refrigerant recovery at the EOL for residential ACs is 20%. Put another way, CARB estimates that 80% of the time, the remaining refrigerant in a residential central AC is emitted into the atmosphere.[12] One way CARB is addressing these emissions is through an accelerated phasedown of HFCs.

HFC refrigerants were first introduced in the 1990s as an ozone-safe substitute to previous generation refrigerants like HCFCs and CFCs. CFCs began being phased out with the 1987 Montreal Protocol, followed by amendments to the protocol and the passage of Section 605 of the US Clean Air Act (1993), which called for the phasedown of HCFCs. The EPA cited the damage HCFC emissions can have on both the ozone layer and climate change when it called for a phasedown of HCFCs. EPA-recommended HFCF replacements like R-410a and R-134a were thought to be optimal choices at the time given their thermodynamic properties, lack of ozone depleting substances (ODS), and lack of flammability. What

[9] CARB, Technical Working Group Meeting, Proposed GWP Limit for New Stationary Air Conditioning Equipment, August 6, 2020.

[10] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

[11] Stationary HVAC equipment includes space cooling chillers, commercial RTUs and heat pumps, residential ACs and heat pumps, and an assortment of smaller split-system, and portable residential or commercial ACs and Heat Pumps. Current annual HVAC refrigerant emissions in California consist primarily of refrigerants like R-410a and R-134a, which are hydrofluorocarbons (HFCs) and the hydrochlorofluorocarbon (HCFC) R-22. The combined 11-million lb of annual HVAC refrigerant emissions is equivalent to the average emissions from 2.1 million passenger cars in a one-year period.

[12] CARB, HFC Emissions Factors, August 2019.

the EPA did not know was these HFC substitutes actually have comparable GWP values to the HCFCs they replaced, and in some cases are worse.

The California Global Warming Solutions Act of 2006, Assembly Bill (AB) 32, specifies California must be carbon neutral and achieve zero net GHG emissions by 2045.[13] In 2016, California passed Senate Bill (SB) 1383 that supported the goals of AB 32 by targeting short-lived climate pollutants (SLCP) and calling for a 40% reduction in HFC emissions relative to 2013 baseline levels by 2030.[14] The California Air Resources Board (CARB) determined that a more aggressive state-lead phasedown of HFCs needed to be enacted in order to meet the 40% reduction by 2030. In March of 2017, the California Air Resources Board released the Short-Lived Climate Pollutant Reduction Strategy (SLCP) that calls for future prohibitions on the use of refrigerants with 100-year GWP levels over 750 in stationary air conditioning equipment. The latest proposed timeline calls for the <750 GWP HFC reduction mandate on stationary air conditioning (which includes heat pumps) equipment to go begin on January 1, 2025.

In 2018, California SB 1013, also called the California Cooling Act, was passed that focused on fluorinated refrigerants.[15] Under SB 1013, the CPUC and other state regulatory agencies are called upon to assess the operational performance of refrigerants with low-GWPs 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.

It should be noted that CARB classifies high-GWP refrigerants as "any compound with a global warming potential (GWP) value equal to or greater than 150 according to the GWPs specified in the Intergovernmental Panel on Climate Change's (IPCCs) fourth Assessment Report (AR4) of 2007."[16] The two most common refrigerants installed in new HVAC equipment today are the HFCs R-410a and R-134a, with 100-year GWP values of 2,088 and 1,430 respectively. The long-term goal is for HVAC equipment to operate on low-GWP refrigerants. However, current HVAC refrigerant options that are both lacking in ODS and have a 100-year GWP value below 750 are either not allowed per building or fire codes or are not being produced in most common types of stationary HVAC equipment. Low-GWP refrigerant options are becoming more available for refrigeration equipment found in supermarkets, cold storage facilities, and industrial refrigeration applications. As a result, the prescribed phasedown for high-GWP refrigerants in these refrigeration equipment targets GWP levels below 150 in the very near term, while the immediate target for HVAC refrigerants is 750 GWP and the effective date continues to evolve.

With so few options for space conditioning or HVAC refrigerants available, the current push is to identify safe and viable lower GWP alternatives. Since the near-term 100-year GWP target for HVAC refrigerants is below 750, this report will refer to potential HVAC refrigerant candidates with GWP levels below 750 as "low-GWP" refrigerants and refrigerants with 100-year GWP values below 10 as "ultra-low-GWP" refrigerants.

This low-GWP refrigerant push has been building over the past decade, and presently there is a considerable number of studies and articles published regarding HVAC refrigerants with 100-year GWP values below 750. There are also significant market barriers preventing the adoption of these alternative HVAC refrigerants. The objective of this research study is to understand the reasons behind

[13] https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006
[14] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB1383
[15] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1013
[16] IPCC is Intergovernmental Panel on Climate Change. https://ww2.arb.ca.gov/resources/documents/high-gwp-refrigerants

the current slow pace of adoption and to help the CPUC and PAs develop strategies to accelerate the adoption of low-GWP refrigerants.

3.2 Study goals, research questions, and scope

This study seeks to help the CPUC, PAs, and stakeholders develop a strategy towards accelerating the adoption of low-GWP HVAC refrigerants. The study looks at both emerging near-term refrigerant alternatives with GWP levels <750 as well as lesser studied low-GWP refrigerant alternatives with a GWP <150. The study's five main research questions and corresponding scope are provided in Table 3-1.

Table 3-1. Research questions and scope

Research Question	Scope
What are feasible HVAC refrigerants with a 100-year GWP <750?	Perform secondary research on wide range of refrigerants with GWP values <750 as well as ones with values <150, assessing their energy efficiency, cost, leakage rates, and feasibility for adoption.
What are the critical barriers in converting existing HVAC systems to use lower or low-GWP alternative refrigerants, seeing new HVAC equipment installed with lower or ideally low-GWP refrigerants, and potential solutions for overcoming the barriers?	Perform interviews and conduct a web survey with an array of subject matter experts to gain more insights on the current and future market for low-GWP refrigerants in HVAC equipment.
What are the performance impacts and lifetime CO2 impacts of lower and low-GWP refrigerants in HVAC equipment relative to existing units? What is the avoided cost to ratepayers?	• Perform a lifetime GWP impact analysis on existing R-22 and R-410a HVAC systems. • Consider the leakage rates identified for various equipment types by sector when performing the lifetime GWP impact analysis. • Perform a simulated HVAC efficiency analysis on various low-GWP refrigerants using the National Institute of Standard and Technology's (NIST) refrigerant simulation tool. • Apply differences to DEER models.
What information is provided in the CPUC's Refrigerant Avoided Cost Calculator (Avoided Cost Calculator) and what recommendations does this study have to improve the Refrigerant ACC?	• Identify viable low-GWP HVAC refrigerants currently not included in the Refrigerant ACC. • Identify ways to incorporate the increased or decreased efficiency performance of identified low-GWP alternative refrigerants. • Review leakage emissions assumptions in the Refrigerant ACC and provide recommendations about how to improve the certainty of those assumptions with respect to equipment types and vintages. • Recommend best practices for the refrigerant ACC with respect to standard practice baselines.

Research Question	Scope
How should the CPUC, PAs, and stakeholders utilize the findings from this study?	• Perform a comparative analysis on the compiled data summarizing the findings. • Provide recommendations on what sectors, vintages, equipment types, and refrigerant types to target with the goal of accelerating the adoption of low-GWP HVAC refrigerants.

3.3 Approach overview

The study sought to collect and examine the most relevant information and expertise currently available about HVAC refrigerants.

The objectives for this research study were pursued through the following tasks:

- Secondary research
- In-depth interviews (IDIs) with research identified subject matter experts
- A web survey with a wider group of subject matter experts
- Alternative low-GWP refrigerant lifecycle global warming impact and raw performance analysis
- Reporting on the findings and recommendations

3.4 Organization of report

This report is organized as follows. You can click on the section number to go straight to that content.

Section	Title	Content
1	Executive Summary	Summary of results and high-level study findings
2	List of Definitions	Glossary of specialized terms and corresponding definitions
3	Introduction	Study background, objectives, research issues
4	Methodology	Research approach, activities, analysis methods, data sources
5	Detailed Results	Extensive summary of research and analysis findings
6	Conclusions and Recommendations	Detailed findings, market barriers and recommendations to improve low-GWP refrigerants adoptions
7	Appendices	Data sources table, invitation to participate in IDIs and web survey, complete web survey,

4 METHODOLOGY

This section details the approach DNV GL used for collecting the data, data processing, conducting the research and the analysis phases of the study. Primarily, our research comprised of three key steps:

- Assess the current state of the HVAC refrigerants market through secondary research, in-depth interviews (IDIs) with HVAC refrigerant-related subject matter experts (SMEs), and a web survey.
- Analyze and report on the potential impacts low-GWP HVAC refrigerants will have on energy performance and long-term greenhouse gas (GHG) emissions.
- Review the CPUC's Refrigerant Avoided Cost Calculator and provide recommendations on how to enhance the tool using the information gathered during the research effort.

We used the findings of each task to help guide and direct the path taken for the subsequent task. Up front early research was done to flush out the performance analysis and lifetime emissions approaches. Knowing the planned approach helped direct research tasks to identify key metrics needed for the analysis tasks. The three research tasks were shaped around informing both the whole HVAC refrigerant market picture and obtaining the targeted information needed for the analysis tasks. The findings of the secondary research were used to identify subject matter experts and determine what questions to ask in our interviews. The interview discussions helped determine which questions to ask in the web survey. The goal of the web survey was to maximize the value of the results while simultaneously keeping the survey short enough for people to complete.

The findings of all tasks will be presented in the results section and the key findings and corresponding recommendations in the conclusion. The full approach for each task is detailed in the subsequent sections.

4.1 Data sources and tools

DNV GL designed the data collection effort to leverage the array of data sources relevant to the current state of HVAC refrigerants and where the market is headed.

Our five primary data resources and tools included:

- **Secondary research** of published reports, research, articles, and related legislation.
- **IDIs** with relevant SMEs. The secondary research authors were also a source for of respondents to the IDIs.
- **Web surveys** with an expanded group of SMEs including HVAC industry members.
- **A modeling analysis tool** that simulates refrigerant performance: The National Institute of Standards and Technology's (NIST) CYCLE_D-HX: NIST Vapor Compression Cycle Model Accounting for Refrigerant Thermodynamic and Transport Properties.
- **Refrigerant Avoided Cost Calculator (ACC)** from the CPUC.

Additionally, we conducted interviews with the CPUC and with CARB to discuss the objectives and methods for the development of the workplan.

4.1.1 Secondary research

DNV GL began the study with a review of secondary resources during the workplan development stage and throughout the writing of the report. The objective was to identify and synthesize the vast amount of current information available on lower and low-GWP HVAC refrigerants and to guide and direct tasks. The review also provided names and contacts of potential SMEs to recruit for IDIs and the web survey.

We reviewed over 110 sources including:

- Government websites and publications including the US Environmental Protection Agency (EPA) and the California Air Resource Board (CARB)
- Industry protocols, standards, and policy documents
- Academic and non-profit publications
- Technical and laboratory reports
- International agreements
- HVAC manufacturer, distributor, contractor, and reclamation websites and blog posts
- Other key sources such as industry white papers and opinion pieces

We also leveraged research studies conducted by California program administrators and their emerging technology partners.

We cataloged the sources, summarized the relevant information found in each of the sources and compiled a refrigerant dataset. Our research team primarily captured relevant information in two main workbooks focusing on quantitative and qualitative assessments of each refrigerant's characteristics and performance. We captured other key findings on key subjects of interest in separate summary notebooks. Our team also met weekly to review the overall findings and adjusted our efforts to ensure all characteristics of interest were covered sufficiently. The categories of interest were:

- Energy efficiency performance
- Cost/economic impact
- Leakage/reclamation/recovery
- Refrigerant-only retrofits
- Low-GWP adoption
- Refrigerant GWP, toxicity, and flammability
- Policy and enforcement

We sought out information relevant to both near-term alternative refrigerants with 100-year GWP values below 750 and long-term alternative refrigerants with GWP values closer to 1. We also looked for and documented cost implications stemming from low-GWP refrigerant adoption. This included costs associated with the environmentally safe accelerated retirement of high-GWP refrigerant systems, identifying cost differences associated with each low-GWP refrigerant with respect to new HVAC manufacturing, and cost implications for refrigerant only system changeouts of existing HVAC systems. The majority of sources were published in the last five years, a few were published in the early 2010s, and in the case of government policy and international treaties, some sources were published as far back as the 1980s.

We monitored data collection progress throughout the study and continued to seek and review new sources as findings were revealed. A detailed list of data sources and their related HVAC refrigerant characteristics is provided in Appendix B: Data sources table.

4.1.2 IDIs of HVAC refrigerant SMEs

The purpose of the IDI task was to gain insight and understanding on the lower to low-GWP HVAC refrigerant options from established industry professionals, which we categorize here broadly as HVAC refrigerant SMEs. These experts represented seven different types of organizations or industries, from environmental consultants to HVAC distributors and refrigerant reclaimers as described in Table 4-1. A total of 18 interviews with 21 individual SMEs were conducted in October, November, and December of 2020.

Table 4-1. SME organization types and distribution of interviews

Interviewee Organization	Participants (n=21)
Environmental policy, research, consulting	5
HVAC contractor organization chairman/director	3
HVAC distributor	4
HVAC original equipment manufacturer	3
Laboratory testing and research	3
Refrigerant manufacturer	1
Refrigerant reclamation	1

We developed a list of IDI topics and questions from the findings from our secondary research task. The list started with topics that the secondary research lacked information about or where the research findings showed inconsistencies. This produced a significant list of questions, which we then consolidated into five overarching interview categories:

- Regulatory policy impacting HVAC equipment
- HVAC manufacturing and R&D
- HVAC maintenance, refrigerant leakage, recovery, and reclamation
- HVAC efficiency/performance
- ASHRAE hazard classifications with respect to HVAC refrigerants

The first research task also provided a list of potential interview candidates that included authors and cited professionals found in the sourced secondary materials. We also reached out to known HVAC industry contacts through past HVAC evaluation work in California and sought referrals from interviewees that indicated willingness to participate. Our outreach to potential interviewees included a summary of the research study scope and an explanation of the intent of the interview.

The complete IDI guide included more than 40 questions. Knowing most interview candidates would likely not agree to more than an hour-long interview, we kept interviews under 45 minutes in most cases. Prior to interviewing, we asked all candidates for general background information such as the organization they work for, their role at the organization, and a summary of their professional experience related to HVAC equipment and refrigerants.

We also asked interview candidates which of the five interview categories they had the most experience with, and the subsequent IDI focused on their top two or three categories to ensure there would be enough time to complete the interview. In some cases, the interviewee had so much expertise or unique insight on one or two single topics that the entire interview would be dedicated to the single topic and the guide was used as a starting point for the conversation. The complete IDI is presented in Appendix .

We also invited the interviewees to participate in a subsequent focused web survey, described next in Section 4.1.3.

After compiling all the findings from the interviews, we then developed a focused web survey for IDI participants and other experts. The results and findings from the IDIs are discussed throughout Section 5 in context of this study's research questions.

4.1.3 Web survey of HVAC refrigerant SMEs

In this task we developed and administered an online survey to collect opinions from HVAC refrigerant SMEs about specific low-GWP HVAC refrigerant topics described below in Section 4.1.3.1.

Survey candidates were emailed an invitation to participate in a CPUC-sponsored survey titled "Low-GWP HVAC Refrigerant Survey for Subject Matter Experts."

We leveraged the following five resources to identify potential candidates for the web survey:

- DNV GL's secondary literature review of subject matter experts and participants from the IDIs
- Former working group committee members of the CPUC sponsored HVAC Code Compliance with the Western HVAC Performance Alliance (WHPA)
- DNV GL internal network of research and policy refrigerant professionals
- Distributors and contractors delivering of the CPUC upstream and downstream HVAC programs
- Referrals from survey respondents

The email invitation included a notification letter, a hyperlink to the survey, and a link to a dedicated page on the CPUC website allowing respondents to validate the sponsor and legitimacy of the survey. The online survey consisted of 20-30 multiple choice or agree/disagree questions.

The email letter and survey contained the following CPUC branding and images as shown below to boost responses and authenticate the survey effort.

4.1.3.1 Web-survey research topics

The results from our IDIs informed the development of limited-scope web survey questions. For example, we targeted research topics discussed in the IDIs that yielded mixed feedback or inconclusive results like low-GWP adoption feasibility and recovery/reclamation rates. The web survey questions fall into the following categories:

- Awareness of the California Cooling Act (SB 1013) and when respondents think the policy will come into effect for new equipment
- The ability to retrofit existing equipment with a low-GWP refrigerant
- The most common low-GWP refrigerant expected to be used in the market for various equipment types and cost implications for buyers.
- Reclamation of existing high-GWP refrigerant in existing systems
- Activities the state should priorities to achieve the overarching goal and asked respondents to rank them

Respondents were not required to answer each question, thus the number of responses varied from question to question. Questions were primarily close-ended, and many provided a Likert scale. A summary of the survey questions are response options are provided in Table 4-2.

The complete survey can be found in Appendix .

Table 4-2. Summary of web survey questions and response options

Question	Response Option
What industry do you work in?	List option
Are you familiar with the California Cooling Act, Senate Bill (SB) 1013?	Yes/No
SB 1013 will result in most new California HVAC equipment installed after January 1, 2023 with a low-GWP refrigerant?	Agree/Disagree
Why disagree (to above question)	Open ended
SB 1013 will result in most new California HVAC equipment installed after January 1, 2025 with a low-GWP refrigerant?	Agree/Disagree
Why disagree (to above question)	Open ended
What will be the most common refrigerant for unitary HVAC equipment installed after January 1, 2025?	List option of refrigerant types
What is the minimum lead time needed for the HVAC supply chain to successfully transition to low-GWP HVAC?	List option of time periods
How much do you expect the transition to a low-GWP refrigerant will increase the price of the equipment to for the California consumer in year 2025?	List option
Rate the practicality/feasibility of retrofitting an existing HVAC equipment's refrigerant to a low-GWP alternative for: • Split-system, computer room, or portable AC units • Residential and small commercial heat pumps • Commercial RTUs with refrigerant charge levels - Up to 50 lbs. • Commercial RTUs with refrigerant charge levels - Over 50 lbs. • Chillers	Agree/Disagree

Question	Response Option
What percent of HVAC equipment types have the remaining refrigerant reclaimed at the end-of-life? • Split-system, computer room, or portable AC units • Residential and small commercial heat pumps • Commercial RTUs with refrigerant charge levels - Up to 50 lbs. • Commercial RTUs with refrigerant charge levels - Over 50 lbs. • Chillers	Rate zero to 100
Rank the following statements where 1 represents the "most effective" and 4 represents the "least effective" action taken towards California's pursuit to lower global warming impacts caused by HVAC equipment. • Finalize California's fire and safety codes to allow for mildly flammable (ASHRAE A2L) refrigerants in HVAC equipment. • Provide incentives to target the early retirement of existing HVAC equipment and replace with low-GWP HVAC equipment. • Improve the success rate of refrigerant reclamation and ensure proper disposal of end-of-life HVAC equipment. • Create a market value for reclaimed high-GWP refrigerants by allowing non-virgin or reclaimed high-GWP to be used in new equipment installations between January 1, 2023 and January 1, 2025.	Effectiveness ranking from one to four
Please provide one or more suggestions on how the state of California could improve the end-of-life refrigerant reclamation success rate:	Open ended
Recommendation of individuals who should participate in this survey	Open ended

4.1.3.2 Web survey sample and response rates

We sent invitations to HVAC refrigerant SMEs to participate in an online survey during a three-week period from December 16, 2020 through January 11, 2021. We also sent at least one reminder invite through the survey fielding period.

The sample disposition and response rate for the survey is summarized in Table 4-3 below. The survey achieved a 47% response rate.

Table 4-3. Web-survey response rates

Category	Total
Invites sent	121
Not started	64
Partial Completes	8
Incompletes (removed)	2
Completes	49

A total of 55 web surveys were conducted by various organizations types. The distribution of respondents covered in the web survey by organization type is presented in Table 4-4.

Table 4-4. Web-survey respondent industry summary

Which of the following best describes the industry you work in?	Survey Participants (n=55)
Environmental policy, research, consulting	12
Laboratory testing and research	10
HVAC contractor	9
HVAC original equipment manufacturer	7
Government agency	5
HVAC distributor	5
Refrigerant manufacturer or refrigerant reclamation	3
Engineer or building design architect	2
Other: Utility employee	2

The results and findings from the web survey are discussed throughout Section 5 in context of this study's research questions.

4.2 Data analysis of EE performance and lifetime GWP

The first task is to assess the theoretical energy-efficiency performance of research identified lower to low-GWP alternative HVAC refrigerants. The second task is to quantify the lifetime GWP of new installations, accelerated retirement equipment installs, and refrigerant-only retrofits, through simulating both the user defined baseline HVAC refrigerant and the identified alternative HVAC refrigerant's performance and emissions. The second task uses the CPUC's Refrigerant Avoided Cost Calculator (ACC) developed by E3 using CARB's annual HFC Emission estimates.

The lifetime GWP task expands the existing Refrigerant ACC by allowing users to specify additional parameter inputs about the alternative lower to low-GWP refrigerants. The lifetime GWP impact task is done using the current mix of HVAC equipment in the market consistent with the CPUC's Refrigerant ACC. The lifetime GWP calculator quantifies the GWP impact from operational leakage estimates, end-of life emissions estimates, and grid emission GWP impacts due to the estimated energy consumption impacts of the alternative HVAC refrigerants on the equipment. In addition, DNV GL investigated the difference of lifetime GWP impacts for drop-in replacement versus whole system replacement as follows:

1. Existing equipment to undergo a refrigerant changeout/conversion at age X with direct drop-in replacement. The direct refrigerant changeout requires minimum to no changes to the existing HVAC system. Under this scenario, the new refrigerant charge level, system efficiency might change depending on the new refrigerant's thermodynamic properties.
2. Accelerated retirement/replacement of existing R-22 or R-410A system with a new low-GWP refrigerant at age X. This scenario is different from direct drop-in in that the new system needs to meet the code minimum efficiency requirement, regardless of the alternative refrigerant's theoretical COP. Therefore, the assumption is that the new system efficiency is at least the same as the baseline equipment, even if the new refrigerant's thermodynamic properties underperform those of R-410A.

The lifetime GWP for when the high-GWP refrigerant system is replaced at age X is calculated as follows:

Equation 1. Lifetime GWP calculation[17]

IF X = 0 (Installing Low-GWP system at new construction)

Lifetime GWP =

(EUL) x Annual Leakage Rate Percentage x Low-GWP Refrigerant Charge Level (lbs/unit) x Low-GWP Refrigerant GWP + EOL Loss Rate Percentage x Low-GWP refrigerant Charge Level (lbs/unit) x GWP + $\sum_{\text{from year x to year EUL-1}}$ *(Annual Energy Consumption with Low-GWP refrigerant (kWh/yr) x Annual Grid Emission Rate (lbs CO2e/kWh))*

Else

Year 0 to Year X-1 Total GWP =

(X) x Annual Leakage Rate Percentage x High-GWP refrigerant Charge Level (lbs/unit) x High-GWP Refrigerant GWP + EOL Loss Rate Percentage x High-GWP refrigerant Charge Level (lbs/unit) x GWP + $\sum_{\text{from year 0 to year x-1}}$ *(Annual Energy Consumption (kWh/yr) with High-GWP refrigerant x Annual Grid Emission Rate (lbs CO2e/kWh))*

Year X to Year EUL-1 Total GWP =

(EUL-X) x Annual Leakage Rate Percentage x Low-GWP Refrigerant Charge Level (lbs/unit) x Low-GWP Refrigerant GWP + $\sum_{\text{from year x to year EUL-1}}$ *(Annual Energy Consumption with Low-GWP refrigerant (kWh/yr) x Annual Grid Emission Rate (lbs CO2e/kWh))*

Lifetime GWP when replaced at year X = Year 0 to Year X-1 Total GWP + Year X to Year EUL-1 Total GWP

When X=0, this becomes installing low-GWP refrigerant at the new construction phase and X=EUL means the high-GWP refrigerant is used for the entire lifetime, which can be considered a baseline scenario.

The annual grid emission rate is a projection of the future grid emission for each year. By default, DNV GL uses the ACC projected grid emission rate in terms of pounds CO2e per kWh generated. In addition, DNV GL also purposed several other future emission scenarios that the user can choose from, including continuing historical trend, 10%year over year emission reduction, 20% year over year reduction and linear reduction to net zero at 2045 to align with the SB 100 goal.

The high-GWP refrigerant charge level, leakage rate percentage and EOL loss rate percentage and annual energy consumption for each equipment type are directly from the existing ACC. The user can modify the leakage rate and EOL loss rate for the alternative refrigerant manually, to account for the more stringent fire code requirement for low-GWP refrigerant that have higher flammability rating.

In order to calculate the charge level and energy consumption appropriately for the low-GWP refrigerant, DNV GL simulated the theoretical performance of common alternative low-GWP refrigerants that we identified from literature review and IDI using CYCLE_D-HX simulation tool. This tool is ideal for this study because it enables users to simulate the performance of over 160 different refrigerant types on a wide array of system types. The tool also allows the user to modify the HVAC cycles and

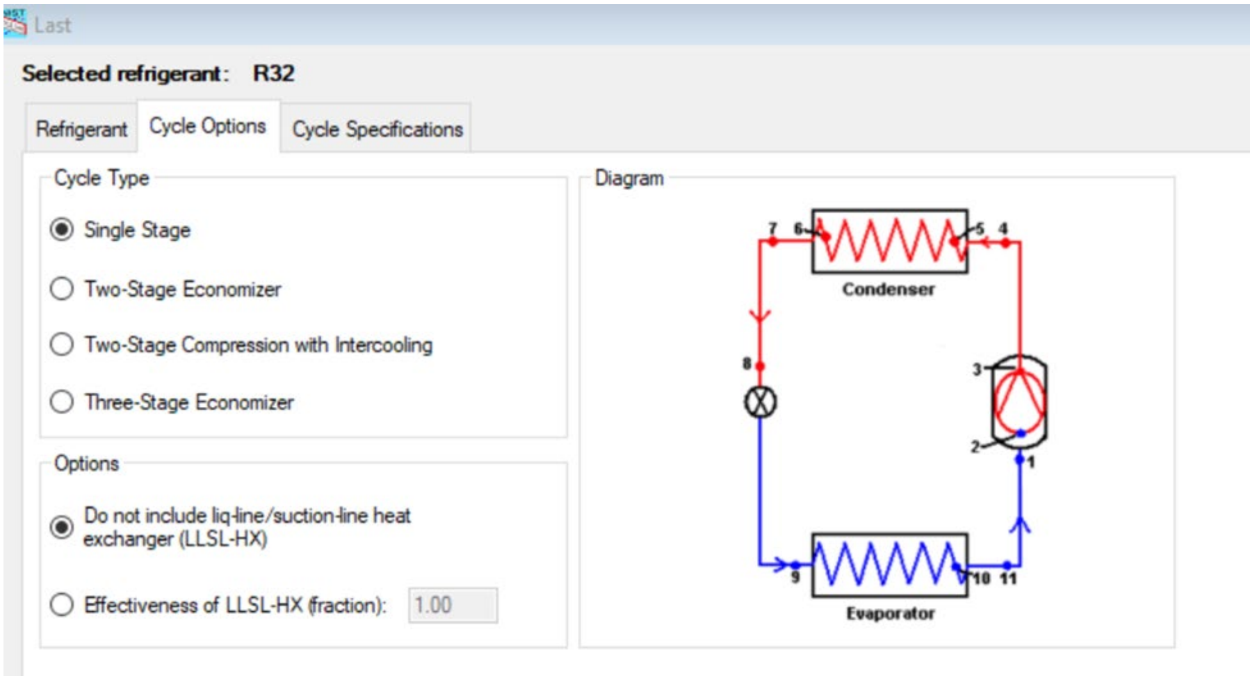
[17] The calculator uses a year beginning convention for naming the intervals, so year 0 represents the first year interval and year 19 represent the year from 19 to 20. Therefore, a chiller with a 20 year, EUL would operate from year 0 to year 19, which is 20 intervals or years.

parameters to simulate the COP and unit capacity to account for different equipment type. DNV GL created three cycle options to simulate as

- Small-to-medium sized direct expansion (DX) system with air-cooled condenser
- Medium-to-large chiller with air-cooled condenser
- Medium-to-large chiller with cooling tower

For small to medium DX system, DNV GL simulated with a simple one-stage cycle that operates between 105°F at condensing temperature and 50°F at evaporating temperature as shown in Figure 4-1.

Figure 4-1. DX system cycle diagram



This temperature condition is maintained constant between all simulated refrigerants to keep the operating condition the same. DNV GL used CYCLE_D-HX to simulate the theoretical COP and unit capacity for each refrigerant which were then used in the charge and energy consumption calculation as follows:

Equation 2. Low-GWP refrigerant charge level

Low-GWP refrigerant charge level (lbs/unit) = High-GWP refrigerant charge level (lbs/unit) x High-GWP refrigerant unit capacity (kBtu/hr-lbs) /Low-GWP refrigerant unit capacity (kBtu/hr-lbs)

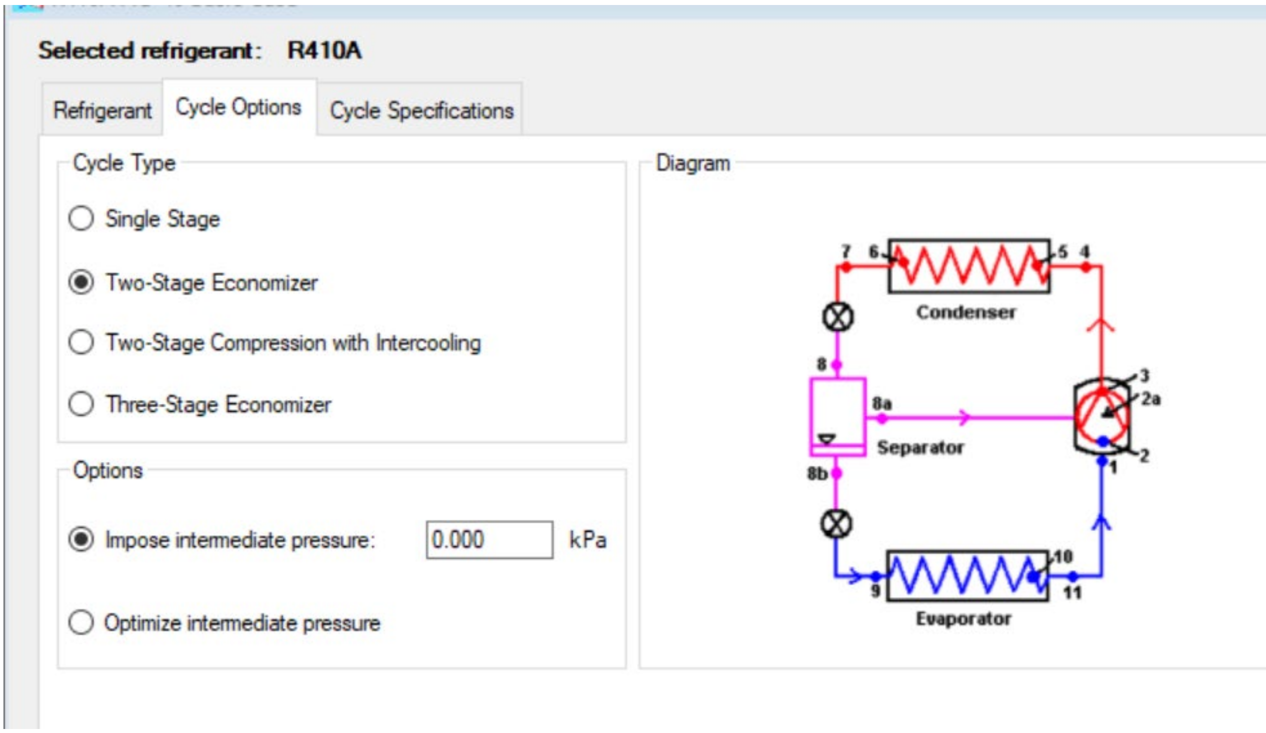
Equation 3. Low-GWP refrigerant annual energy consumption

Annual Energy Consumption with Low-GWP refrigerant = Annual Energy Consumption with High-GWP refrigerant x COP of High-GWP refrigerant / COP of Low-GWP refrigerant

The calculated results in Equation 2 and Equation 3 will feed into Equation 1 for lifetime GWP calculation.

The other two HVAC types have different evaporating and condensing temperature due to the different operating conditions of the chiller and cooling tower. Additionally, for medium to large chillers, the cycle option is changed to two-stage cycle with economizer as shown in Figure 4-2. The calculation methodology remains the same as Equation 2 and Equation 3.

Figure 4-2. Medium-to-large chiller cycle diagram



Finally, DNV GL converted the lifetime GWP to GHG cost using the annual per lbs of CO2e cost data from ACC. The total lifetime GHG cost when high-GWP refrigerant is replaced at year x is calculated as follows:

Equation 4. Lifetime GHG cost calculation

IF X = 0 (Installing Low-GWP system at new construction)

Total GHG Cost =

$\Sigma_{\text{from year 0 to year EUL-1}}$ *[Annual GWP with low GWP refrigerant x Corresponding Yearly GHG cost ($/lbs CO2e)] + EOL Loss Rate Percentage x Low-GWP Refrigerant Charge Level (lbs/unit) x Low-GWP Refrigerant GWP] x Corresponding Yearly GHG cost ($/lbs CO2e)*

Else

Year 0 to Year X-1 Total GHG Cost =

$\Sigma_{\text{from year 0 to year X-1}}$ *[Annual GWP with high GWP refrigerant x Corresponding Yearly GHG cost ($/lbs CO2e)] + EOL Loss Rate Percentage x High-GWP Refrigerant Charge Level (lbs/unit) x High-GWP Refrigerant GWP] x Corresponding Yearly GHG cost ($/lbs CO2e)*

Year X to Year EUL Total GHG Cost =

$\Sigma_{\text{from year 0 to year X-1}}$ [Annual GWP with low GWP refrigerant x Corresponding Yearly GHG cost ($/lbs CO2e)]

Lifetime Total GHG Cost when replaced at year X = Year 0 to Year X-1 Total GHG cost + Year X to Year EUL Total GHG cost

The lifetime GHG cost is adjusted to the net present value using 2020 dollar (NPV 2020) using the built-in function of excel.

As a results of lifetime GWP and performance analysis effort, DNV GL developed a prototype GWP calculator based on the CPUC's refrigerant calculator to include all the aforementioned enhancements. Figure 4-3 shows the major inputs that users can specify in the calculator (shaded in blue) and intermediate outputs based on the user selection (no shading).

Figure 4-3. Sample inputs for lifetime GWP calculation

Inputs	
GHG Method	GHG (20 year)
Equipment Type	Residential Unitary AC_Air Cooled
EUL	15
Baseline Refrigerant	R-410a
Baseline GWP	4340
Baseline Fire Class	A1
Baseline Theoretical COP Ratio: COP/COP_410A	100%
Baseline Capacity Ratio: Q/Q_R410A	100%
Alternative Refrigerant	HFC-32
Alternative GWP	2330
Alternative Fire Class	A2L
Alternative Theoretical COP Ratio: COP/COP_410A	102%
Alternative COP Overwrite to be the same as baseline?	No
Alternative Capacity Ratio: Q/Q_R410A	150%
Annual Leakage Rate reduction due to fire rating	0%
Low-GWP Annual Leakage Rate	5%
Baseline Refrigerant Annual Leakage Rate	5%
End of life loss rate improvement	0%
End of life loss rate	80%
Emission Scenario	Default Scenario (ACC Scenario)
Year when baseline refrigerant is replaced with alternative	New Construction
WACC selection	PG&E
Active WACC (%)	7.81%

The new prototype lifetime GWP calculator includes the following enhancements:

- The lifetime calculator gives users the ability to calculate lifetime GWP impacts for accelerated replacement and direct drop-in retrofit scenarios.
- The lifetime calculator incorporates the theoretical COP and unit capacity of each refrigerant using the NIST CYCLE_D-HX outputs.
- The lifetime calculator includes additional HVAC refrigerant options with GWP levels <750 that were not previously included in the ACC calculator.
- The lifetime calculator integrates future grid emission scenarios when calculating the lifetime GWP impact of equipment energy consumption.
- The lifetime calculator accounts for the simulated energy consumption impacts due to the alternative refrigerant's theoretical capacity and projected grid emission throughout the lifetime

GWP analysis. This typically applies to direct drop-in scenarios where the system is not optimized for the new refrigerant.

- The lifetime calculator accounts for the GWP emissions impacts from the alternative refrigerant’s charge level difference relative to the baseline refrigerant’s charge using both refrigerants’ theoretical unit capacity. The lifetime calculator also allows the user to modify the assumed leakage rates of future low-GWP refrigerants if studies emerge showing evidence that code enforced reduced leakage requirements are considerably reducing refrigerant leakage.
- The lifetime calculator allows users to modify end-of-life loss rate estimates manually to simulate the impact of measures targeting improved EOL recovery rates.

5 DETAILED RESULTS

In this section we present the study findings and results of our research. In the seven detailed sub-sections we present the findings of our secondary research, the feedback received in the in-depth interviews (IDIs), and the results of the web-surveys.

5.1 Regulatory and policy impacts

While California Senate Bills 1383 (SB 1383) and 1013 (SB 1013)[18] are most responsible for shaping the objectives of this report, understanding the evolution of fluorinated gas regulation outside of the United States is critical to understanding the current state of HVAC refrigerant regulation in California. The next section summarizes key regulation in this evolution.

5.1.1 The Montreal Protocol

Seen as one of the world's most successful environmental treaties,[19] the Montreal Protocol began as a global pact to protect the earth's stratospheric ozone through regulation and the prescribed phase-out of substances that harm the ozone. Now over 30 years since the original Protocol was ratified, there are signs that the ozone layer is recovering. This result is directly attributed to the Montreal Protocol. Following the original signing of the protocol in 1987, parties have met annually to monitor the success of the agreement and to periodically adjust or draft amendments to the original protocol. The parties met in London in 1990 and agreed to the phase-out of chlorofluorocarbons (CFCs) by the year 2000, which became the London Amendment.[20] The HVAC Refrigerants impacted by the London Amendment includes the CFCs R-11, R-12, R-113, and R-500.

In 1992 the parties met again in Copenhagen and agreed to accelerate the phase-out of CFCs by 1995, five years ahead of the original 2000 target. In Copenhagen the parties also agreed to phase out hydrofluorocarbons (HFCFs) by 2030. This 1992 agreement later became the Copenhagen Amendment to the Montreal Protocol.[21] The HVAC refrigerants impacted by the phase out of HFCFs include R-22, and R-123.

California is still phasing out HVAC HCFCs today. New HVAC equipment with R-22 was legally installed in California if it was manufactured prior to January 1, 2010, and new HVAC equipment (mainly large centrifugal chillers) with R-123 was still legally installed if it was manufactured prior to January 1, 2020.[22]

In response to concerns about the ozone depleting impacts of CFCs and HCFCs, chemical manufacturers developed alternative hydrofluorocarbon (HFC) refrigerants that are void of ozone-depleting substances. The two most common HFC HVAC refrigerants today are R-410a and R-134a. When first introduced these refrigerants were appealing for their thermodynamic properties, lack of ozone depleting substances, and lack of flammability. What was not commonly known at the time, is

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[18] State of California, Senate Bill No. 1013, SEC. 2. 76002, 9/13/2018, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1013

[19] UN Environment Program, Thirty Years on, what is the Montreal Protocol doing to protect the ozone?, 11/15/2019, https://www.unenvironment.org/news-and-stories/story/thirty-years-what-montreal-protocol-doing-protect-ozone#:~:text=The%20Montreal%20Protocol%20has%20been%20successful%20in%20reducing%20ozone%2Ddepleting,the%20first%20signs%20of%20recovery.

[20] https://ozone.unep.org/treaties/montreal-protocol/amendments/london-amendment-1990-amendment-montreal-protocol-agreed

[21] https://ozone.unep.org/treaties/montreal-protocol/amendments/copenhagen-amendment-1992-amendment-montreal-protocol-agreed

[22] https://www.epa.gov/ods-phaseout/phaseout-class-ii-ozone-depleting-substances

that when these new alternative HFC HVAC refrigerants are emitted into the atmosphere, they contain a GWP 1,430 to 3,985 times greater than that of $C0_2$ over a 100-year period.

5.1.2 The Kigali Amendment

In October 2016, parties of the Montreal Protocol met in Kigali, Rwanda, and drafted an amendment to phase down the use of HFCs, now known as the Kigali Amendment. The United States contributed to the research and proposals that lead to the agreement, which was adopted by 197 countries at the time of signing. It became an official amendment in 2017 and entered into force in 2019. The prescribed phasedown of HFCs and other impacts of the Kigali Amendment are estimated to reduce potential global warming impacts by up to 0.5^{o}C by 2100. The US Department of State summarizes the benefits of the amendment:

> "This amendment creates market certainty and opens international markets to new technology that is better for the environment, without compromising performance. It calls on all countries to gradually phase down their production and consumption of HFCs in the coming decades using the flexible, innovative, and effective approaches the Montreal Protocol has used for three decades. Global stakeholders endorsed adoption of the Kigali Amendment, including most of the major U.S. companies working in related sectors."[23]

Currently over 100 countries have ratified the Kigali Amendment, including Canada, Mexico, and all of Western Europe.[24] Notably, the United States has not formally ratified the agreement.

5.1.3 F-Gas regulation in the European Union

Whilst US efforts to address global warming impacts caused by HFCs were stuck in courts, the European Union forged ahead with aggressive legislation. In 2015, the EU updated its previous F-gas regulation first adopted in 2006. The summary of the 2015 F-gas regulations found on the European Commission's website includes the following:

The current Regulation strengthened the previous measures and introduced far-reaching changes by:

- **Limiting the total amount** of the most important F-gases that can be sold in the EU from 2015 onwards and eliminating them in steps to one-fifth of 2014 sales in 2030. This will be the main driver of the move towards more climate-friendly technologies.
- **Banning the use** of F-gases in many new types of equipment where less harmful alternatives are widely available, such as fridges in homes or supermarkets, air conditioning, and foams and aerosols.
- **Preventing emissions** of F-gases from existing equipment by requiring checks, proper servicing, and recovery of the gases at the end of the equipment's life.

These measures were built on the successful phase-out of ozone-depleting substances which was achieved in the EU 10 years ahead of the internationally agreed schedule.[25]

[23] https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/the-montreal-protocol-on-substances-that-deplete-the-ozone-layer/

[24] https://www.k-cep.org/wp-content/themes/kigali/page-templates/map/MapRatification.html

[25] https://ec.europa.eu/clima/policies/f-gas/legislation_en

Several things worth considering about the F-Gas regulations:

- The plan includes emission prevention measures.
- The plan is designed to exceed the phasedown requirements placed on the EU per the Kigali Amendment.
- As a result of this plan, mildly flammable, low-GWP refrigerant alternatives are now being installed in single-split, multi-split, and mini-VRF systems.[26]
- The plan includes the use of recovered and reclaimed high-GWP refrigerants like R-410a as means of minimizing GWP impact through reducing the demand for virgin R-410a to be produced and creating a market value for recovered R-410a.[27]

Many of these actions are being replicated by California and other states through state-level initiatives.

5.1.4 The Clean Air Act and the Significant New Alternatives Policy (SNAP) program

In 1990, the United States significantly revised the Clean Air Act to curb four major threats to the environment and to the health of Americans: acid rain, urban air pollution, toxic air emissions, and stratospheric ozone depletion.[28] Title VI of the Clean Air Act charges the EPA to implement policy and regulation designed to protect the ozone layer and to ensure that the United States adheres to the Montreal Protocol.[29] The EPA created a series of programs to facilitate this effort, one program in particular, is the SNAP Program. The definition found on the SNAP homepage of the EPA Website states:

> "SNAP was established under Section 612 of the Clean Air Act to identify and evaluate substitutes for ozone-depleting substances. The program looks at overall risks to human health and the environment of existing and new substitutes, publishes lists and promotes the use of acceptable substances, and provides the public with information …."[30]

In July 2015, SNAP finalized Rule 20, prohibiting "… the use of certain high-GWP HFCs as alternatives."[31]

Then in December 2016, SNAP finalized Rule 21 and provided "new listings of safer substitutes and prohibition on the use of certain high-GWP alternatives."[32]

Both rules are significant in that they directly address future US obligations to the Kigali Amendment, and they were finalized under the Obama Administration. Roughly two years after SNAP Rule 20 was finalized, in August of 2017, the US Court of Appeals for the District of Columbia Circuit ruled that the EPA overstepped its authority with Rule 20. An excerpt of the Opinion for the Court filed by then Circuit Judge, Brett Kavanaugh:

> "The fundamental problem for EPA is that HFCs are not ozone-depleting substances, as all parties agree. Because HFCs are not ozone-depleting-substances, Section 612 would not seem to grant EPA authority to require replacement of HFCs."[33]

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[26] https://ec.europa.eu/clima/sites/clima/files/news/docs/c_2020_6637_en.pdf

[27] https://www.fluorocarbons.org/news/spotlight-on-refrigerant-recovery-reclamation-and-destruction/

[28] https://www.epa.gov/clean-air-act-overview/clean-air-act-highlights-1990-amendments

[29] https://www.epa.gov/ozone-layer-protection/ozone-protection-under-title-vi-clean-air-act

[30] https://www.epa.gov/snap

[31] https://www.epa.gov/snap/final-rule-protection-stratospheric-ozone-change-listing-status-certain-substitutes-under

[32] https://www.epa.gov/snap/fact-sheet-final-rule-21-protection-stratospheric-ozone-significant-new-alternatives-policy

The fall-out of Kavanaugh's court ruling, along with Trump's unilateral policy to roll-back regulation,[34] is that the US did not ratify the Kigali Amendment and national efforts to address global warming impacts caused by HFCs were held in a state of purgatory for the duration of the Trump Administration. How California responded to this national environmental setback is described below.

5.1.5 California Assembly Bill 32 and SB 1383

In 2006, California became the first state in the US to pass comprehensive legislation targeting a phase down of GHG emissions through the passage of State Assembly Bill 32, the California Global Warming Solutions Act. The bill calls for the California Air Resources Board (CARB) to lead the implementation of the law and to be assisted by seventeen other state agencies known as the Climate Action Team. The CPUC is one of those seventeen state agencies that makes up the Climate Action Team. One of the seven GHGs AB32 regulates is HFCs.[35]

In September of 2016, then Governor Jerry Brown, approved SB 1383, which sought to reduce "Short-lived climate pollutants: methane emissions: dairy and livestock: organic waste; landfills." The bill also called for the reduction in HFCs by 40% below 2013 levels by 2030. In December 2017, CARB published a 142-page document "Potential Impact of the Kigali Amendment on California HFC Emissions." In this document CARB reported that if California were to only follow the provisions of the Kigali Amendment set forth for developed nations, California would not achieve the SB 1383 HFC emission reduction targets by 2030.

The document laid out four possible scenarios which California could follow towards achieving compliance with the directives of the Kigali Amendment. Under the best case scenario the document assumes "a fast transition away from using high-GWP HFCs in refrigeration and air-conditioning (AC) equipment to low-GWP alternatives, including the "natural refrigerants" of carbon dioxide (as refrigerant), ammonia, hydrocarbons, and the newest generation of synthetic fluorinated compounds, the hydrofluoro-olefins (HFOs)."[36] CARB predicts that even under this best case scenario, the emissions reduction goal set forth in SB 1383, would not be achieved until 2038 ($\pm$3 years).

Note that CARB's prediction was made before US efforts to adhere to the phasedown requirements in the Kigali Amendment were stalled for the almost the entire duration of the Trump administration. Figure 5-1 is sourced directly from Figure ES-1 in the CARB study. The figure presents the four hypothetical scenarios of how the Kigali Amendment impacts alone would alter HFC emissions in California as well as a no phasedown/no new measures scenario.

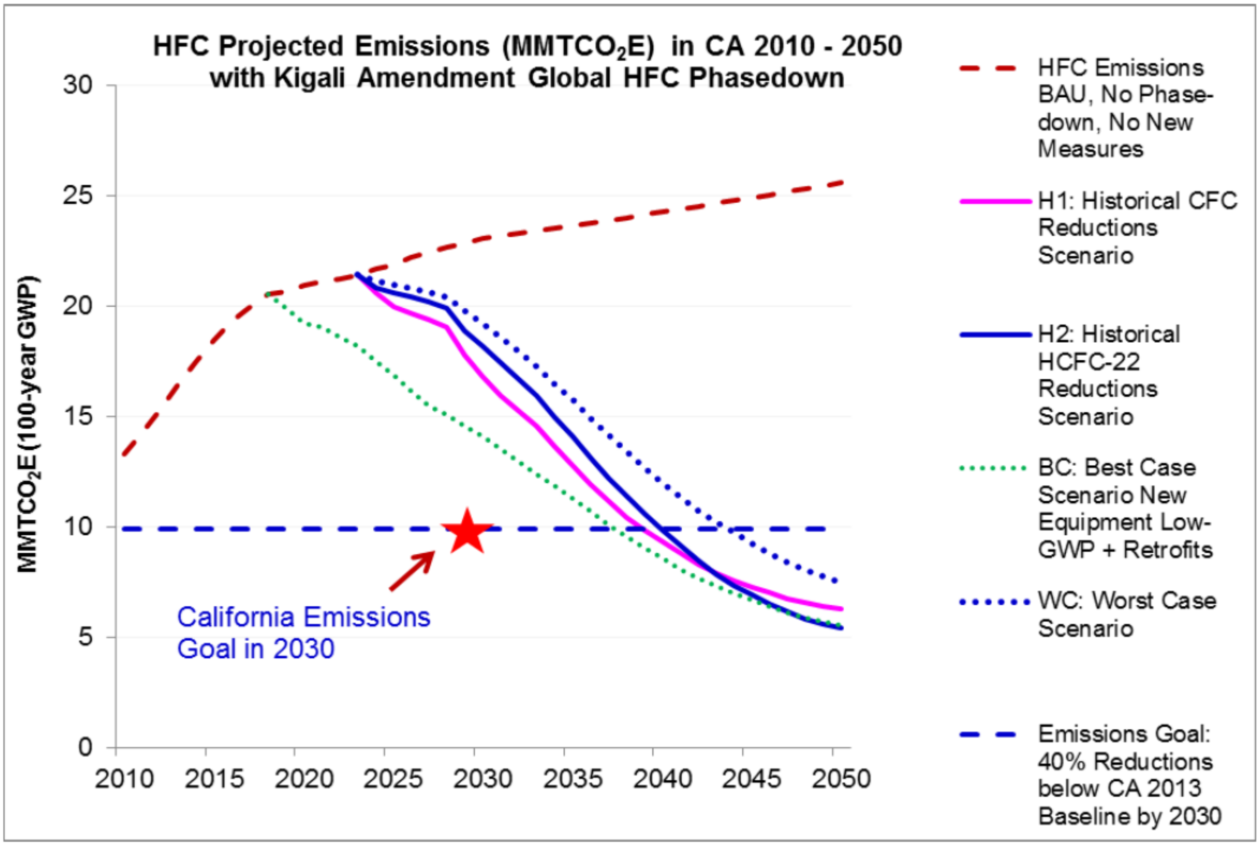
[33] https://www.govinfo.gov/app/details/USCOURTS-caDC-15-01328

[34] https://www.federalregister.gov/documents/2017/02/03/2017-02451/reducing-regulation-and-controlling-regulatory-costs

[35] https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006

[36] https://ww2.arb.ca.gov/resources/documents/potential-impact-kigali-amendment-california-hfc-emissions

Figure 5-1. Estimated HFC emissions in CA from the Kigali Amendment[37]



Source: California Air Resources Board, Potential Impact of the Kigali Amendment on HFC Emissions, Figure ES-1. Estimated HFC Emissions in CA from the Kigali Amendment, 12/15/2017

Up until the Kavanagh US District court ruling restricting the EPA's ability to regulate high-GWP HFC replacements to HCFCs, California was relying on federal HFC phasedown efforts to meet SB-1383 targets.

5.1.6 SB-1013 and fluorinated refrigerants

On September 13, 2018, then Governor Jerry Brown approved SB 1013, which included a new Section (39734) in the Health and Safety Code as follows:

"The Legislature finds and declares that certain fluorinated gases are potent causes of global warming, and it is in the public interest that restrictions or prohibitions on the use of these gases be maintained and enhanced as appropriate in the state."[38]

Among other things, SB-1013 calls for the reduction of fluorinated gases found in array of products that include air conditioning equipment, foam expansion agents, solvents, and fire suppressants.

SB-1013 calls to accelerate the adoption of low-GWP refrigerants and minimize emissions of fluorinated gases. Funding for these actions will come from the Fluorinated Gas Reduction Incentive Program (FRIP), the Greenhouse Gas Reduction Fund. The bill also specifies that the state board my issue penalties to violators of the requirements. SB-1013 states that the state board may modify deadlines,

37 https://ww2.arb.ca.gov/resources/documents/potential-impact-kigali-amendment-california-hfc-emissions

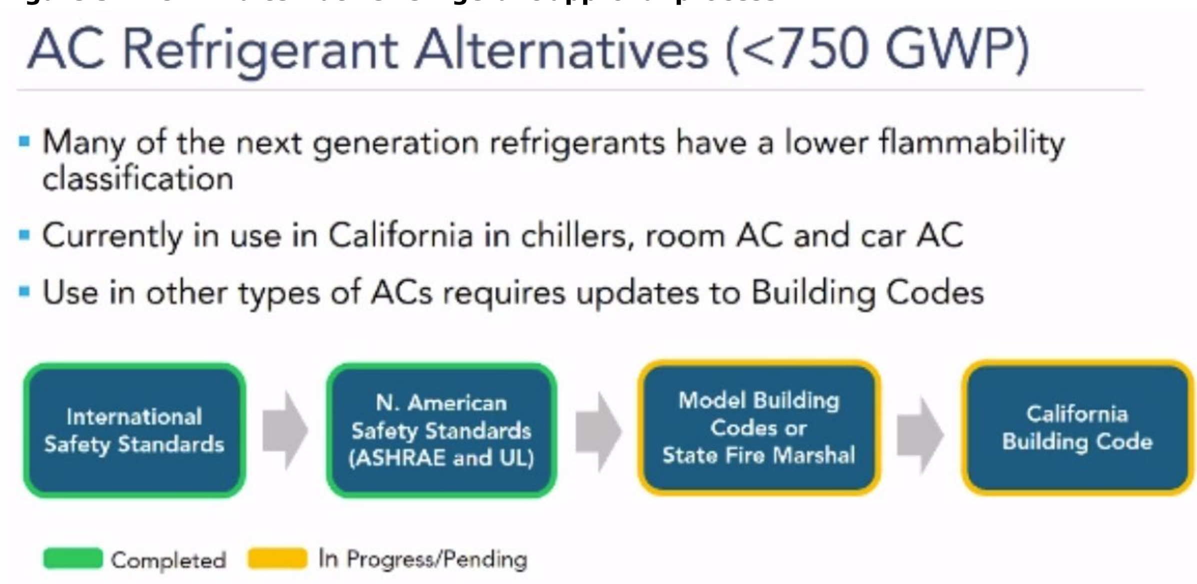
38 https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1013

if they reduce the risk to human health or the environment or if they reflect the earliest date a substitute is available.

Since 2017, CARB worked and engaged with stakeholders to develop the high-GWP rules for refrigeration and Air Conditioning equipment. Stakeholders, which includes the various players in the HVAC production supply chain, have raised significant concern that the January 2023 date is an untenable goal. The biggest concern is the fact that current California building and fire codes do not allow lower flammability A2L refrigerant in stationary HVAC equipment. There are indications the next California Title-24 code cycle set to be released in January 2022, will not include provisions that would allow the use of A2L refrigerants in HVAC equipment and it will most likely not be until January, 2024 when the interim code updates are released. However, until the codes are finalized, the supply chain maintains they can't know for sure what the new requirements will be and won't have enough time adjust their products in time for the 2023 deadline.

In October 2020, CARB released a notice of a; "Public Hearing to consider the proposed amendments to the prohibitions on use of certain hydrofluorocarbons in stationary refrigeration, chillers, aerosols-propellants, and foam end-uses regulation." A public hearing was held in December 2020, to discuss the proposed amendments and to hear public comment. In the proposed amendment CARB acknowledged many stakeholders expressed concerns about the ability to meet the January 2023 deadline to provide California customers with code compliant HVAC equipment operating on refrigerants with a 100-year GWP less than 750. A simplified flow chart which was presented by CARB in the December 2020, representing the standards and codes approval process for A2L refrigerants in stationary HVAC is presented in Figure 5-2 below.[39]

Figure 5-2. CARB alternative refrigerant approval process



CARB issued the following statement during the presentation of the slide shown in Figure 5-2 above:

> "In 2018 and 2019, ASHRAE and UL approved updated safety standards with provisions for the safe use of lower flammability refrigerants…This year (2020), the state fire marshal convened a working group to consider incorporating the latest ASHRAE and UL standards

[39] https://ww3.arb.ca.gov/board/books/2020/121020/20-13-4pres.pdf

into the California building code for 2023. The state fire marshal decision is not finalized at this time and the final decision could the delay potential building code updates from 2023 to the next code cycle."

The proposed amendment addresses the codes and standards time crunch by pushing the 2023 deadline back two years to January 2025 for stationary ACs and January 2026 for chillers. CARB will maintain the January 2023 requirement date for portable ACs and dehumidifiers.

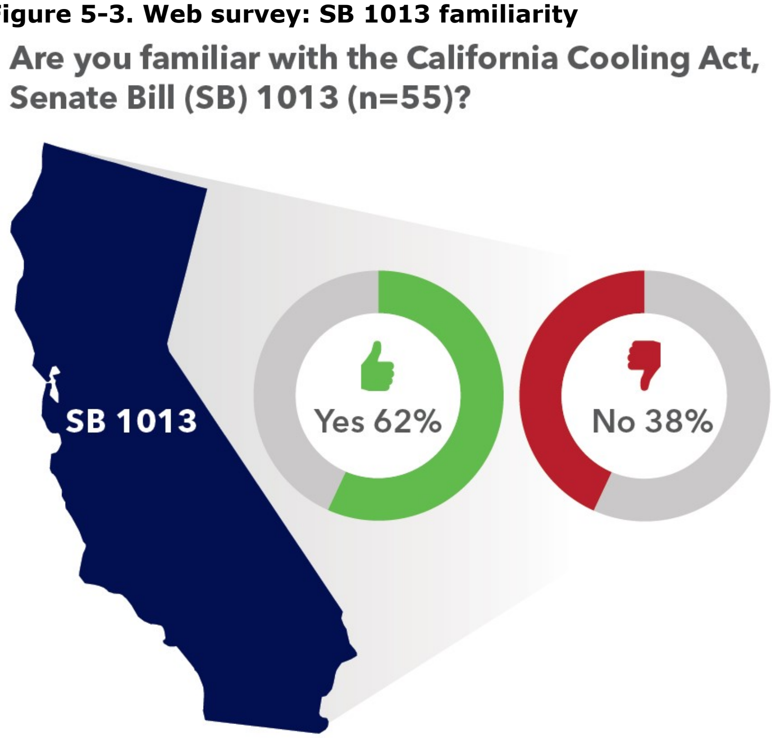
The proposes amendment also calls for the jumpstart of the Refrigerant Recovery, Recycle and Reuse Program (R4) and also calls for manufacturers to source 10% of their existing high-GWP HFC refrigerant needs from certified refrigerant reclamation facilities. The goal of this being to improve refrigerant recovery rates, create a market value for non-virgin or reclaimed refrigerant, and require less overall high-GWP HFC refrigerant from being produced. While at the time of writing this report the amendment hasn't been formally adopted, it is expected to be adopted in the first half of 2021.

If adopted, this amendment will give the HVAC supply chain two additional years to further design, test and build new A2L refrigerant equipment that meets the updated building and fire codes. Recent federal legislation indicates the process won't be limited to California.

5.1.7 HVAC refrigerant SMEs understanding of California regulations

In our IDIs with HVAC Refrigerant SMEs we asked every participant about their level of familiarity with regulatory policy impacting HVAC equipment. All respondents with regulatory policy familiarity were aware of SB-1013 and most were aware of the proposed amendment to push the deadline back from 2023 to 2025. Some of the respondents that admitted to not having significant expertise in HVAC regulations and policy were not immediately aware of the California Cooling Act or SB-1013, but later claimed they were aware of California legislation calling for low-GWP refrigerant in stationary HVAC by January 2023. Respondents to the HVAC refrigerant web survey showed mixed knowledge about SB 1013 as presented in Figure 5-3.

Figure 5-3. Web survey: SB 1013 familiarity

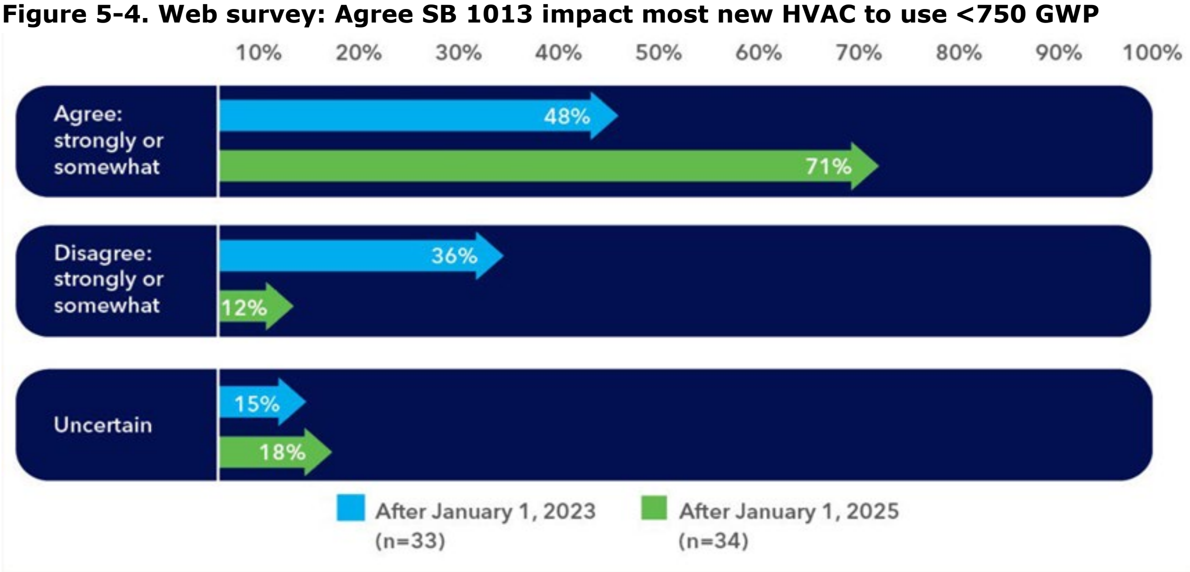


Q: Are you familiar with the California Cooling Act Senate Bill 1013?

All IDI respondents who represent some portion of the HVAC supply chain expressed concern over the lack of time to meet the 2023 deadline. While many felt the timeline was unreasonable, some still believed the OEMs would still be able to offer a few low-GWP HFC refrigerant equipment options by 2023. These same SMEs believe California customers will be not be happy with the lack of compliant equipment options available in 2023 if the CARB deadline does not get moved.

Considering all the feedback about the 2023 low-GWP deadline being rushed, coupled with the public hearing about an amendment to partially delay the transition to 2025, we wanted to elicit feedback from SMEs in the web survey about the perceived impact of SB 1013 in both 2023 and 2025. asking how strongly you agree that SB 1013 will result in most new California HVAC equipment installed after January 1, 2023 and January 1, 2025, to utilize a lower global warming potential refrigerant (100-year GWP < 750). The results of the two questions are presented in Figure 5-4.

Figure 5-4. Web survey: Agree SB 1013 impact most new HVAC to use <750 GWP



Q: How strongly do you agree that SB 1013 will result in most new California HVAC equipment installed after January 1, 2023 and then 2025, to utilize a low global warming potential refrigerant (100-year GWP <750)?

The overwhelming feedback from HVAC supply chain IDIs was that industry prefers the transition to A2L refrigerants be coordinated at the national level. Many SMEs brought up proposed federal legislation in both the US House and Senate that called for the phasedown of HFC refrigerants in compliance with provisions in the Kigali Amendment.

Given the IDIs took place during Q4 of 2020, DNV GL asked many SMEs the hypothetical question: If we have a new president in January, how quickly will the US move to back the Kigali Amendment? All agreed the Biden administration would take some kind of action to phasedown HFCs but many thought the most likely scenario would be one of the proposals in the House or Senate would be passed. One SME even predicted legislation would be passed in the final two months of the Trump administration.

5.1.8 Consolidated Appropriations Act, 2021 which includes Sec. 103, "American Innovation and Manufacturing Act of 2020"

On December 27, 2020, the US Congress enacted the Consolidated Appropriations Act, 2021, which includes $900 billing in stimulus relief for COVID-19 and $1.4 trillion in Omnibus spending for fiscal year 2021. Included in the Consolidated Appropriations Act is the American Innovation and Manufacturing Act (AIM), which was originally introduced in the senate by a bipartisan mix of 16 US Senators in 2019. The bill states:

> "To create jobs and drive innovation and economic growth in the United States by supporting and promoting the manufacture of next-generation technologies, including refrigerants, solvents, fire suppressants, foam blowing agents, aerosols, and propellants."[40]

The bill calls for the phasedown of HFC refrigerants and other controlled substances in line with the provisions of the Kigali Amendment. The impact of this will be that the rest of the country will join California in transitioning away from high-GWP HFC refrigerants, although at a slightly slower pace than California is seeking. In the end the passing of the AIM bill will still be a mixed bag for the HVAC supply chain stakeholders. There is no longer a question as to whether HFCs will be phased down on the national level but, California and possibly a handful of other states, will still pursue a more aggressive timeline for the transition.

Christina Starr, Senior Policy Analyst at the Environmental Investigation Agency, who provides regular analysis and technical input to CARB, summarized her thoughts on California's efforts to adopt low-GWP refrigerants as follows:

> "California should do everything possible to incentivize a transition to future-proof alternatives when it comes to refrigerants rather than send a signal that the market can take it's time getting there. Sending a signal that the goal is zero emissions from refrigerants is very important. This is because the incremental approach to refrigerants is very costly. Being clear on that is important. California has an opportunity to accelerate things in that direction and serve as a role model for US leadership on an international stage."

5.2 Refrigerant leakage, recovery, reclamation, and reuse

The single most effective way to reduce harmful global warming impacts from HVAC Refrigerants is to eliminate emissions. In the 1990s the EPA established Section 608 of the Clean Air Act to regulate the testing and certification requirements of technicians who maintain, service, repair, or dispose of equipment that could release refrigerants into the atmosphere.[41] According to many of the HVAC contractors or related SME's we spoke with about the release of EPA Section 608, the proposed fines and penalties included in this regulation, gave the HVAC industry quite a scare. However, all SMEs said that after a while it became clear there was little to no enforcement of the regulation. Some of the SMEs reported knowing of instances or even being witness to HVAC contractors reported to the EPA for egregious violations, only to never face any fines or penalties. While all the SMEs we spoke with said they strictly follow the rules and regulations of EPA Section 608, they also acknowledged there are some that don't have to save a time and money.

[40] https://www.congress.gov/bill/116th-congress/senate-bill/2754/text

[41] https://www.epa.gov/section608/section-608-technician-certification-0

All of this is widely known by the EPA and CARB. The EPA began performing annual inventories of US greenhouse gas (GHG) emissions and sinks in the early 1990s.[42] CARB performs a similar emissions inventory but uses a slightly modified methodology more specific to California as a region.[43] EPA categorizes HVAC refrigerant emissions into three distinct stages: emissions that occur prior to and during installation, emissions that occur during operation from leaks or servicing (reported on an annual rate), and emissions that occur at the EOL from venting, improper disposal, or leaks after recovery. CARB's emissions report does not include a separate category for emissions that occur during installations and it also varies the way the end-of life emissions estimates considers operational leakage impacts on the end-of-life remaining charge. CARB's emissions factors table includes a column that defines the estimated, "Number of years prior to EOL with no "top-off" refrigerant added to replace full charge."[44]

If the number is zero in this column the emissions factors workbook assumes that the equipment refrigerant charge is "topped off" so frequently that the full system charge will remain at EOL. This is the case for both chiller size categories as well as both commercial unitary HVAC equipment size categories. For smaller equipment types the number of years prior to EOL with no "top off" varies between 3 years for residential unitary ACs and Heat Pumps to the full average equipment lifetime for all remaining equipment types. That means CARB estimates assume portable ACs, window/room/wall ACs, PTACs, and dehumidifiers are essentially never given additional refrigerant charge over their operational lifetimes. DNV GL agrees with CARBs approach for assuming operational leakage will impact the remaining charge available at EOL however, the yearly interval rates of charge assumptions are higher than what DNV GL has typically seen when performing impact evaluation on HVAC refrigerant charge and maintenance programs.

For the purposes of comparison DNV GL combined the two emission rate estimates into one table. The EPA emissions estimates provide annual leakage rate average ranges while CARB defines the average annual leakage rate as a set percentage. In this comparison, the average of the EPAs leakage rate ranges is used. Some of the EPA equipment categories do not line up perfectly with CARB categories with CARB table categories being more granular than those in the EPA table. DNV GL's best attempt at combining the estimated emission rates can be found in Table 5-1.

Table 5-1. EPA and CARB HVAC operational emission rate comparison

Device Type	CARB Average Lifetime (years)	EPA First-Fill Emission Rates % (not included in CARB)	CARB Average Annual Operational Leak Rate	EPA Average Annual Operational Leak Rate	CARB Number of Years Prior to EOL with No "Top-Off" Refrigerant Added	CARB Percent of Full-Charge Emitted between Install and EOL	EPA Percent of full-Charge Emitted between Install and EOL
Large Chiller 2,000 lbs. +	20	0.35%	2%	6%	0	70%	129%
Medium Chiller 200-2,000 lbs.	20	0.35%	3%	1%	0	75%	20%
Commercial Unitary AC 50-200 lbs., > 135,000 BTUh size	20	0.75%	7%	8%	0	88%	166%

42 https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

43 https://ww2.arb.ca.gov/ghg-inventory-data

44 CARB, HFC Emissions Factors, August 2019

Commercial Unitary AC, < 50-lbs., < 135,000 BTUh size	15	0.75%	5%	8%	0	56%	125%
Window/Room AC and PTAC Units, commercial	12	0.88%	2%	2%	12	25%	29%
Residential Unitary AC	15	0.60%	5%	8%	3	55%	120%
Residential Heat Pumps	15	0.60%	5%	8%	3	56%	120%
Window/Room/Wall AC and Packaged Terminal AC (PTAC) Units, residential	12	0.88%	2%	2%	12	25%	29%
Portable AC	10	0.75%	1%	0.6%	10	10%	7%
Dehumidifiers	5	0.75%	1%	0.5%	5	5%	3%

Average end-of-life loss rates reported by the EPA and CARB vary across the two both in what the rates of emissions are, how the rates are calculated, and the granular equipment type categories. CARB end-of-life emission rates assume some equipment types have their refrigerant charges adjusted or "topped off" annually while for smaller equipment types like window and portable ACs, the lifetime average annual leakage is assumed to no longer present at end-of-life. The EPA estimates say, "Because equipment lifetime emissions are annualized, equipment is assumed to reach the end of its lifetime with a full charge. Therefore, recovery rate is equal to 100 percent – Disposal Loss Rate (%). In both emissions estimate sources, the HVAC equipment with the smallest charge levels have the highest rates of EOL emissions and the lowest are seen with chillers. The combined EPA and CARB estimated EOL loss rate or emissions rate of remaining refrigerant are presented in Table 5-2.

Table 5-2. EPA and CARB HVAC end-of-life emission loss rate comparison

Device Type	CARB Average Lifetime (years)	CARB Average End-of-Life Loss Rate of Remaining Refrigerant	CARB to EPA Adjusted Avg End-of-Life Loss Rate of Remaining Refrigerant*	EPA Average End-of-Life Loss Rate of Remaining Refrigerant
Large Chiller 2,000 lbs. +	20	20%	18%	10%
Medium Chiller 200-2,000 lbs.	20	20%	17%	10%
Commercial Unitary AC 50-200 lbs., > 135,000 BTUh size	20	20%	13%	29%
Commercial Unitary AC, < 50-lbs., < 135,000 BTUh size (includes smaller "residential-type" central AC and heat pumps)	15	56%	51%	29%
Window/Room AC and PTAC Units, commercial	12	99%	75%	45%
Residential Unitary AC	15	80%	65%	30%

Residential Heat Pumps	15	80%	64%	30%
Window/Room/Wall AC and Packaged Terminal AC (PTAC) Units, residential	12	99%	75%	45%
Portable AC	10	99%	89%	50%
Dehumidifiers	5	99%	94%	50%

CARB to EPA Adjusted Avg end-of-life loss rate of remaining refrigerant value incorporates the assumed annual operational leakage emission impacts CARB uses to demonstrate the EPA equivalent EOL loss rate value

Both the EPA and California have regulations that require commercial and industrial facilities with either refrigeration or HVAC equipment containing a refrigerant charge of 50 lbs. or more to track and document leakage rates. This applies to any refrigerant with a 100-year GWP level >150. Additionally, if a single piece of equipment shows to be leaking more than 25% of its full rated charge, owners are required to take measures to address the leak. Laws and regulations to minimize leakage from HVAC and refrigeration systems with charge levels over 50 lbs. have been in place for many years and the emission estimates associated with this equipment reflects these laws.

Leakage rates and end-of-life emissions were addressed in both the in-depth-interviews and in the web survey. All subject matter experts that reported to have knowledge on HVAC equipment maintenance and leakage were probed on this topic. When asked if regularly maintenance includes checks for refrigerant leaks all reported that such activities were rare. Again, all SMEs stated independently that it is now seen as best practice to avoid connecting hoses, gauges, or equipment of any kind to refrigerant service ports unless performance diagnosis lead them to believe that the unit was operating significantly under charged. Not wanting to introduce a leak, tamper with a Schrader valve, or introduce a foreign substance into the refrigerant system were common reasons given for this practice.

When asked if certain system types have higher incidents of leakage, all HVAC maintenance SMEs reported split-system AC or Heat Pump systems commonly seen in residential applications as having the highest leakage rates. In virtually all instances of split-system installations, refrigerant lines are set in the field to connect outdoor condensing units with the indoor fan coil unit. The field installations are more prone to human error relative to factory assembled portable units and package units. One HVAC maintenance SME also cited a rash of poorly designed evaporative coil units installed between 2006 and 2010, with high instances of formicary corrosion and leakage rates. When asked how frequently leaking equipment is repaired as opposed to being replaced, HVAC SMEs indicated it would vary entirely on the equipment and the equipment owner. For smaller equipment, older equipment, or on equipment when the leaks were too difficult to find, HVAC SMEs reported that often they would either replace the component that contained the leak or replace the unit entirely because it was the most cost effective solution.

5.2.1 Exploring leakage rates from other studies

We examined data from the 2013-2014 California Statewide Commercial Quality Maintenance [CQM] program to understand annual refrigerant leakage from commercial packaged HVAC systems that were serviced annually through the quality maintenance programs. These programs check the refrigerant charge annually using tests and adjust the refrigerant based on the test results. The amount of refrigerant added each year is equal to the amount that leaked out of the system in the previous year. According to the data, the average leakage rate is approximately 6% per year. One sub-group (R22 refrigerant type) showed slightly higher annual leakage rate, at almost 7%. Two sub-groups showed much lower leakage rates, on the order of 1.5% annual leakage. Those sub-groups were R410A systems which were predominantly TXV systems and SCE program participant systems. It makes sense that TXV systems would have fewer charge adjustments since the TXV acts to maintain the superheat/subcool at optimal operation points. We don't know why the systems in the SCE program had lower leakage rates.

One SME we spoke with at the UC Davis Western Cooling Efficiency Center referred us to a research study his colleague, Theresa Pistochini, recently completed looking at leakage rates across smaller HVAC equipment. Currently there's extensive tracking data on refrigerant charge activities and leakage rates for larger HVAC equipment containing at least 50 lb but marginal data on equipment that fall below the 50 lb charge level. The results of this study are currently under peer review, but the methodology and initial findings were presented in an October 12, 2020 presentation.[45] The study leveraged existing refrigerant tracking records kept by the East Side Union High School District in Santa Clara County. The district kept records of refrigerant quantities purchased over a four-year period and catalogs their extensive inventory of HVAC equipment using the AkitaBox online inventory software. The research reviewed hundreds of receipts, the AkitaBox database, and also performed on-site inspections to get accurate equipment model numbers, system types, refrigerant types, factory rated charge volumes for over 99% of the district's HVAC equipment. The preliminary results estimate leakage rates for the older inventory of equipment operating on the HCFC refrigerant R-22, was 2.8%. The results estimate the average leakage rates for relatively newer equipment operating on R-410a, was 0.7%. A summary of the calculation and the results is presented in Table 5-3.

While the findings do not present a statistically relevant representation of California HVAC equipment at large, there are several things to note about these findings

- Average leakage rates fall between 0.7 and 2.8% and most of the surveyed equipment types fall in the commercial Unitary AC equipment categories. This is a significant decrease compared to CARB estimate of 5% and the EPA estimate of 8%
- Leakage rates for equipment operating on the HFC R-410a was significantly lower indicating leakage rates are higher for older equipment.
- There is tracking data available that can be leveraged to perform a statistically relevant study on refrigerant leakage rates.

[45] University of California at Davis Western Cooling Efficiency Center, Global Energy Managers Workshop, 07/12/2020, https://www.youtube.com/watch?v=V8YpBEPb778&feature=youtu.be

Table 5-3. Wester cooling efficiency center, refrigerant use for maintenance and operations at a school district

Result - Refrigerant Use Calculation

Description	R22 (kg)	R410A (kg)
Assumed District Refrigerant Inventory March 1, 2016	0	0
Refrigerant Purchases, Supplier 1	545.5	11.4
Refrigerant Purchases, Supplier 2	109.1	22.7
Refrigerant Recovery, Supplier 3	(16.8)	0
Refrigerant Purchases, Service Contractor 1	109.5	0
Refrigerant Recovery, Service Contractor 1	(13.2)	0
Refrigerant Purchases, Service Contractor 2	0	13.1
Refrigerant Purchases, Service Contractor 2 (pending)	0	28.6
Refrigerant Purchases, Service Contractor 3	2.3	4.5
Reported District Refrigerant Inventory May 20, 2020	(150)	0
Net Refrigerant Used for Maintenance and Operations March 1, 2016 to May 20, 2020	586.4	80.3
Average Refrigerant Use Per Year (over 4.22 years)	139	19
Average Refrigerant Charge of District HVAC Systems	5039	2813
Average Calculated Percent of Total Refrigerant Charge Consumed for Maintenance and Operations	2.8%	0.7%

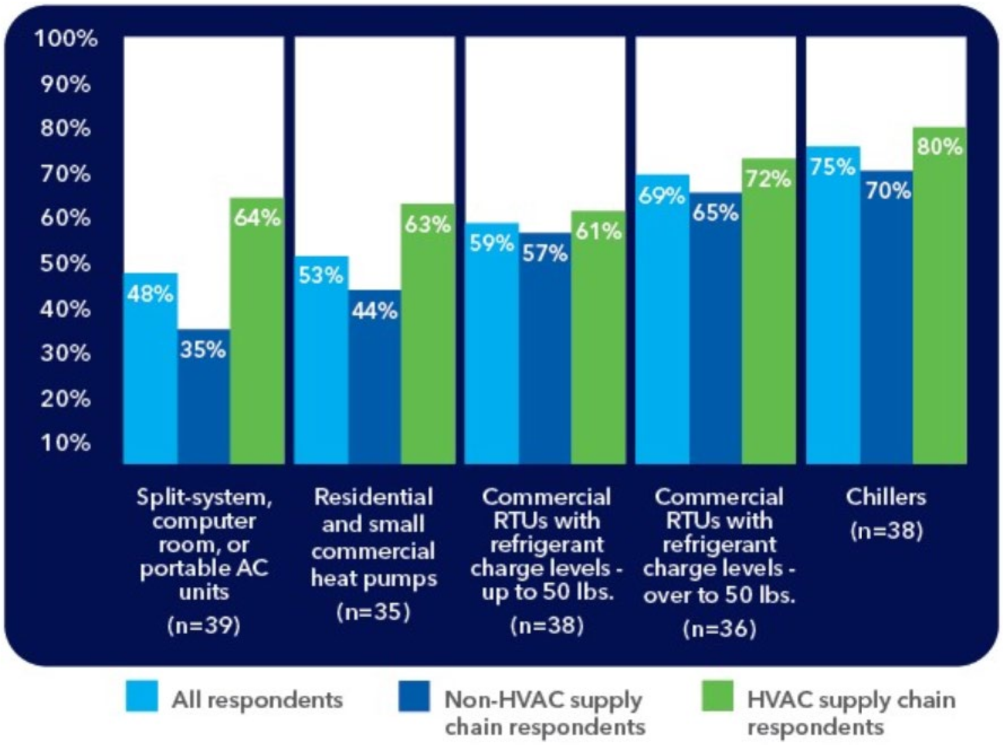
UC DAVIS Western Cooling Efficiency Center

Source: University California at Davis Western Cooling Efficiency Center, Global Energy Managers Workshop, 10/12/2020, https://www.youtube.com/watch?v=V8YpBEPb778&feature=youtu.be

For end-of-life recovery and reclamation all HVAC SMEs we spoke with reported it is standard practice to recover the remaining refrigerant. They include the cost to recover the refrigerant, have the recovered refrigerant tanks picked up by a licensed refrigerant reclaimer, and the cost to dispose of the removed equipment, in with the overall cost of the new unit. One HVAC SME reported that in events when they are extremely busy, they will contract out the task of recovering remaining refrigerant and removing equipment to prioritize internal employees time for new equipment installations. All SMEs said they knew of "outfits" that would cut corners when it came to recovering remaining refrigerant. When asked what barriers are preventing 100% recovery of remaining refrigerant, almost all cited lack of enforcement, with a few citing the lack of monetary incentive to recover and sell the refrigerant.

In the web survey we asked respondents to estimate the successful reclamation rate of remaining refrigerant at end-of-life across five different equipment size category bins. Unlike most other web survey questions asked, for this question, the results of the web survey showed a consistent disparity between the non-HVAC supply chain participant responses and the HVAC supply chain responses. Not all participants provided an estimated value for every equipment category, so the number of responses varies by equipment category. The results of each group of respondents as well as the overall average is presented in Figure 5-5.

Figure 5-5. Web survey: What percent remaining refrigerant is reclaimed at EOL



Q: What percent of the following HVAC equipment types have the remaining refrigerant reclaimed at the end-of-life?

There are several things to note when comparing these results with the emission rate estimates by the EPA and CARB.

- Figure 5-5 presents the estimated successful reclamation rate where the EPA and the CARB tables (Table 5-1) present the estimated emission rates.
- The HVAC supply chain respondents have significantly more optimistic estimates for reclamation success rates for the smaller equipment types than the non-HVAC supply chain respondents with that disparity narrowing considerably for the commercial RTUs and chiller categories.
- The web survey question asked what percent of the remaining refrigerant and not what percent of the full rated charge is successfully reclaimed. Operational leakage that goes uncorrected is not included in this estimate like it is in CARB estimate.
- Everyone agrees the smaller the equipment the less likely it is to have the remaining refrigerant properly recovered.
- Given the level of rigor and effort by both the EPA and CARB to develop their EOL emission, these estimates show how even HVAC SMEs overestimate the EOL recovery rates.

5.3 In the web survey we asked respondents to provide one or more recommendations as to how the state of California could improve the end-of-life refrigerant reclamation success rate. Below are some of the most compelling

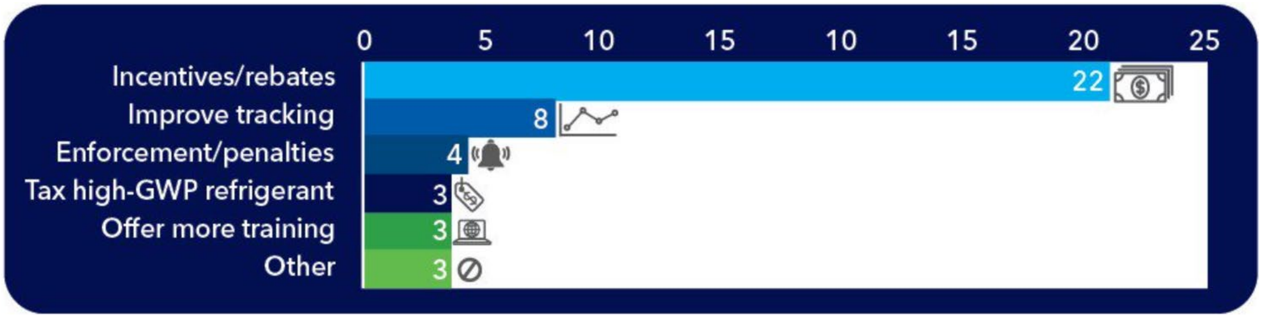
comments received. A complete listing of the 39 responses received can be found in

Appendix .

- "Market forces need to create a value to the certified contractor to 1) recover the gas responsibly under Refrigerant Management rules and, 2) deliver the "dirty" gas to a certified reclaimer. The reclaim industry must have an integrous process, certified by third parties to 1) certify the reclamation (mass balance and purity) and 2) sell the certified reclaim only through auditable channels such as OEM's and licensed wholesalers and contractors."—Bruce Ernst, Executive VP Regulatory & Government Affairs, A-Gas
- "Review operation and lessons learned from other nations and/or states that have EOL refrigerant reclamation systems in place today, especially for A2L refrigerants."—HVAC Original Equipment Manufacturer
- "Build value to incent the contractor to reclaim; support streamlined reclamation processes with contractors and distributors."—HVAC Original Equipment Manufacturer
- "1. Ban virgin high-GWP refrigerants (>750) for servicing existing equipment starting in 2025 (require use of reclaim but allow it to come from out of state until 2030 to allow ramp up in supply). 2. Tax/fee on the sale of virgin refrigerants that are >150 GWP but less than 750 GWP, use the proceeds to fund rebates for recovery and reclaim, i.e. amt of refrigerant a servicing company verified through R4 program as having recovered and delivered for reclaim gets a corresponding rebate. 3. Create a robust R4 certification program for verifying recovery and emission reductions in California that includes a traceability mechanism for lifecycle of refrigerant recovered from within California and then reclaimed: i.e. an app used to scan bar codes on reusable cylinders required to be scanned and entered at points of a) initial collection/recovery b) received by reclaimer c) sold reclaim refrigerant. 4. Mandate reusable cylinders with barcodes for reclaimed refrigerant."—Christina Star, Senior Policy Analyst at the Environmental Investigation Agency
- "To effectively transition to low GWP refrigerants will require equipment manufacturers to also modify compressor technology to not only accept these new Freon's but to also keep pace with Title 24 energy codes and equipment efficiency levels. We expect there to be a variety of low GWP refrigerants used based on equipment capacity requirements. It will also be important that equipment is designed to make use of heat recovery in order to improve the overall system COP and further reduce greenhouse gas emissions. I also believe the use of natural refrigerants like ammonia, CO2 and propane will have a place for certain commercial applications."—HVAC Distributor
- "Enforce the damn law. Require a permit to replace major HVAC equipment, and require a building inspector to be on-site during HVAC change-outs to verify that the contractor is recovering refrigerant at end-of-life. Penalize the s*#@ out of companies that vent and quadruple the penalty for repeat offenders."—Environmental policy, research, consulting
- "From experience only the regulatory control of refrigerant management systems will force compliance. We hear too many times from technicians and contractors that since there is no 'real' control or enforcement of the requirements many contractors simply lower their prices to be hyper-competitive and 'dump the refrigerant.' By 'dumping' they seem to mean venting it."—HVAC Contractor

In total 38 of the 55 web survey participants provided responses to the request for reclamation rate improvement question. Some of the responses were not directly related to improving the reclamation rate of refrigerant at EOL. Those that were relevant were binned into one or more common recommendation categories they covered. The refrigerant reclamation and recovery focused results of the open-ended response binning exercise are presented in Figure 5-6.

Figure 5-6. Web Survey: Ways to improve end-of-life refrigerant reclamation



Q: Please provide one or more suggestions on how the state of California could improve the end-of-life refrigerant reclamation success rate.

5.4 Current and future low-GWP refrigerant alternatives

This section discusses the current and future low-GWP refrigerants identified through DNV GL's secondary research and IDIs. Based on these findings, the consensus for a viable low-GWP candidate must possess the following attributes:[46]

- Zero (or very low) ozone-depletion potential
- Chemical stability within the refrigeration system
- Thermodynamic properties suitable for HVAC application. Have properties that are a relatively close match to the baseline refrigerant that they are replacing
- Low toxicity and other practical considerations, such as compatibility with the materials of construction
- 100-year GWP level below 750 for short-term alternative refrigerant. 100-year GWP close to zero for long-term alternative refrigerant

Existing safety codes require nonflammable refrigerants for typical applications, but that requirement is being reconsidered. The commonly acceptably flammability and toxicity ratings based on ASHRAE Standards 34 is A1, but A2L and in some cases A3 is also being considered. Table 5-4 provides the safety group classifications.

[46] Mclinden et al, 2017. Limited options for low-global-warming-potential refrigerants, Nature Communications.

Table 5-4. ASHRAE Standards 34 refrigerant ratings[47]

SAFETY GROUP

INCREASING FLAMMABILITY

Higher Flammability	A3	B3
Flammable	A2	B2
Lower Flammability	A2L	B2L
No Flame Propagation	A1	B1
	Lower Toxicity	Higher Toxicity

INCREASING TOXICITY

Common refrigerants used in HVAC systems are typically classified based on their chemical composition and the same classification typically processes similar characteristics. Here DNV GL discusses their suitability as future refrigerants according to the attributes listed mentioned earlier.

1. Hydrochlorofluorocarbon (HCFC): R-22, R-123 or other similar refrigerants that are comprised of Hydrogen, Chlorine, Fluorine, and Carbon. All HCFC have non-zero ODP and per Montreal Protocol, developed countries may only use HCFCs for servicing existing equipment (not new equipment) starting in 2020. All HCFC will be phased out by 2030.
2. Hydrofluorocarbon (HFC): R-32, R-125 R-134a or similar refrigerants that are comprised of Hydrogen, Fluorine, and Carbon. They typically have high GWP and no ODP. HFC blends, such as the most used R-410A is also considered HFC refrigerant. Despite R-410A's good thermodynamic, no flame propagation, and nontoxic characteristics, its high GWP (2087 GWP100) poses a threat to the global warming and is being phased out in the near future. R-32 has lower GWP than R-410A with relatively good thermodynamic properties. However, it is mildly flammable and therefore requires special consideration if used in HVAC systems. Nonetheless, R-32 is one of the promising short-term low-GWP refrigerant alternatives to R-410A since it has the best overall attributes compared to other alternatives. R-466A is a relatively new refrigerant developed by Honeywell as a direct drop-in alternative to R-410A. It has comparable thermodynamic properties as R-410A and also have ASHRAE A1 (no flame propagation/non-toxic) ratings while reducing the GWP100 to 733.
3. Hydrofluoro-olefin (HFO): R-1234yf, R-1234ze(E) or similar refrigerants that are composed of hydrogen, fluorine and carbon. HFO refrigerants have zero ODP and low and therefore are more

[47] ASHRAE, 2016. ASHRAE Standards 34: Designation and Safety Classification of Refrigerants.

environmentally friendly than CFCs, HCFCs and HFCs. R-1234yf is the most common HFO in production, however the cost is approximately ten times more expensive than that R-134a (Expected to drop to two or three times in long term when the patent expires). HFO-1234ze(E) is second most developed HFO in terms of production capacity. It is also a component in many blends (R-444A, R-444B, R-445A, R-447A, R-447B) and is suitable for stationary AC/heat pump applications. R-1233zd(E) is mostly used as liquid blowing agent but is also used as a replacement for R-123 in centrifugal chillers (SNAP). It is A1 rated (nonflammable, nontoxic) which is a distinct advantage in terms of regulatory approval and consumer acceptance over other HFOs. R-1336mzz(Z) is marketed as blowing agent but is also SNAP listed for use in chillers. R-513A (R-1234yf and R-134a blend) has ASHRAE A1 rating and low-GWP, which can be good candidate for large chiller operations where operating pressure is low. Based on the IDI response, R-513A can't be used as R-410A replacement for residential application because "in smaller system, there is lots of pressure drop and cause too much efficiency loss". Overall, HFOs are long-term low-GWP alternatives while manufacturers working on to optimize the production to make them more cost-effective.

4. Hydrocarbon (HF): Propane, ethane or similar refrigerant that are composed of hydrogen and carbon, which occurs naturally and found in crude oil. Hydrocarbons, are considered natural refrigerants, have zero ODP, and very low GWP levels (close to 1). However, they are typically highly flammable, which requires enhanced safety standards for transportation, proper handling, and operation, which is prohibitive in US residential applications at charge levels above 150 grams which includes virtually all HVAC options on the market today. In parts of Europe and Asia regulations allow hydrocarbon charge levels up to 500 grams in "hermetically sealed" refrigerant systems. The increased charge level opens up the potential for smaller AC and Heat Pump systems to efficiently operate on 500-gram hydrocarbon charge levels.
5. Inorganic natural refrigerants: CO2, ammonia or other inorganic refrigerants. They typically have very low GWP and are relatively inexpensive to produce. CO2 is a promising candidate as it meets most of the attributes except that the CO2 system operates at extremely high pressure (over 1000 psig) if used in HVAC application. This significantly increases the system cost and can be a potential hazard if the system fails. Additionally, as one of the IDI interviewees indicated, "CO2 works well in low-ambient temperature, high ambient temperature will push CO2 to trans-critical cycle which will lose efficiency." However, "CO2 is good for Heat Pump Water heater because the gas cooler side temperature profile matches the water heating profiles." Other natural refrigerants also have their own limitations, for example, ammonia is toxic despite its favorable thermodynamic properties and ASHRAE A1 (no flame propagation) ratings.

In our research and through our discussions with HVAC manufacturers, it's become clear the transition from high-GWP HFCs like R-410a and R-134a to low-GWP A2L HFCs will not be the last. In other parts of the world the shift towards natural refrigerants like hydrocarbons, ammonia, and CO_2 is well underway. Widespread adoption of natural refrigerants is a key milestone needed meet the full phasedown schedule of the Kigali Amendment. Because of the aggressive goals found in Europe's F-Gas regulations they are already ahead of the Kigali Amendment prescribed phasedown. HFOs will also be in the mix long-term but both their cost, high production energy intensity, and stability make them slightly less appealing long-term solutions. Undoubtably the immediate options for California will be A2Ls.

Figure 5-7 presents a rough approximation of historic, present, and anticipated future HVAC refrigerant installation rates by refrigerant category. We also provided several noteworthy events or milestones that contributed to the refrigerant trends at the time.

Figure 5-7. Historic, present, and likely future California HVAC refrigerant installation rates by overall market share

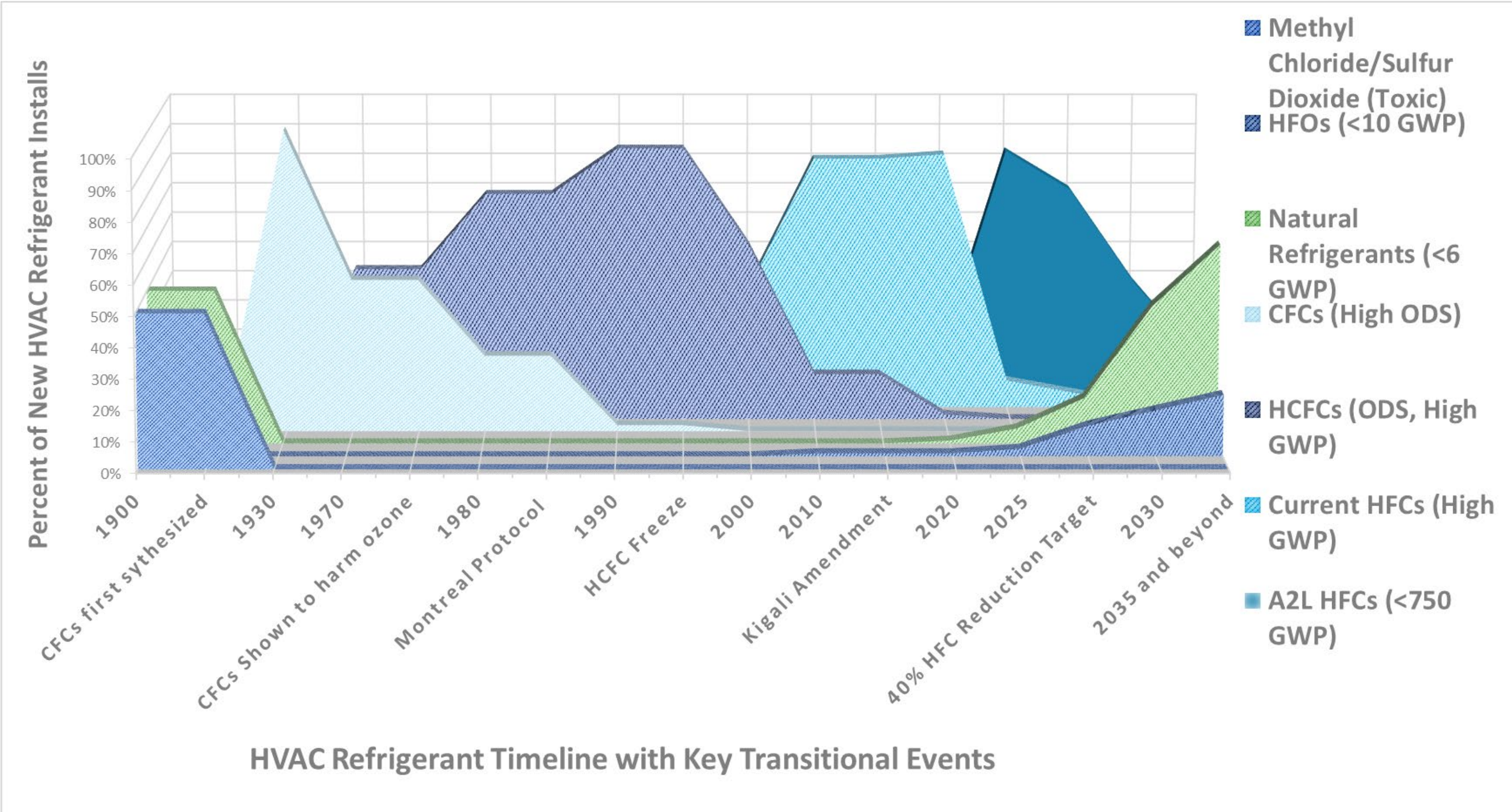


Table 5-5 summarizes the common current and future refrigerants identified by this study and their typical applications. The major hurdle for the short-term low-GWP refrigerants is flammability.

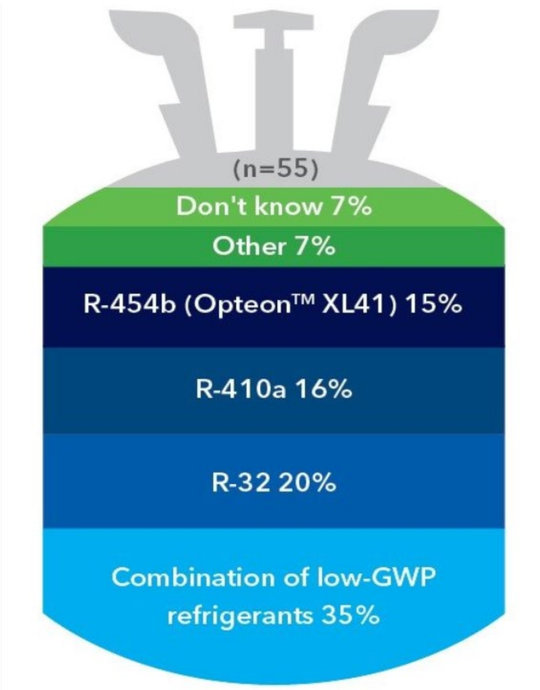
Table 5-5. Common refrigerants and their applications

HVAC Equipment Type	Current Common Practice	GWP	ASHRAE Standard 34 Safety Classification	Short-Term Replacement (less than 750 GWP)			Long-Term Replacement (ideally less than 10 GWP)		
				Refrigerant	GWP	ASHRAE Standard 34 Safety Classification	Refrigerant	GWP	ASHRAE Standard 34 Safety Classification
Centrifugal & Screw Chillers	R134a (large)	1430	A1	R-513A	630	A1	R744 (CO_2)	1	A1
	R123 (very large)	80	A1	HFO-1234ze(E)	<1	A2L	R-290 (Propane)	4	A3
				HFO-1336mzz	2	A1	R-600a (Isobutane)	5	A3
Scroll Chillers	R410a	2088	A1	R-32	675	A2L	R744 (CO_2)	1	A1
				R-454B (DR-5A)	476	A2L	HFO-1234yf	4	A1
RTUs	R410a	2088	A1	R-452B (DR-55)	698	A2L	HFO-1234yf	4	A1
				R-447B	739	A2L	HFO-1234ze(E)	<1	A2L
				ARM-71a	460	A2L	R744 (CO_2)	1	A1
				R-454B (DR-5A)	476	A2L	R-290 (Propane)	4	A3
				R-32	675	A2L			
Heat Pumps	R410a	2088	A1	R-32	675	A2L	HFO-1234yf	4	A1
							R744 (CO_2)	1	A1
				R-452B (DR-55)	698	A2L	R-600a (Isobutane)	5	A3
				R-454B (DR-5A)	476	A2L	R-290 (Propane)	4	A3
Split, CRAC, & Portable Systems	R410a	2088	A1	R-32	675	A2L	HFO-1234yf	4	A1
				R-452B (DR-55)	698	A2L	R-290 (Propane)	4	A3
				R-447A (L41-2)	583	A2L	R744 (CO_2)	1	A1
				ARM-71a	460	A2L			
				HPR-2A	600	A2L			

Subject matter experts we spoke with in the IDIs with direct knowledge of HVAC manufacturing and R&D were asked about the future of HVAC refrigerants. Specifically, we asked if they believed the upcoming transition away from higher-GWP refrigerants will unfold similar to the way the transition from HCFCs to HFCs or R-22 to R-410a did over the past 20 years. All said that while the idea would be nice, they don’t anticipate the transition will be as simple this time around. The DNV GL interviewers shared the above table of both near term and long term lower to near zero GWP refrigerant alternatives with the SMEs via screensharing. Many called out the recent adoption of R-32 in mini-split systems and heat pumps in Europe and Asia. For long-term options one SME was adamant pure CO2, or R-744 would become a viable option for commercial HVAC and possibly in heat pumps as well in the next 5-10 years. Others voiced concerns about the long-term stability, cost implications, and potential refrigerant glide issues associated with the HFO blends with 100-year GWPs below 10.

In the web survey we asked respondents to indicate what do they anticipate will be the most common refrigerant used in California residential and light commercial unitary HVAC equipment installed after January 1, 2025? The results show a diversified mix or low-GWP refrigerants with even some anticipating the current high-GWP R-410a will still be the most common in 2025 as shown in Figure 5-8.

Figure 5-8. Web Survey: Anticipated most common HVAC refrigerant installed in 2025



Q: What do you anticipate will be the most common refrigerant used in California residential and light commercial unitary HVAC equipment installed after January 1, 2025? Because this question is targeting unitary equipment, we are not including CO2 as a likely fluid in the near term.

5.5 Barriers and solutions of low-GWP adoption in new HVAC

The single biggest barrier of adopting low-GWP refrigerants is the issue of flammability. Virtually all low-GWP alternative refrigerants with comparable performance characteristics of the existing refrigerants have an ASHRAE Standard 34, A2L (slighting flammable) classification. This classification is significantly different from the ASHRAE Std. 34, A1 (no flame propagation) classification of existing refrigerants (R-410a, R-22, and R-134a).

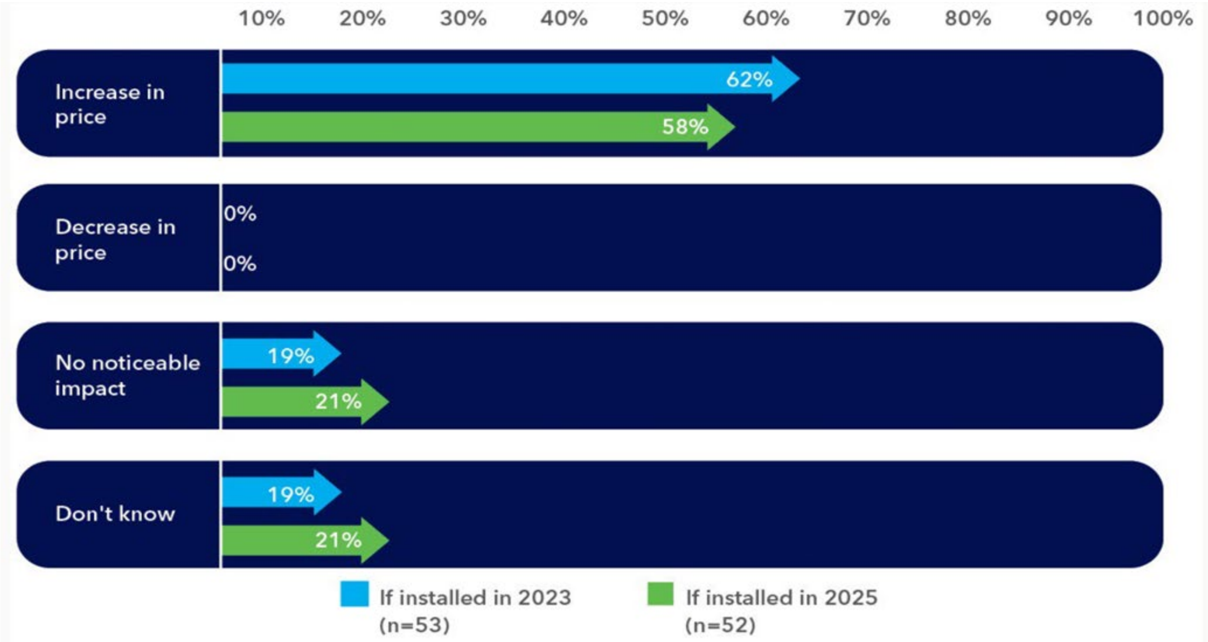
It will not be until the next California building code cycle update, in January 2022, that potential modifications may be adopted that would allow for A2L HVAC refrigerants. ASHRAE, United Laboratories (UL), the International Commercial Code (ICC), the Uniform Mechanical Code (UMC), and other local jurisdictional authorities all play a role in developing protocols and adopting rules that allow for the legal installation of A2L HVAC refrigerants. All of the HVAC supply chain SMEs we spoke with said the industry would need a bit of time after all the applicable building codes and regulations permit low-GWP A2L refrigerants. The amount of time stated by the SMEs varied between six-months and three-years. We asked this question as well in the web survey and **the average time given was two-years**. There was virtually no disparity between respondents from the HVAC supply chain and non-HVAC organizations. The distribution of results is presented in Figure 5-9.

Figure 5-9. Web survey: Minimum lead time to transition to <750 GWP refrigerants following code finalization

Q14_What is the minimum lead time needed for the HVAC supply chain to successfully transition to low-GWP HVAC refrigerant technologies and installation procedures once code updates allow for a ASHRAE A2L (mildly flammable) HVAC refrigerants in California? (10 don't know responses also provided)

As previously mentioned, many IDI SMEs said they would prefer if the transition to low-GWP HVAC refrigerants occurred simultaneously across the country, but (at the time of the interviews) it appeared California would blazing the path before most of the US. Many SMEs believed the disjointed adoption rate of A2L HVAC refrigerants would mean things get rushed. Some speculated the HVAC supply chain would pass down the increased cost of equipment directly to California customers alone. They also anticipated there would be limited options available in California until the rest of the national market made the transition. It appears that with the passing of the AIM Act in the 2021 Omnibus Bill, the entire US may attempt to also meet the 2025 phase-down date with California. The feedback from the IDIs lead to the web survey question asking what impact the transition to <750 GWP HVAC refrigerants will have on the cost paid by end-customers. The web survey asked what the cost impact would be in 2023 and then what the impact would be if installed in 2025 as shown in Figure 5-10.

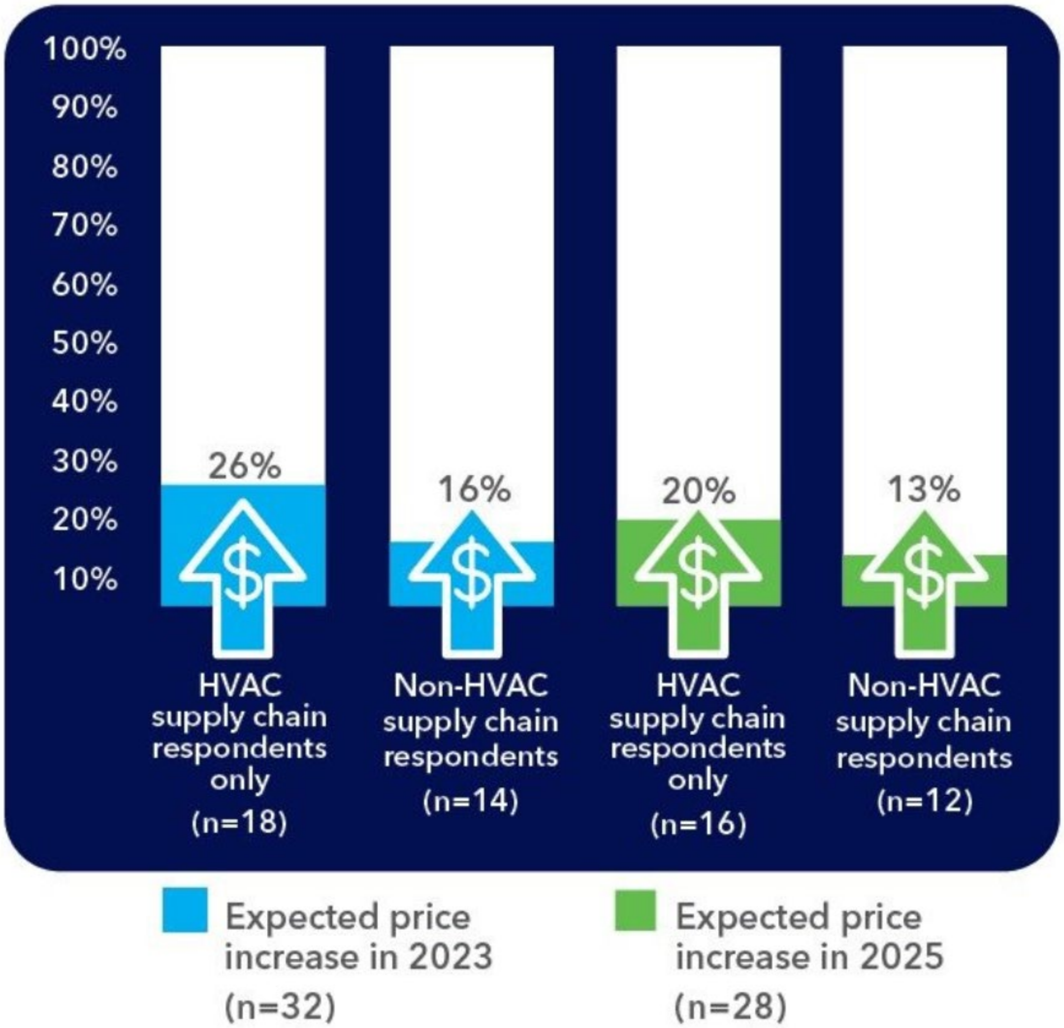
Figure 5-10. Web survey: Cost impact of <750 GWP new HVAC in both 2023 and 2025



Q: The transition to new HVAC equipment utilizing low-GWP refrigerants may impact the cost paid by the end-consumers. Please provide your best estimate on how this will impact the cost of new low-GWP installations in California in 2023 and 2025.

Not surprisingly, zero respondents expect the transition will decrease prices and most believe prices will increase. For the respondents that said prices would increase we asked them to indicate what percent the price increase will be if the transition happens in 2023 and then again if the transition happens in 2025. The average price increase estimate for all respondents is 21% in 2023 and 17% in 2025. The results show a disparity when comparing the average increase estimates from HVAC related responses with the responses of everyone else as shown in Figure 5-11.

Figure 5-11. Web survey: Average estimated price increase reported by respondent sector



Q: How much do you expect the transition to a low-GWP refrigerant will increase the price of the equipment for the California consumer in year 2023 and in year 2025?

CARB performed an analysis to see what impact the transition to low-GWP HVAC refrigerant equipment will have on cost paid by California customers in terms of equipment and installation costs. This analysis was presented in an October 20, 2020, CARB staff report. In the report CARB presented what it called a conservative cost impact assessment that assumed California would be initially advance the HFC phase down requirements ahead of the US at large. This assessment predicted California customers would pay between 4-8% more for the combined equipment and installation cost of low-GWP equipment.[48] CARB report also noted the incremental cost increase would likely come down as other states or the US as a whole adopted the HFC reduction mandates and low-GWP HVAC equipment became standard.

[48] The California Air Resources Board, Staff Report: Initial Statement of Reasons, Public hearing to consider the proposed amendments to the prohibitions on certain hydrofluorocarbons in stationary refrigeration, chillers, aerosols-propellants, and foam end-uses regulation, 10/20/2020

5.6 Barriers and solutions to refrigerant only retrofits on existing HVAC

Many challenges exist preventing safe and effective refrigerant only retrofits on existing HVAC equipment. Under ASHRAE Standard 15, changing the refrigerant to a different safety classification would require among other things that, “the system shall comply with the requirements of this standard for a new installation, and the change of refrigerant shall require (the) authority having jurisdiction approval.” [49] Current state and county building codes do not permit common residential and commercial HVAC equipment to contain refrigerants with any flame propagation.

Once all the hurdles preventing the safe and legal adoption of A2L refrigerants are cleared, there may be scenarios where existing high-GWP refrigerant HVAC equipment can be retrofitted with low-GWP A2L refrigerants. Depending on the size of the refrigerant charge, the location of the equipment, and the flammability level of the refrigerant itself, there would be varying levels of leakage detection, ventilation, and possibly leakage mitigation measures required. Aside from saying, “that would be illegal,” most contractors responded to questions about the feasibility of a refrigerant only change-out on existing HVAC with skepticism. Not knowing exactly what the soon-to-be finalized building, fire, and mechanical codes will mandate for A2L refrigerants, the SMEs we spoke with were hesitant to say such retrofits would be feasible. The SMEs did concede some refrigerant only retrofits could be feasible when presented with a hypothetical scenario in which such a project would be incentivized through some type of IOU program, especially if the retrofits targeted larger unitary HVAC equipment or chillers.

One category of HVAC equipment that poses an almost insurmountable challenge for A2L refrigerant only retrofits is residential style split system ACs. Virtually all split system ACs require on-site welded joints to connect the refrigerant lines between the interior evaporative coil and the exterior condensing unit. Because the increased leakage potential associated with welded joints, the introduction of even a mildly flammable refrigerant in this scenario, shows little promise. Anything with an ignition source also presents a significant additional barrier. Residential split-system ACs are commonly paired with natural gas combustion furnaces housed in the same air handler/location as the evaporative coil. The combined risks associated with a moderately flammable refrigerant leaking in this scenario make the consideration of an A2L type refrigerant retrofit a non-starter for forced air furnace/split system AC systems. What’s more electrification goals should prioritize replacing existing split-AC/gas furnace systems with lower or low-GWP split-system heat pumps. The overall global warming potential benefits of this action, when considering the avoided natural gas usage, are significant.

As mentioned in section 5.4 one alternative refrigerant does exist with an ASHRAE A1 (no flame propagation) classification and a 100-year GWP level below 750. That refrigerant is Honeywell’s Solstice N41 or R-466a, with a 100-year GWP level just below the 750 GWP threshold at 733. A June 2018 article in coolingpost.com says that “While not actually claiming that N41 would be a “drop-in” replacement for R410A, Honeywell states that early tests have indicated that switching to Solstice N41 would require minimal changes to equipment and may allow OEMs to easily convert from R410A.”[50] While both simulated and lab performance testing shows R-466a to have close to equivalent performance as R-410a, it is not seen as a long-term replacement for R-410a. For one reason, long-term alternative low-GWP solutions must have a low GWP value, meaning something closer to 1 than

[49] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Standard 15, 2019, Section 5.3, https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_15_2019

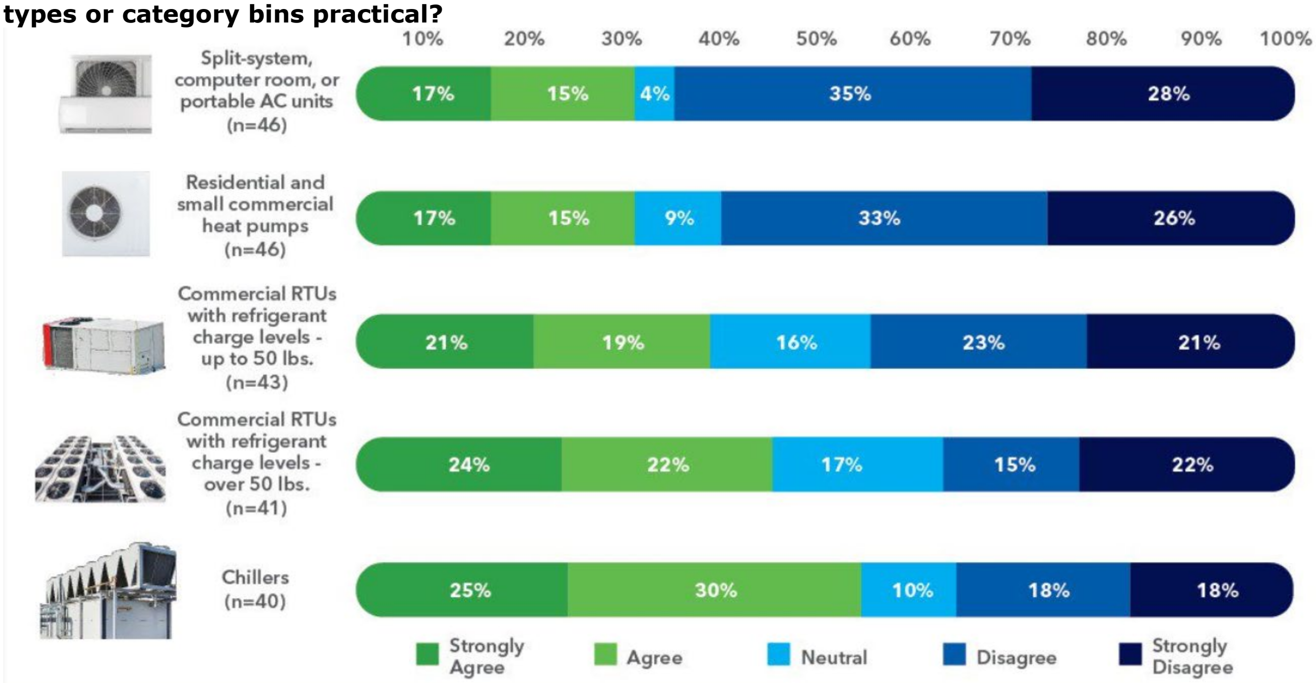
[50] Coolingpost.com, Honeywell announces R410A breakthrough, 6/26/2018, https://www.coolingpost.com/world-news/honeywell-announces-r410a-breakthrough/

750, ideally much closer to 1. Additionally, there is a small component of R-13I1 (tri-fluoroiodomethane) included in R466a that has not been previously used in refrigeration. R-13I1 is not traditionally used in refrigeration and that is controversial because of its slight trace in ozone depleting potential. The presence of this substance brings into question the long-term chemical stability of R466a and warrants further testing.[51] There is also concern about the price Honeywell will charge for this as it is under copyright protection and the price-point Honeywell will charge for the fluid is still yet to be determined. In terms of performance it falls short of the other leading <750 GWP candidates, and it's relatively unproven. Manufacturers have been planning and are ready to make the transition to mildly flammable refrigerants. R-466a is seen as a step in the wrong direction by most.

For smaller HVAC equipment regardless of the alternative refrigerant flammability, there is an over-arching concern that testing, adjusting, or altering the refrigerant unit comes with an added risk of introducing leakage. When asked if typical maintenance on residential or smaller commercial sized equipment includes refrigerant charge testing, the answer was always "no." Every single HVAC contractor we spoke with indicated they will only test the refrigerant charge on a unit if there is a problem and diagnostic tests rule out most other common issues. By and large their goal when servicing equipment is to leave the refrigerant lines untouched in the hopes that the existing charge is holding well. This approach and overall mentality around smaller HVAC equipment refrigerant does not support refrigerant only retrofits on those units.

In Figure 5-12 we present the responses to the web survey question on the practicality or feasibility of refrigerant only retrofits on an array of HVAC equipment types/categories. Note that the practicality agreement increases in parallel with the increase in equipment size categories.

Figure 5-12. Web survey Are low-GWP refrigerant only retrofits for listed existing equipment types or category bins practical?



Q: We would now like you to consider the practicality/feasibility of retrofitting an existing HVAC equipment's refrigerant to a low-GWP alternative. Please indicate your level of agreement with the statement that "Low-GWP alternatives are practical" for retrofitting the following equipment types:

[51] Bitzer Refrigerant Report. "Low GWP" HFO and HFO/HFC Blends: Aspects on the development of HFO and HFO/HFC Refrigerants. https://www.bitzer-refrigerantreport.com/refrigerants/low-gwp-hfos-and-hfohfc-blends/

5.7 Performance analysis

This section discusses the results of the performance analysis simulated by CYCLE_D-HX for common high (GWP>750), low (GWP<750) and ultra-low GWP (GWP close to 0) refrigerants. Depending on their thermodynamic properties, the COP and unit capacity vary greatly. The charge level is then calculated from the unit capacity of refrigerants.

Equation 5. Relative charge-level calculation

Relative Charge Level of Refrigerant X = Unit Capacity of R-410A (kW/kg) / Unit Capacity (kW/kg) of Refrigerant X

Figure 5-13 shows the COP and charge level of different refrigerants benchmarked to R-410A. It is more desirable for a refrigerant to have relative COP larger than 1 and relative charge level smaller than 1 (in the Forth Quadrant) so that the equipment will consume less energy and has less refrigerant leaked compared to R-410A under the same operating condition. Based on the result, R-454B, ARM-71a, R452B, R-32, HPR-2A and R-290, ARM-71a all falls into this category. Additionally, there are a number of refrigerants that outperform R-410A in either COP (First and Forth Quadrants) or charge level (Third and Forth Quadrants).

However, most of the low-GWP or ultra-low-GWP refrigerants have ASHRAE Flammability ratings of A2 or worse, and therefore requires measures to reduce refrigerant leak for safety reasons. R-290 (propane) as an ultra-low refrigerant, have good COP and charge level performance but due to its highly flammable characteristics, it is unsafe to be used in residential application. This performance analysis didn't include CO2 as refrigerant because it operates in transcritcal cycle. This unique characteristic makes the operating condition of CO2 significantly different from the rest of the refrigerant, which prevents an apple-to-apple comparison between different refrigerants.

Figure 5-13. Refrigerant performance for unitary AC

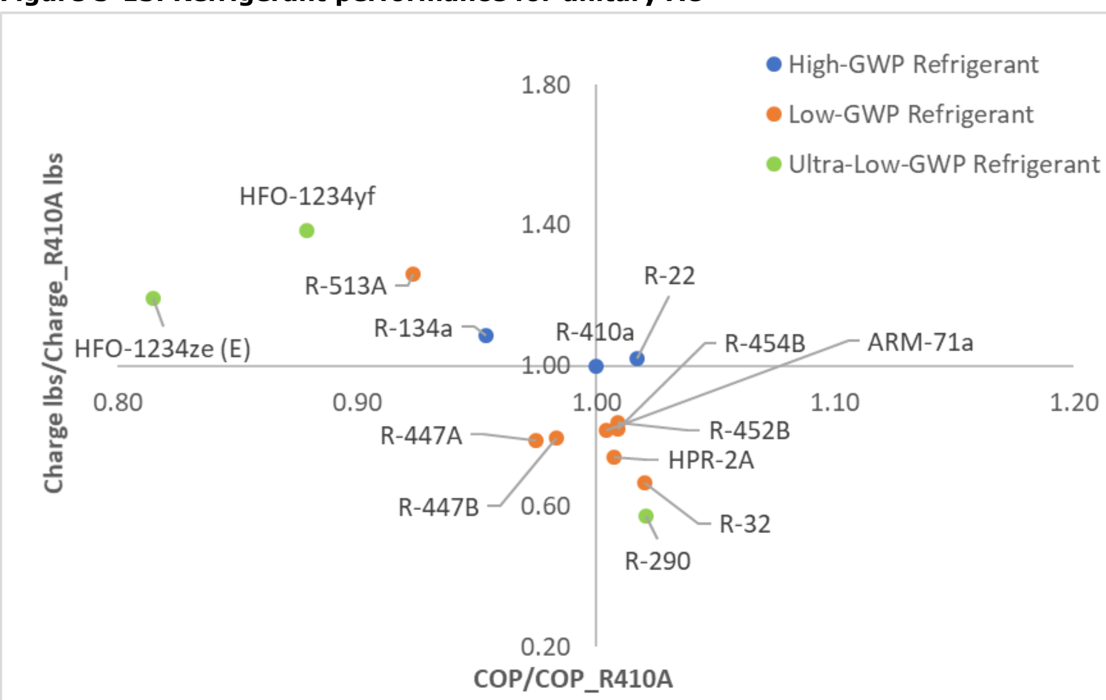


Table 5-6 shows the detailed performance parameters of each refrigerant for unitary AC, air-cooled and water-cooled chillers. The air-cooled and water-cooled chillers generally follows the same COP and charge level ratios as unitary AC. For certain HFOs and HFO/HFC blends, the 20-year GWP is not readily available. For HFOs where their 100-year GWP is less than 5, DNV GL assumes their 20-year GWP is the same as 100-year GWP and marked with "*" in the table. For refrigerant blends where the 20-year GWP is not available but the individual component's 20-year GWP is available, DNV GL calculated the 20-year GWP from the GWP of each component as

Equation 6. 20-year GWP calculation

$$\text{20-year GWP of refrigerant blend} = \sum_{\text{all refrigerant}} \text{20-year GWP of each refrigerant x Corresponding Mass ratio}$$

The calculated 20-year GWP are marked with "**" in the table below. For R-466A, DNV GL is unable to simulate the theoretical performance because the property of one of the components R-13i1 is not publicly available. Therefore, DNV GL obtained their performance data directly from Schultz's study and marked the data with "***".[52]

[52] Schultz, K. 2019. Performance of R466A, a non-flammable replacement for R410A, in unitary air-conditioning and transport refrigeration. Proceedings of the 25th IIR International Congress of Refrigeration

Table 5-6. Performance of different refrigerant

Refrigerant	GWP (20 year)	GWP (100 year)	ASHRAE Std. 34 Class	Unitary AC			Air-Cooled Chiller			Water-Cooled Chiller		
				COP/COP R-410A	Vol Cap Ratio to R-410A	Charge lbs Ratio to R-410A	COP/COP_R-410A	Vol Cap Ratio to R-410A	Charge lbs Ratio to R-410A	COP/COP_R-410A	Vol Cap Ratio to R-410A	Charge lbs Ratio to R-410A
R-22	5160	1810	A1	1.02	0.67	1.02	1.02	0.67	1.02	1.01	0.67	1.06
R-134a	3830	1430	A1	0.95	0.42	1.09	0.96	0.38	1.12	0.95	0.38	1.12
R-410a	4340	2088	A1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
R-513A	1686	630	A1	0.92	0.42	1.26	0.95	0.40	1.28	0.94	0.40	1.28
R-32	2330	675	A2L	1.02	1.08	0.67	0.997	1.046	0.68	0.99	1.04	0.69
HFO-1234ze (E)	1*	1	A2L	0.82	0.27	1.19	0.85	0.25	1.21	0.83	0.24	1.22
HFO-1234yf	1*	1	A1	0.88	0.38	1.39	0.92	0.38	1.39	0.91	0.37	1.39
R-290	3*	3	A3	1.02	0.58	0.57	1.02	0.57	0.59	1.02	0.57	0.60
R-454B	1606**	466	A2L	1.01	0.96	0.82	1.00	0.94	0.84	1.00	0.94	0.84
R-447A	1807**	600	A2L	0.97	0.89	0.79	0.98	0.87	0.81	0.98	0.87	0.82
ARM-71A	1585	460	A2L	1.00	0.94	0.82	1.00	0.92	0.84	1.00	0.92	0.84
R-452B (DR-55)	2006	698	A2L	1.01	0.97	0.84	1.00	0.95	0.85	1.00	0.95	0.86
R-447B	2093	739	A2L	0.98	0.91	0.80	0.99	0.89	0.82	0.99	0.89	0.89
HPR-2A	2001**	600	A2L	1.01	0.89	0.74	0.99	0.91	0.77	0.99	0.90	0.77
R-466A	1872	733	A2L	1.005***	N/A	1.02***	N/A	N/A	N/A	N/A	N/A	N/A
HCFC-123	273	80	A1	N/A	N/A	N/A	1.10	0.06	1.27	1.08	0.05	1.29
HFO-1233zd	1	1	A1	N/A	N/A	N/A	1.09	0.08	1.13	1.08	0.08	1.15

5.8 Lifetime GWP analysis

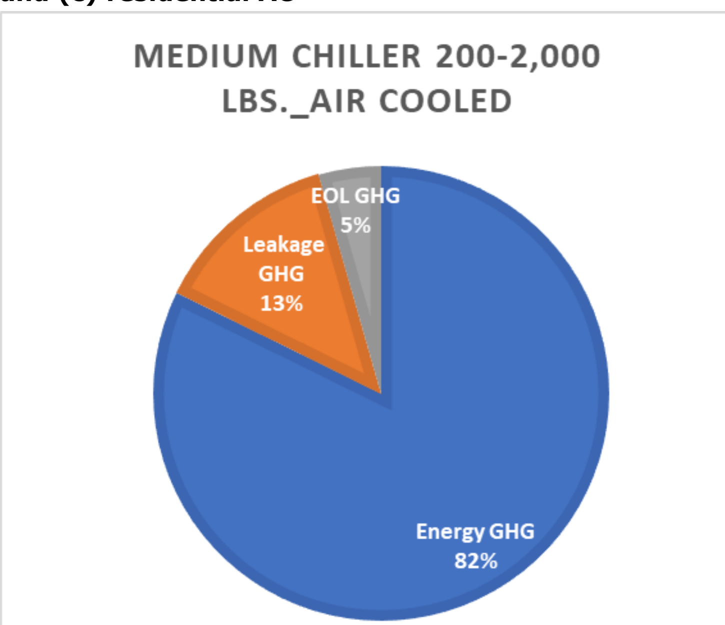
This section presents and discusses the lifetime GWP results for some representative scenarios using the DNV GL's newly developed refrigerant calculator.

5.8.1 Lifetime GWP

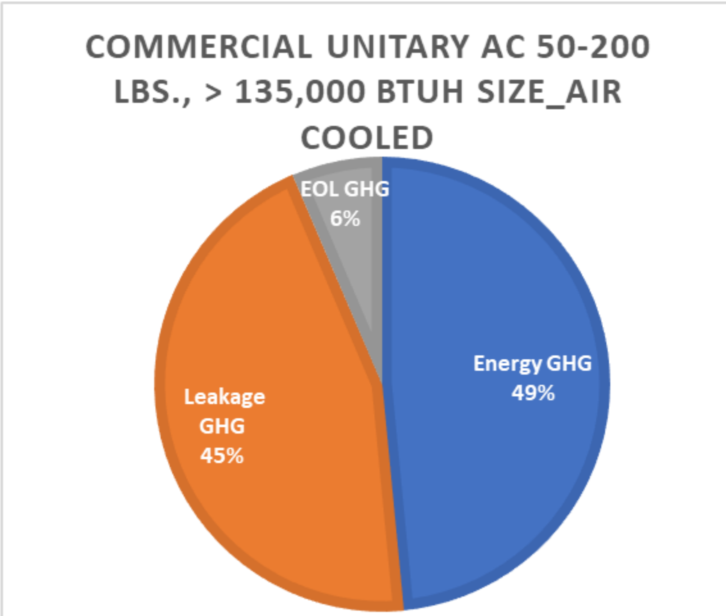
As discussed in Section 4.2, the lifetime GWP is consisted of GWP from grid emission due to equipment energy consumption, GWP from annual leakage and GWP from EOL loss. Depending on the equipment type, the distribution of each GWP source varies significantly.

As shown in Figure 5-14 for large commercial and industrial HVAC systems, such chillers, most of the GHG emission comes from the energy consumption since chillers consumes large amount of energy and leakage rate and EOL are relatively low because the maintenance and repairs are more frequent and there is more strict requirements for refrigerant reclamation for equipment with 50 lbs or more refrigerant. On the contrary, for residential units, the GHG emission from energy consumption is less than 30%, but the GHG emission from EOL loss and leakage each makes up to over one third of the lifetime GHG emission. The main goal of replacing high-GWP refrigerant to low-GWP refrigerant is to reduce the GHG emission from leakage and EOL loss, therefore, it is more effective to focus on replacing the high-GWP refrigerants in residential and small commercial units, where the leakage and EOL loss is significant to maximum the benefit of low-GWP refrigerant.

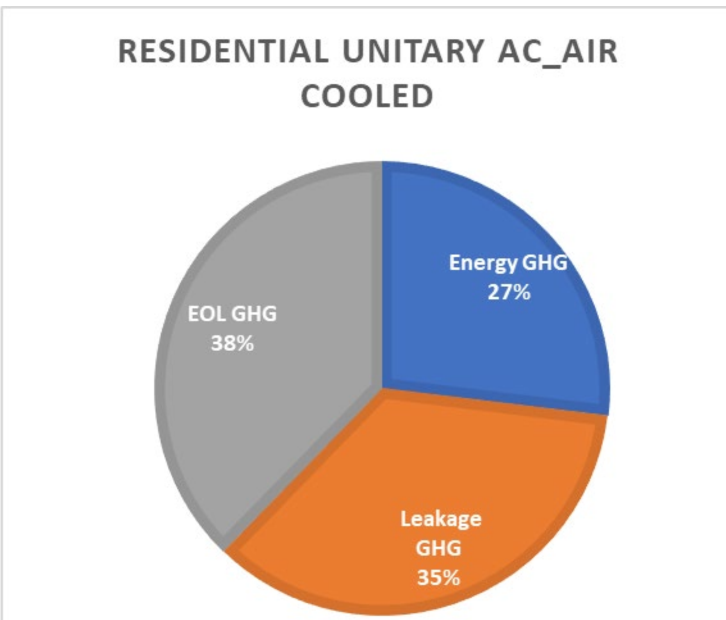
Figure 5-14. Lifetime GWP distribution for (a) medium chiller; (b) commercial unitary AC, and (c) residential AC



(a)



(b)



(c)

5.8.2 New system vs direct drop-in retrofit analysis

When implementing low-GWP refrigerant, the existing can be either retrofitted and only replace the refrigerant or the owner can replace the entire HVAC system with low-GWP refrigerant. The main difference between a direct drop-in and whole system replacement is that installing new system will trigger energy efficiency code requirement, and the new system has to meet the minimum efficiency standards regardless of the new refrigerant's thermodynamic properties. The manufacture has the responsibility to optimize the new system to meet the code even if the new refrigerant has lower COP performance than R-410A. DNV GL assumes that the system efficiency of the alternative refrigerant remains the same as the high-GWP refrigerant when the whole system is replaced. When direct refrigerant drop-in occurs, the alternative refrigerant efficiency follows the simulated relative COP as shown in Table 5-7.

Table 5-7 compares the lifetime GWP savings and avoided cost associated with GHG emission for these two scenarios. R-513A has lower theoretical COP than R-410A (95% of R-410A). In a direct drop-in scenario, the existing system is not optimized for R-513A, so the alternative refrigerant can only achieve 95% of the efficiency compared to when the system is operating with R-410A. On the other hand, if the whole system is to be replaced, the new system needs to meet the energy code and maintain at least the same COP as the system with high-GWP refrigerant. Therefore, replacing with a new system will achieve more GWP and GHG cost savings compared to a direct drop-in.

Table 5-7. Comparison of new system versus direct drop-in

Equipment Type	Commercial Unitary AC 50-200 lb > 135,000 BTUh Air Cooled	
Baseline Refrigerant	R-410A	
Alternative Refrigerant	R-513A	
	New System	Direct Drop-in
Baseline Theoretical COP Ratio: COP/COP_410A	100%	100%
Alternative Theoretical COP Ratio: COP/COP_410A	100%	95%
GWP saved (+ = Savings) if replaced at year 5 (lbs CO2e)	160,634	142,999
Total GHG Cost Avoided (+ = Savings) if replaced at year 5	$14,683	$13,569

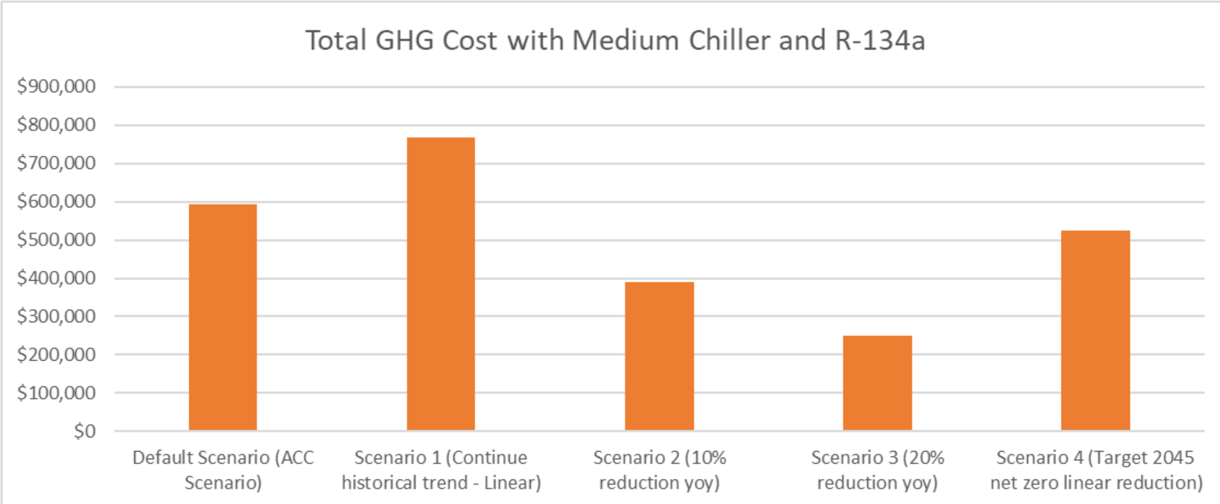
5.8.3 Grid Impact

As discussed earlier, the GHG from energy consumption is a major contributor for the overall lifetime GHG emission. Apart from the equipment energy use, the grid emission rate also plays a major role in the lifetime GHG emission. With cleaner grid in the future, the GHG emission from the energy consumption can be reduced significantly, especially for large systems. DNV GL uses the future grid emission projection from ACC as default grid emission scenario. In addition, DNV GL's calculator includes the following assumed emission projections:

- Continue historical trend using linear regression model
- 10% year over year emission reduction
- 20% year over year emission reduction
- Linear reduction to net zero in 2045

Figure 5-15 shows the grid impact on the lifetime GHG cost for a medium chiller with R-134a. Even with the same equipment and operating condition, the lifetime GHG cost can vary by almost 70% under different grid emission. Therefore, an accurate prediction of grid emission can have larger impact on the GHG calculation.

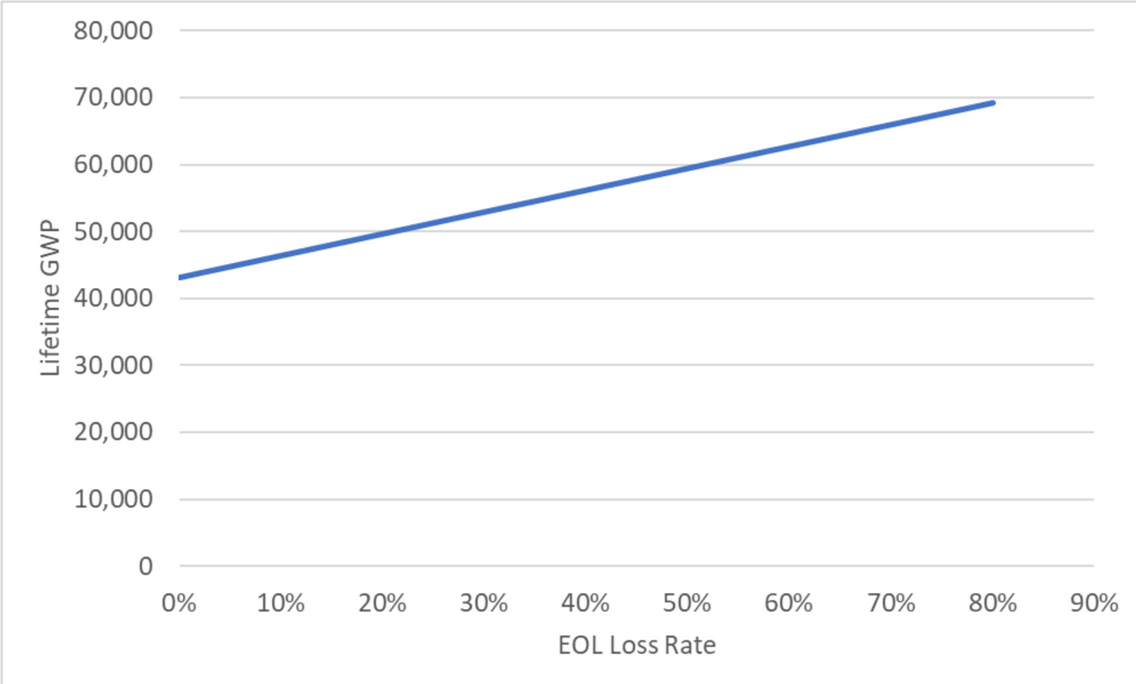
Figure 5-15. Total GHG cost under different grid emission scenarios



5.8.4 Improved reclamation impacts

As shown in Figure 5-16 the EOL loss contributes to over 50% of the residential GHG lifetime emission. Therefore, it is important to enforce the reclamation of the refrigerant to reduce the lifetime GWP impact. This study investigated the impact of simply improving the reclamation on the lifetime GHG emission. Figure 5-16 shows the total lifetime GWP for residential AC using R-410A with various EOL loss rate. The lifetime GWP can be reduced by 38%. (26,040 lbs CO2e) if all the refrigerants are reclaimed, compared to the default condition (80% EOL loss rate). Therefore, regardless of how low- the alternative refrigerant's GWP is, without proper reclamation of the existing high-GWP refrigerant, the implantation of low-GWP might be a threat to climate change as it will trigger high-GWP EOL loss early.

Figure 5-16. Impact of EUL loss rate for residential AC with R-410A



5.8.5 Accelerated Replacement (AR) vs. Normal Replacement (NR)

Another function of the new prototype calculator is to analyze lifetime total GHG cost between accelerated replacement at different equipment age versus ROB. Depending on the equipment type and alternative refrigerant to be implemented, the GHG cost benefit of early replace will vary greatly. For system with low leakage, low EOL loss rate and high energy consumptions, such as large commercial units, the benefit of implementing low-GWP refrigerant is relatively small since majority of the GHG cost is from energy consumption, which is irrelevant to the refrigerant's GWP. On the other hand, for residential units, the leakage and EOL loss contributes most of the total lifetime GHG cost, thus replacing the refrigerant early have larger benefit than ROB.

Figure 5-17 shows the lifetime GWP of a Residential AC with R-410A to be replaced by R-466A at different equipment age. The results indicated that the maximum GWP reduction occurs if R-466A is used in new construction, which have over 40% GWP savings compared to installing a R-410A equipment. For existing R-410A system, the benefit of accelerated replacement decreases by about 1.4% as the equipment age increase every year.

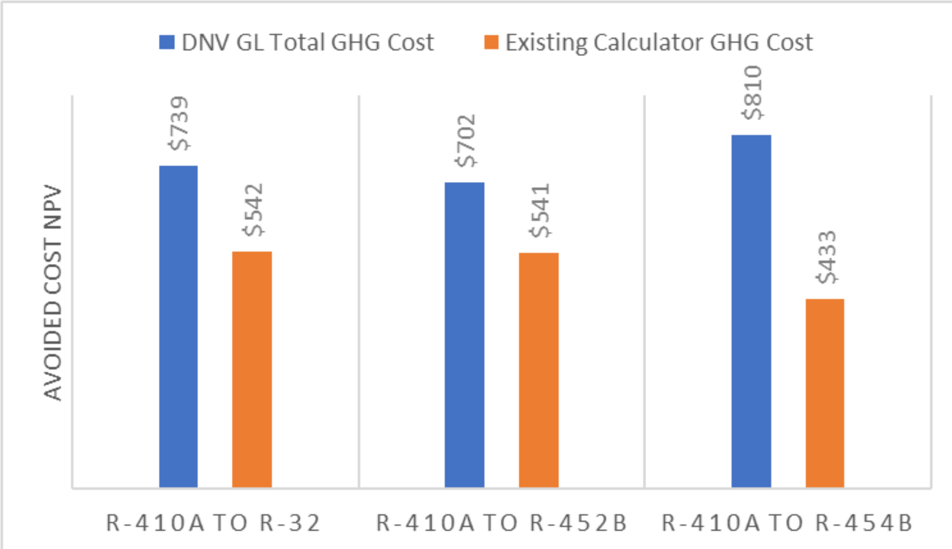
Figure 5-17. Residential AC lifetime GWP of accelerated replacement at various equipment age

5.8.6 Comparison between existing refrigerant ACC and DNV GL's prototype calculator

The existing refrigerant calculator calculates the lifetime GHG cost due to leakage and EOL loss and the charge level of different refrigerants stays the same by default. However, depending the refrigerant's unit capacity (kBtu/kg), the charge level needs to be adjusted to achieve the same cooling capacity when replacing a high-GWP refrigerant with an alternative refrigerant.

Figure 5-18 compares the avoided costs calculated by the existing Refrigerant ACC versus DNV GL's new prototype calculator developed. This residential AC example shows the impacts of installing R-32, R-452B and R-454B in lieu of R-410a at new construction. The main reason for the difference between the results is the change of charge level for different refrigerants included in the DNV GL prototype calculator. The CPUC's existing Refrigerant ACC assumes the charge level stays constant, regardless of the refrigerant's unit capacity, whereas DNV GL uses the unit capacity to adjust the charge level. Since the leakage rate and EOL loss percentage is applied to the charge level to calculate the GWP, the charge level will have impact on the lifetime GWP results.

Figure 5-18. Comparison between existing calculator vs. DNV GL calculator



As shown in in the figure, the DNV GL calculated values are higher than the existing calculator. The reason is the low-GWP refrigerants in all three cases have higher unit capacity than R-410A, meaning to maintain the same system capacity, less charge is needed of the alterative refrigerants than the charge needed of R-410A. Therefore, the leakage and EOL loss will be smaller than assuming the alternative refrigerant charge level is the same as R-410A, as used by the existing Refrigerant ACC. Note that this comparison is only for new construction whole system installs. For accelerated replacement and direct drop-in scenarios, the impact of energy consumption change will also affect the lifetime GWP, of which the existing calculator does not consider. However, since the existing calculator is limited to only calculating the avoided cost if an alternative refrigerant is installed in new construction phase in lieu of a high-GWP Refrigerant, we are unable to compare DNV GL's results to the existing calculator.

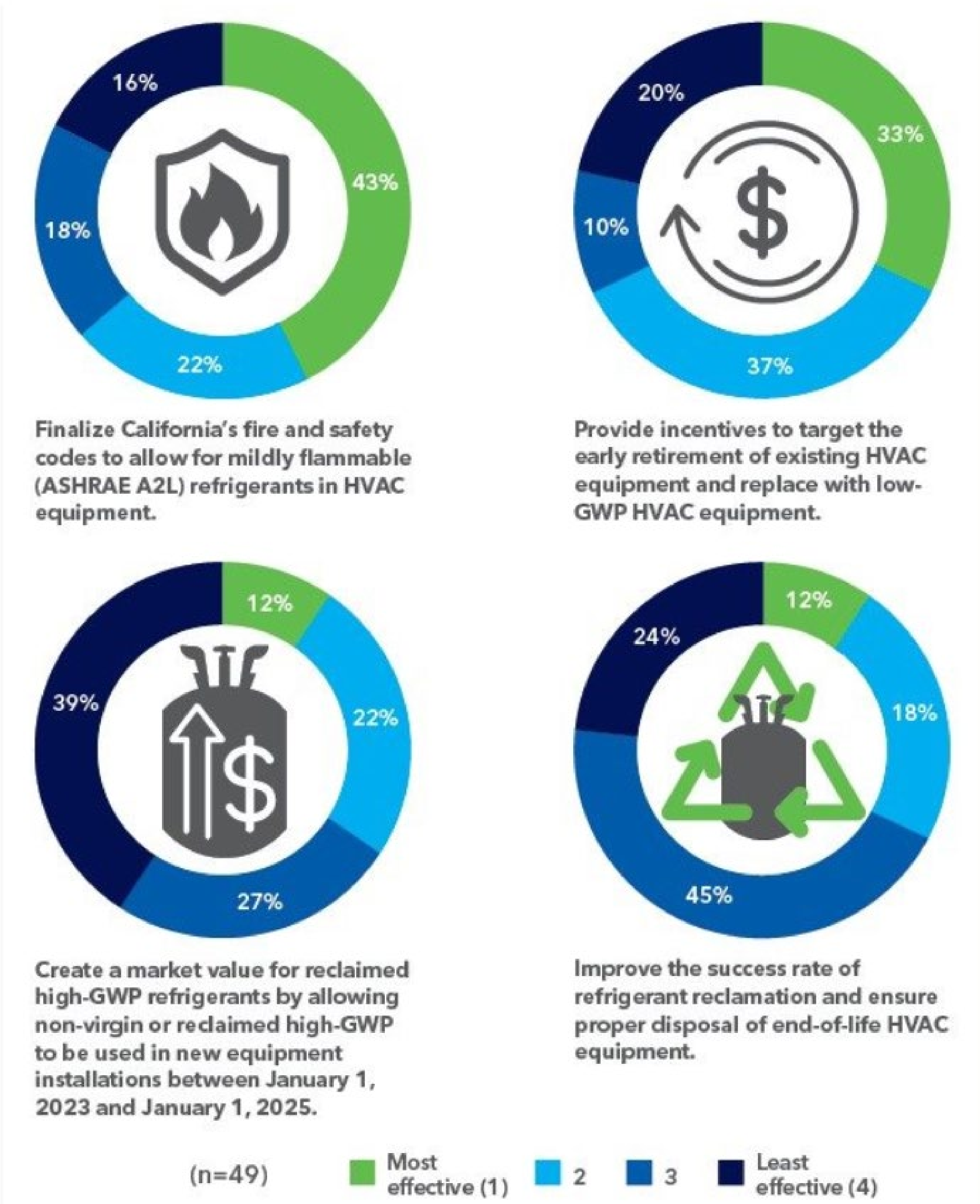
5.8.7 Uncertainty disclosure

The new prototype calculator developed by DNV GL is built on the CPUC's Refrigerant Avoided Cost Calculator developed by E3 using CARBs emissions estimates, including but not limited to the leakage rate, EOL loss rate, average charge level and annual energy consumption of the high-GWP refrigerant for different HVAC types. The values are based on database compiled in 2018, which might not represent the current HVAC stock. In addition, the values represent the average system and individual system performance may vary greatly depending on their unique operating conditions. Therefore, for individual system analysis, DNV GL advises the user to obtain more relevant inputs for their specific calculation.

5.8.8 Web survey feedback on GWP actions

Throughout the IDI discussions we heard a lot of ideas and suggestions about what California should do to pursue lower GWP impacts caused by HVAC equipment. One common topic or action brought up was the need for building and fire codes to get finalized so low-GWP HVAC refrigerants can begin widespread adoption. Other suggestions focused on improving end-of-life recovery rates. Some of the more informed SMEs were aware of the proposed amendment to allow reclaimed high-GWP refrigerant between 2023 and 2025 and suggested that could significantly increase the market value for recovered HFC refrigerant. In the web survey we presented the four most common actions discussed and asked the respondents to rank the actions based on the action's efficacy in lowering GWP impacts caused by HVAC equipment. While the results are mixed, respondents slightly favored finalizing codes and incentives for the early-retirement of existing (high-GWP) equipment with low-GWP equipment. The combined results are presented in Figure 5-19.

Figure 5-19. Web survey: Rank the listed actions' potential to lower GWP impacts



Q: Rank the following statements where 1 represents the "most effective" and 4 represents the "least effective" action taken towards

6 KEY FINDINGS, RECOMMENDATIONS, & CONSIDERATIONS

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

- Key findings: Highlight interesting trends and findings from the body of the report. Key findings are noted with the key symbol. Not all key findings have recommendations.
- Recommendations: These are provided directly in response to key findings and their implications. Recommendations are noted with the gear symbol.

6.1 Key findings and recommendations

This section lists the key findings and recommendations in order of importance starting with the top two, which are flammability and time issues.

Flammability is the problem.

The single biggest current barrier of adopting low-GWP refrigerants is the issue of flammability. Virtually all low-GWP alternative refrigerants with cooling capacity and energy-efficiency performance characteristics similar to refrigerants currently in use are mild to highly flammable. All the HVAC experts we spoke with emphasized the fact that they are not currently permitted to install mildly flammable refrigerants in most common HVAC equipment today. Lab testing performed by one of the experts we interviewed shows mildly-flammable refrigerants being considered for near-term adoption are only flammable in conditions where high rates of leakage occur in a confined space.[53] Mechanical,

[53] https://www.osti.gov/servlets/purl/1465066

fire, and building codes are currently being modified to allow for mildly flammable refrigerants given appropriate measures to minimize risk are in place.

Refrigerant transitions take time.

Our secondary research and interviews with HVAC-refrigerant experts revealed an extensive list of national organizations, state and local codes, and other authorities required to approve the use of new refrigerants in the United States. Any increase in flammability or change in toxicity for a refrigerant extends the length of time for its approval. The United States is a safety-focused society relative to some other industrialized countries. For instance, Europe and Asia are already moving quickly ahead in using mildly flammable refrigerants and to some degree natural refrigerants in HVAC equipment. The proposed HFC reduction timeline and the recent passing of the American Innovation and Manufacturing Act of 2020[54] ensures the transition will happen in California and the rest of the United States eventually.

Figure 6-1. Web survey: Minimum lead time needed to transition to <750 GWP refrigerants following code finalization

*The distribution presented above does not include the 19% of "don't know" respondents.

The refrigerant evolution continues.

The current transition away from high-GWP HFCs towards HFCs with GWP levels <750 is rife with challenges and the likely outcome is still pending. All 10 of the HVAC manufacturers and contractors we spoke with agree the preferred near-term refrigerant candidates are all mildly flammable HFCs. There is one technically viable refrigerant, R-466a (Solstice® N41), that is not flammable under normal conditions and has a GWP just below 750. On the surface, these characteristics would make R-466a the preferred option, but it has drawbacks. In terms of performance, it falls short of the other leading <750 GWP candidates, and it's relatively unproven. It also contains a molecule not traditionally used in refrigeration that is concerning because of its slight ozone-depleting potential. Six experts we spoke with at length about R-466a see it as a step in the wrong direction. All experts we talked to said manufacturers are transitioning to mildly flammable refrigerants to meet the low-GWP phasedown requirements.

The Refrigerant Avoided Cost Calculator is a valuable tool.

The CPUC Refrigerant ACC is a relatively new tool that holds a lot of value. The tool provides users a simple yet informative option for calculating refrigerant carbon-equivalent emission impacts. The tool's approach is based on a well vetted methodology by the Intergovernmental Panel on Climate Changes (IPCC). Using the IPCC methodology and leveraging CARB emissions estimates, the tool predicts refrigerant impact in a dollar equivalent value. Our review of the tool and based on the findings of this research study, the outputs of the tool are very noteworthy but can be further improved. For example,

54 https://www.congress.gov/bill/116th-congress/senate-bill/2754/text

the current CPUC Refrigerant ACC tool does not consider the energy performance or refrigerant charge required of alternative refrigerants.

Explore DNV GL's prototype lifetime GWP calculator.

The CPUC should consider using the DNV GL prototype lifetime GWP calculator to update the current CPUC Refrigerant ACC. The research findings of this study provide the data needed to expand the outputs of the current CPUC Refrigerant ACC tool. Using our evaluation approach, we defined variables impacting equipment energy operation and refrigerant emissions. Using the sourced variables, we developed a prototype add-on tool that calculates energy impacts from alternative refrigerants as well as required charge-level impacts on emissions. The framework of the tool can be extended to measures beyond HVAC refrigerants.

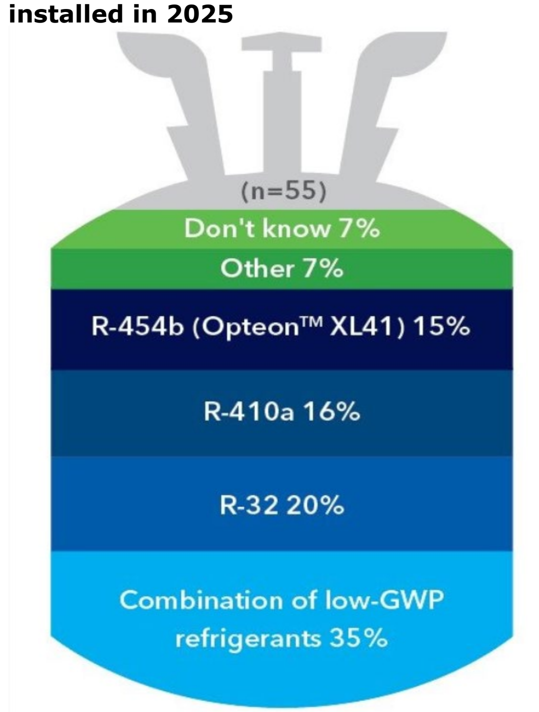
Accurate outputs rely on accurate inputs.

Many of the estimates both the CPUC and our add-on tools produce are based on CARB emission inventories. Our discussion with CARB determined annual inventories take a year or more to summarize and become available for use. It is important to incorporate the latest findings when estimating future impacts. Some operational leakage rates found in current estimates track higher than our outside research indicates. End-of-life emissions could also be tracked better for the purposes of this tool. The outputs of both tools are significant and noteworthy. Minimizing the uncertainties in the tool are that much more important given the significance of the findings.

Mildly flammable HFCs are the near-term solution.

Currently, HVAC contractors are not permitted to install mildly flammable refrigerants in most common HVAC equipment today. The leading mildly flammable HFC candidates for the most common residential and commercial HVAC applications include R-32, R-454B, and R-452B. However, state fire marshal delays now indicate building and fire codes most likely won't be updated to allow these mildly flammable refrigerants for use in most California HVAC equipment until January 1, 2024. Web survey responses indicate the HVAC supply chain will likely take around two years from when building and fire code requirements are finalized to have a representative selection of <750 GWP HVAC refrigerant equipment offerings.

Figure 6-2. Web survey: Anticipated most common HVAC refrigerant installed in 2025



Promote mildly flammable HFCs in the near-term.

PAs should begin including a requirement for the use of mildly flammable HFCs into their HVAC incentive programs where these refrigerants are currently permitted. The mildly flammable HFC refrigerants are currently allowed in portable, window and smaller air-conditioners as well as in some larger commercial settings. As more mildly flammable HFCs become viable with updated building codes, the PAs should provide incentives for those options as well.

The goalposts are still moving.

CARB's latest proposed amendment to regulations on HFCs will delay the transition timing from the current 2023 <750 GWP HFC reduction timeline, to 2025.[55] A public hearing was held on December 10, 2020, with the board voting in favor of adopting the amendment, but the bill is still undergoing approval and likely won't receive final approval until October 2021. HVAC experts we spoke with point to updates in the next cycle of California Building and Fire Codes that will include revised policies and guidelines to allow for the use of mildly flammable HFC refrigerants in most major HVAC equipment. Until those updates are released, the goalposts are not set, and the timing of the transition remains uncertain. Once the building and fire codes get finalized, most likely not until the interim code update is published in January 2024, the policy and timing of California's transition, will be more certain.

Closely follow CARB, California building and fire code updates.

The CPUC and PAs should follow the timing of the building and fire code updates. As soon as the building and fire codes allow mildly-flammable HFCs, the PAs should promote these HFCs via their HVAC incentive programs. In the near-term, the PAs should provide incentives for the use of reclaimed high-GWP refrigerants in HVAC equipment.

Natural refrigerants are the long-term solution.

The refrigerant evolution will not stop with mildly flammable HFCs. The HFC reduction goals mean that in the next 10-20 years, HVAC equipment will need to push past <750 GWP HFCs towards refrigerants with GWP levels below 150. Findings from literature reviews and interviews with HVAC experts all indicate the long-term goal is refrigerants with GWP levels close to 1. Natural refrigerants like pure CO_2, R-290 (propane), and ammonia have GWP levels below 10, but also require significant HVAC system redesigns before they can be made widely available.

Promote natural refrigerants.

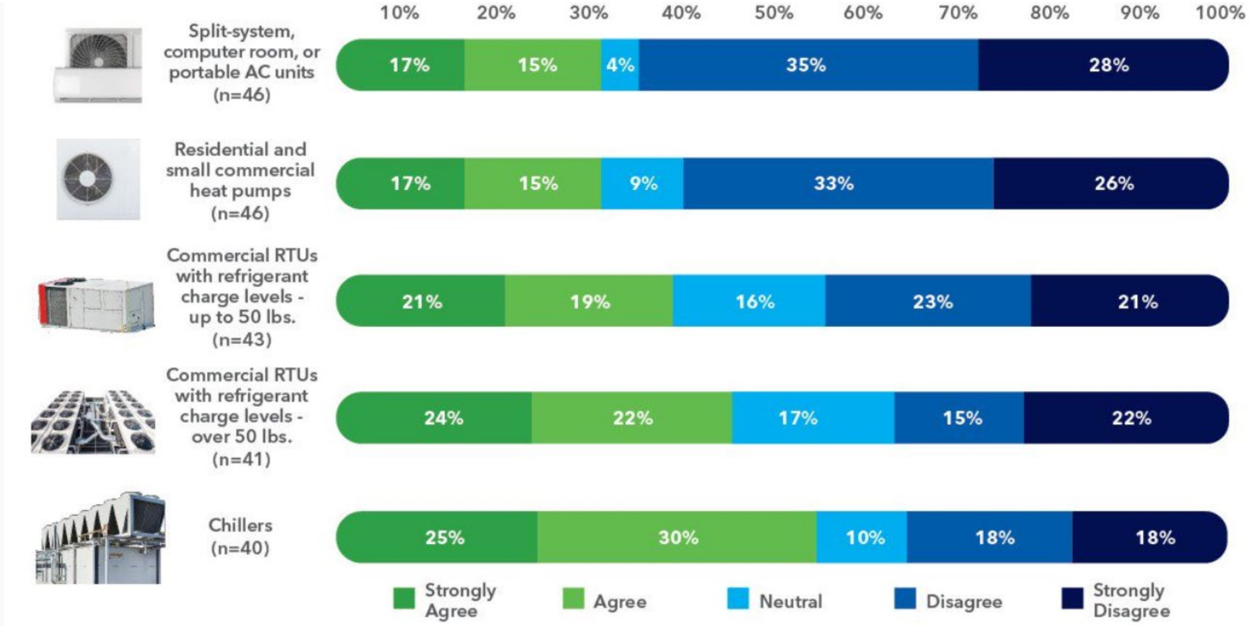
The CPUC should recommend the PAs promote the use of natural refrigerants wherever code permits. Incentives should be directed towards accelerating the use of natural HVAC refrigerants over HFCs and HFOs. We recommend the PAs promote natural refrigerants either through the emerging technology program, under custom programs, or any other HVAC program.

Significant barriers limit refrigerant-only retrofits.

In all 12 interviews with HVAC experts in which we discussed refrigerant only change-outs, the interviewees reported extensive challenges to changing refrigerants in most existing HVAC equipment. A refrigerant-only changeout would include simply replacing the existing refrigerant with a low-GWP alternative refrigerant with only minimal alterations to the equipment. The list of barriers includes various code violations including mechanical, fire and building codes, the need for partial system redesign once codes permit mildly flammable refrigerants, authorization from the manufacturer, authorization from the owner, and the need for the action to be cost-effective. Web-survey responses show increased feasibility for refrigerant-only retrofits on commercial HVAC equipment and chillers.

[55] https://ww2.arb.ca.gov/rulemaking/2020/hfc2020

Figure 6-3. Web survey: Are <750-GWP refrigerant-only retrofits practical?



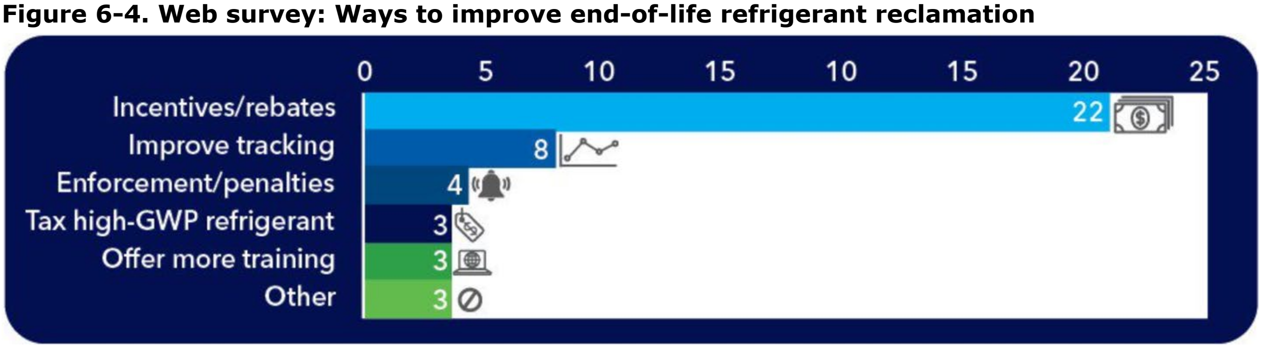
Direct drop-in of the refrigerants only viable for larger HVAC equipment.

PAs should only consider the option of refrigerant-only changeouts in larger HVAC equipment like chillers and commercial roof-top units. The cost of replacing larger existing HVAC equipment is substantially higher than the cost and challenges of a refrigerant only change-out.

End-of-life emissions are alarming.

Our research on CARB and EPA emission estimates show emissions either from intentional venting, improper disposal, or leaks during transport, are highest for residential and small commercial HVAC equipment. Everyone we spoke with said there is little to no incentive for contractors to recover and reclaim existing refrigerant in smaller equipment. All contractors we spoke with said the laws regulating intentional venting come with virtually zero enforcement. Among the people we spoke with and surveyed about refrigerant emissions, the most common solution shared is to offer incentives.

Figure 6-4. Web survey: Ways to improve end-of-life refrigerant reclamation



Provide incentives for safe and documented end-of-life refrigerant recovery.

PAs should require the safe and documented recovery of remaining end-of-life refrigerant a prerequisite for any HVAC system change-out incentive. Providing incentives to promote end-of-life refrigerant recovery would not only reduce emissions but it will help track the rate of end-of-life emissions and improve future estimates.

Refrigerant charge adjustments cause emissions to increase.

Our research on CARB and EPA emissions estimates shows operational refrigerant leakage stems from system leakage and incidental leaks when servicing the system. These types of emissions increase every time refrigerant is added to a system. Whenever hoses and gauges are attached to a unit, some minor leakage will occur. Significant leakage can occur because of a temperamental valve or a system getting overcharged. Feedback from HVAC contractors indicates that the standard practice is to avoid even checking the refrigerant charge unless all other common issues are ruled out, but this was not standard practice until just recently. Historical evaluated energy efficiency performance for air-conditioner maintenance programs focusing on refrigerant charge adjustments demonstrate these activities often provide minimal energy performance improvements.

Stop funding refrigerant charge adjustments.

PAs should consider discontinuing any HVAC maintenance programs that promote refrigerant charge adjustments. PAs should educate HVAC contractors about the problems associated with pro-active refrigerant charge adjustments and promote best practices for assessing charge levels without tapping refrigerant lines.

7 APPENDICES

7.1 Appendix A: IESR – Recommendations resulting from the market research

Study ID	Study Type	Study Title	CPUC Study Manager
Group A HVAC Sector	Market Study	Impact Evaluation Report – HVAC – Proposer Defined Study – A Roadmap for Accelerating the Adoption of low-Global Warming Potential HVAC Refrigerants	CPUC

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
1	All Programs	Flammability is the problem	The single biggest current barrier of adopting low-GWP refrigerants is the issue of flammability. Virtually all low-GWP alternative refrigerants with cooling capacity and energy-efficiency performance characteristics similar to refrigerants currently in use are mild to highly flammable. All the HVAC experts we spoke with emphasized the fact that they are not currently permitted to install mildly flammable refrigerants in most common HVAC equipment today. Lab testing performed by one of the experts we interviewed shows mildly-flammable refrigerants being considered for near-term adoption are only flammable in conditions where high rates of leakage occur in a confined space. Mechanical, fire, and building codes are currently being modified to allow for mildly flammable refrigerants given appropriate measures to minimize risk are in place.	This is a key finding and no recommendation is associated with this finding.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
2	All Programs	Refrigerant transitions take time.	Secondary research and interviews with HVAC-refrigerant experts revealed an extensive list of national organizations, state and local codes, and other authorities required to approve the use of new refrigerants in the United States. Any increase in flammability or change in toxicity for a refrigerant extends the length of time for its approval. The United States is a safety-focused society relative to some other industrialized countries. For instance, Europe and Asia are already moving quickly ahead in using mildly flammable refrigerants and to some degree natural refrigerants in HVAC equipment. The proposed HFC reduction timeline and the recent passing of the American Innovation and Manufacturing Act of 2020, ensures the transition will happen in California and the rest of the United States eventually.	This is a key finding and no recommendation is associated with this finding.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
3	All Programs	The refrigerant evolution continues	The current transition away from high-GWP HFCs towards HFCs with GWP levels <750 is rife with challenges and the likely outcome is still pending. All 10 of the HVAC manufacturers and contractors we spoke with agree the preferred near-term refrigerant candidates are all mildly flammable HFCs. There is one technically viable refrigerant, R-466a (Solstice® N41), that is not flammable under normal conditions and has a GWP just below 750. On the surface, these characteristics would make R-466a the preferred option, but it has drawbacks. In terms of performance, it falls short of the other leading <750 GWP candidates, and it's relatively unproven. It also contains a molecule not traditionally used in refrigeration that is concerning because of its slight ozone-depleting potential. Six experts we spoke with at length about R-466a see it as a step in the wrong direction. All experts we talked to said manufacturers are transitioning to mildly flammable refrigerants to meet the low-GWP phasedown requirements.	This is a key finding and no recommendation is associated with this finding.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
4	All Programs	The Refrigerant Avoided Cost Calculator is a valuable tool	The CPUC Refrigerant ACC is a relatively new tool that holds a lot of value. The tool provides users a simple yet informative option for calculating refrigerant carbon-equivalent emission impacts. The tool's approach is based on a well vetted methodology by the Intergovernmental Panel on Climate Changes (IPCC). Using the IPCC methodology and leveraging CARB emissions estimates, the tool predicts refrigerant impact in a dollar equivalent value. Our review of the tool and based on the findings of this research study, the outputs of the tool are very noteworthy but can be further improved. For example, the current CPUC Refrigerant ACC tool does not consider the energy performance or refrigerant charge required of alternative refrigerants.	The CPUC should consider using the DNV GL prototype lifetime GWP calculator to update the current CPUC Refrigerant ACC. The research findings of this study provide the data needed to expand the outputs of the current CPUC Refrigerant ACC tool. Using our evaluation approach, we defined variables impacting equipment energy operation and refrigerant emissions. Using the sourced variables, we developed a prototype add-on tool that calculates energy impacts from alternative refrigerants as well as required charge-level impacts on emissions. The framework of the tool can be extended to measures beyond HVAC refrigerants.	All PAs	
5	All Programs	Accurate outputs rely on accurate inputs	Many of the estimates both the CPUC and our add-on tools produce are based on CARB emission inventories. Our discussion with CARB determined annual inventories take a year or more to summarize and become available for use.	It is important to incorporate the latest findings when estimating future impacts. Some operational leakage rates found in current estimates track higher than our outside research indicates. End-of-life emissions could also be tracked better for the purposes of this tool. The outputs of both tools are significant and noteworthy. Minimizing the uncertainties in the tool are that much more important given the significance of the findings.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
6	All Programs	Mildly flammable HFCs are the near-term solution.	Currently, HVAC contractors are not permitted to install mildly flammable refrigerants in most common HVAC equipment today. The leading mildly flammable HFC candidates for the most common residential and commercial HVAC applications include R-32, R-454B, and R-452B. However, state fire marshal delays now indicate building and fire codes most likely won't be updated to allow these mildly flammable refrigerants for use in most California HVAC equipment until January 1, 2024. Web survey responses indicate the HVAC supply chain will likely take around two years from when building and fire code requirements are finalized to have a representative selection of <750 GWP HVAC refrigerant equipment offerings.	PAs should begin including a requirement for the use of mildly flammable HFCs into their HVAC incentive programs where these refrigerants are currently permitted. The mildly flammable HFC refrigerants are currently allowed in portable, window and smaller air-conditioners as well as in some larger commercial settings. As more mildly flammable HFCs become viable with updated building codes, the PAs should provide incentives for those options as well.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
7	All Programs	The goalposts are still moving	CARB's latest proposed amendment to regulations on HFCs will delay the transition timing from the current 2023 <750 GWP HFC reduction timeline, to 2025. A public hearing was held on December 10, 2020, with the board voting in favor of adopting the amendment, but the bill is still undergoing approval and likely won't receive final approval until October 2021. HVAC experts we spoke with point to updates in the next cycle of California Building and Fire Codes that will include revised policies and guidelines to allow for the use of mildly flammable HFC refrigerants in most major HVAC equipment. Until those updates are released, the goalposts are not set, and the timing of the transition remains uncertain. Once the building and fire codes get finalized, most likely not until the interim code update is published in January 2024, the policy and timing of California's transition, will be more certain.	In the near-term, the PAs should provide incentives for the use of reclaimed high-GWP refrigerants in HVAC equipment. As soon as the building and fire codes allow mildly-flammable HFCs, the PAs should promote these HFCs via their HVAC incentive programs.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
8	All Programs	Natural refrigerants are the long-term solution	The refrigerant evolution will not stop with mildly flammable HFCs. The HFC reduction goals mean that in the next 10-20 years, HVAC equipment will need to push past <750 GWP HFCs towards refrigerants with GWP levels below 150. Findings from literature reviews and interviews with HVAC experts all indicate the long-term goal is refrigerants with GWP levels close to 1. Natural refrigerants like pure CO2, R-290 (propane), and ammonia have GWP levels below 10, but also require significant HVAC system redesigns before they can be made widely available.	Promote natural refrigerants. The CPUC should recommend the PAs promote the use of natural refrigerants wherever code permits. Incentives should be directed towards accelerating the use of natural HVAC refrigerants over HFCs and HFOs. We recommend the PAs promote natural refrigerants either through the emerging technology program, under custom programs, or any other HVAC program.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
9	All Programs	Significant barriers limit refrigerant-only retrofits	In all 12 interviews with HVAC experts in which we discussed refrigerant only change-outs, the interviewees reported extensive challenges to changing refrigerants in most existing HVAC equipment. A refrigerant-only changeout would include simply replacing the existing refrigerant with a low-GWP alternative refrigerant with only minimal alterations to the equipment. The list of barriers includes various code violations including mechanical, fire and building codes, the need for partial system redesign once codes permit mildly flammable refrigerants, authorization from the manufacturer, authorization from the owner, and the need for the action to be cost-effective. Web-survey responses show increased feasibility for refrigerant-only retrofits on commercial HVAC equipment and chillers.	PAs should only consider the option of refrigerant-only changeouts in larger HVAC equipment like chillers and commercial roof-top units. The cost of replacing larger existing HVAC equipment is substantially higher than the cost and challenges of a refrigerant only change-out.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
10	All Programs	End-of-life emissions are alarming	Our research on CARB and EPA emission estimates show emissions either from intentional venting, improper disposal, or leaks during transport, are highest for residential and small commercial HVAC equipment. Everyone we spoke with said there is little to no incentive for contractors to recover and reclaim existing refrigerant in smaller equipment. All contractors we spoke with said the laws regulating intentional venting come with virtually zero enforcement. Among the people we spoke with and surveyed about refrigerant emissions, the most common solution shared is to offer incentives.	Provide incentives for safe and documented end-of-life refrigerant recovery. PAs should require the safe and documented recovery of remaining end-of-life refrigerant a prerequisite for any HVAC system change-out incentive. Providing incentives to promote end-of-life refrigerant recovery would not only reduce emissions but it will help track the rate of end-of-life emissions and improve future estimates.	All PAs	

Rec #	Program or Database	Summary of Findings	Additional Supporting Information	Best Practice/Recommendations	Recipient	Affected Workpaper or DEER
11	All Programs	Refrigerant charge adjustments cause emissions to increase	Our research on CARB and EPA emissions estimates shows operational refrigerant leakage stems from system leakage and incidental leaks when servicing the system. These types of emissions increase every time refrigerant is added to a system. Whenever hoses and gauges are attached to a unit, some minor leakage will occur. Significant leakage can occur because of a temperamental valve or a system getting overcharged. Feedback from HVAC contractors indicates that the standard practice is to avoid even checking the refrigerant charge unless all other common issues are ruled out, but this was not standard practice until just recently. Historical evaluated energy efficiency performance for air-conditioner maintenance programs focusing on refrigerant charge adjustments demonstrate these activities often provide minimal energy performance improvements.	Stop funding refrigerant charge adjustments. PAs should consider discontinuing any HVAC maintenance programs that promote refrigerant charge adjustments. PAs should educate HVAC contractors about the problems associated with pro-active refrigerant charge adjustments and promote best practices for assessing charge levels without tapping refrigerant lines.	All PAs	

7.2 Appendix B: Data sources table

Table 7-1 below lists all of the sources of data used in this study.

Table 7-1. Data sources

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Stationary Refrigeration Leak Repair Requirements	1/10/2021	https://www.epa.gov/section608/stationary-refrigeration-leak-repair-requirements	US Environmental Protection Agency (EPA)/ government website			Yes				Yes
Low-GWP Refrigerants	2019	https://collateral-library-production.s3.amazonaws.com/uploads/asset_file/attachment/2689/tmp_uploads_2F1548189888-522131a2653f6849c17db3af68989d58_2FULCT_LowGWP_brochure_vDIGITAL1.pdf	UL LLC/ industry publication	Yes			Yes	Yes	Yes	
Safety Standard for Refrigeration Systems	2019	https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_15_2019	American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)/ industry standard publication			Yes	Yes		Yes	
Designation and Safety Classification of Refrigerants	2019	https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_34_2019	ASHRAE/ industry standard publication			Yes	Yes		Yes	
California HFC Phase-down Schedule Continues	7/2/2019	https://emersonclimateconversations.com/2019/07/02/california-hfc-phase-down-schedule-continues/	Emerson/ industry publication						Yes	Yes
Top 25 Commercial HVAC Manufacturers	6/23/2020	https://www.mpofcinci.com/blog/top-commercial-hvac-manufacturers/	Metalphoto of Cincinnati/ blog							
Next Generation of HFC Alternative Refrigerants Are More Environmentally Responsible	7/10/2017	https://www.facilitiesnet.com/hvac/article/Next-Generation-of-HFC-Alternative-Refrigerants-Are-More-Environmentally-Responsible--17287?source=next	Rita Tatum for facilitiesnet/ blog							

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Low-GWP Incentives: Incentives supportive of Low-GWP refrigerant technologies	Last viewed: 1/10/2021	https://ww2.arb.ca.gov/resources/documents/low-gwp-incentives	California Air Resources Board/ government publication						Yes	
Are you ready for the next big step-down?	Last viewed: 1/10/2021	http://www.phaseoutfacts.org/default.aspx	Air-Conditioning, Heating, and Refrigeration Institute (AHRI)/ industry publication			Yes			Yes	
Things To Be Aware Of When Considering R 22 Replacement Refrigerants	Last viewed: 1/10/2021	https://legacyac.com/things-to-be-aware-of-when-considering-r-22-replacement-refrigerants/#:~:text=The%20best%20replacement%20for%20R,simply%20add%20to%20the%20R22.	Legacy Air/ contractor website	Yes			Yes	Yes		
What Will Happen to HVAC Refrigerants with the HFC Phase Out?	Last viewed: 1/10/2021	https://www.kw-engineering.com/hfc-phase-out-hvac-natural-refrigerants-commercial-grocery-impact-energy-efficiency/	Jim Kelsey for kW Engineering/ blog	Yes					Yes	
What's R-32? R-32 is a next generation refrigerant that efficiently carries heat and has lower environmental impact	Last viewed: 1/10/2021	https://www.daikin.com/corporate/why_daikin/benefits/r-32/	Daikin/ industry publication	Yes					Yes	
Manufacturers maintain R32 is safe	9/16/2014	https://www.coolingpost.com/world-news/manufacturers-maintain-r32-is-safe/	Cooling Post/ industry blog						Yes	
Daikin's Policy on the Environmental Impact of the Refrigerant	Last viewed: 1/10/2021	https://www.daikin.com/csr/information/influence	Daikin/ industry publication						Yes	

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Quantitative Risk Assessment For Flammable Refrigerants	6/11/2020	http://lifefront.eu/quantitative-risk-assessment-of-flammable-refrigerants-to-validate-the-level-of-safety-of-proposed-mitigation-measures-for-minimising-flammability-risk/	Pauline Bruge for LIFE FRONT/ EU government publication						Yes	
Daikin looks to replace R32 in 2023	5/15/2019	https://www.coolingpost.com/world-news/daikin-looks-to-replace-r32-in-2023/	Cooling Post/ industry blog						Yes	
System efficiency more important than GWP	5/9/2020	https://www.coolingpost.com/features/system-efficiency-more-important-than-gwp/	Cooling Post/ industry blog	Yes		Yes			Yes	
Daikin's Policy and Comprehensive Actions on the Environmental Impact of Refrigerants	7/2020	https://www.daikin.com/csr/information/influence/daikin_policy-en.pdf	Daikin/ industry publication						Yes	
HFC-32: Next generation refrigerant that helps reduce global warming	9/10/2015	https://www.daikin.com/press/2015/150910/WS_Daikin_Factsheet_ver2.1.pdf	Daikin/ industry publication	Yes		Yes				
Accelerated Fatigue Testing of Aluminum Refrigeration Press Fittings for HVAC & R Applications	7/2016	https://docs.lib.purdue.edu/iracc/1753/	Stefan Elbel et al. for University of Illinois at Urbana-Champaign and Creative Thermal Solutions and RLS Refrigeration/ academic publication			Yes				
Assessment of Commercially Available Energy-Efficient Room Air Conditioners Including Models With Low GWP Refrigerants	10/2017	https://escholarship.org/uc/item/01h8g7zb	Won Young Park et al. for Lawrence Berkeley National Laboratory/ academic publication	Yes	Yes				Yes	

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Update on Air Conditioning Safety Standards for HVAC/R Equipment	4/25/2019	https://www.ul.com/news/update-air-conditioning-safety-standards-hvacr-equipment	UL LLC/ industry publication					Yes	Yes	
Update--Revisiting Flammable Refrigerants: white Paper	1/2017	https://collateral-library-production.s3.amazonaws.com/uploads/asset_file/attachment/1747/UL_Flammable_Refrigerants_White_Paper_2017_Update.pdf	UL LLC/ industry publication						Yes	
New Developments Drive Adoption of Low-GWP Refrigerants In Commercial Refrigeration	8/6/2019	https://www.achrnews.com/articles/141693-new-developments-drive-adoption-of-low-gwp-refrigerants-in-commercial-refrigeration	Lisa Tryson et al. for Air Conditioning, Heating, Refrigeration (ACHR) News/ industry blog		Yes			Yes	Yes	
Next Generation Refrigerants	3/29/2018	https://www.trane.com/content/dam/Trane/Commercial/global/newsroom/blogs/Documents%202018/HVAC%20Industry%20Update.pdf	Trane/ industry publication	Yes					Yes	
Refrigerants: Market Trends and Supply Chain Assessment	2/2020	https://www.nrel.gov/docs/fy20osti/70207.pdf	Chuck Booten et al. for National Renewable Energy Laboratory (NREL) and Omar Abdelaziz for Oak Ridge National Laboratory (ORNL)/ government technical report	Yes	Yes			Yes		
California enacts HFC refrigerant bans	1/1/2019	https://www.coolingpost.com/world-news/california-enacts-hfc-bans/	Cooling Post/ industry blog				Yes			

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Technical Working Group Meeting: Stationary AC Rulemaking	3/6/2019	https://ww2.arb.ca.gov/sites/default/files/2019-03/Final%20Presentation%20-%20Technical%20Working%20Group%20Meeting%20%28March%205%202019%29.pdf	California Air Resources Board/ government publication		Yes		Yes	Yes		Yes
Board Meeting Comment Log: High-Global Warming Potential Refrigerant Emissions Reductions Regulation	Last viewed: 1/10/2021	https://www.arb.ca.gov/lispub/comm/bccommlog.php?listname=casnap	California Air Resources Board/ government publication							Yes
Public Hearing to Consider the Proposed Regulation for Prohibitions on Use of Certain Hydrofluoro-carbons in Stationary Refrigeration and Foam End-Uses: Staff Report: Initial Statement of Reasons	1/30/2018	Available through sub-scription only	California Air Resources Board/ government publication		Yes					Yes
Comment Log for Proposed Regulation: Restrictions on Refrigerant Gases Used in Refrigeration and Air-Conditioning Appliances (hfc-measure-ws).	Last viewed: 1/10/2021	https://www.arb.ca.gov/lispub/comm2/bccommlog.php?listname=hfc-measure-ws	California Air Resources Board/ government publication						Yes	
Refrigerants for New and Retrofit Applications		https://www.opteon.com/en/products/refrigerants	Opteon/ industry publication							Yes
HFC Reduction Measures: Meetings & Workshops	7/22/2020	https://ww2.arb.ca.gov/our-work/programs/hfc-reduction-measures/meetings-workshops	California Air Resources Board/ government publication							Yes

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Public Workshop: Amendments to California's HFC Regulation	7/22/2020	https://ww2.arb.ca.gov/sites/default/files/2020-07/CARB%20HFC%20Workshop%20Presentation%20%28ADA%29.pdf	California Air Resources Board/ government publication						Yes	Yes
Alternative Refrigerant Evaluation for High-Ambient-Temperature Environments: R-22 and R-410A Alternatives for Rooftop Air Conditioners	9/2016	https://www.energy.gov/sites/prod/files/2016/09/f33/ORNL%20High%20Ambient%20RTU%20Testing%20Report.pdf	Omar Abdelaziz et al. for ORNL/ government technical report	Yes				Yes	Yes	
Investigation of Low GWP Flammable Refrigerant Leak from Rooftop Units	10/2015	https://www.energy.gov/sites/prod/files/2015/10/f27/bto_pub59157_101515.pdf	Omar Abdelaziz et al. for ORNL/ government technical report	Yes				Yes	Yes	
Investigation of Low GWP Flammable Refrigerant Leak from Rooftop Units	1/1/2018	https://www.osti.gov/biblio/1465066	Omar Abdelaziz et al. for ORNL/ government technical report			Yes				
Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants	11/2014	https://www.energy.gov/sites/prod/files/2014/12/f19/Refrigerants%20Roadmap%20Final%20Report%202014.pdf	W. Goetzler et al. for US DOE/ government technical report						Yes	
Lower Global Warming Potential Refrigerants: Frequently Asked Questions	2019	https://www.ahrinet.org/App_Content/ahri/files/Resources/AHRI_SRTTF_Low_GWP_Refrigerants_FAQs.pdf	AHRI/ industry publication						Yes	
Refrigerant Management: Drawdown Technical Assessment References	Last viewed: 1/10/2021	https://www.drawdown.org/sites/default/files/tech_references/References%20REFRIGERANT%20MANAGEMENT.pdf	Project Drawdown/ industry publication							
Manual for Refrigeration Servicing Technicians	1/2010	https://wedocs.unep.org/handle/20.500.11822/7916	technical manual	Yes		Yes				

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Contact Us About Responsible Appliance Disposal (RAD)	Last viewed: 1/10/2021	https://www.epa.gov/rad/forms/contact-us-about-responsible-appliance-disposal-rad	EPA/ government website			Yes				Yes
Refrigerant Management Program	Last viewed: 1/10/2021	https://ww2.arb.ca.gov/our-work/programs/refrigerant-management-program	California Air Resources Board/ government publication			Yes				
California Air Resources Board Explores Feasibility and Costs of New Refrigerant Regulations - Stakeholders share concerns over California's rapid transition to low-GWP refrigerants	9/9/2019	https://www.eesi.org/articles/view/the-magic-of-end-of-life-refrigerant-management	Joanna R. Turpin for ACHR News/ industry blog						Yes	Yes
The Magic of End-of-life Refrigerant Management: Better Disposal of HFC Refrigerants Would Greatly Reduce GHG Emissions	10/11/ 2019	https://www.eesi.org/articles/view/the-magic-of-end-of-life-refrigerant-management	Environmental and Energy Study Institute (EESI)/ industry blog			Yes				
Limited options for low-global-warming-potential refrigerants	2/17/2017	https://www.nature.com/articles/ncomms14476	Mark O. McLinden et al. in *Nature Communications*/ technical publication			Yes				
Construction and Demolition, How to Properly Dispose of Refrigeration and Air-Conditioning Equipment	2/2011	https://www.epa.gov/sites/production/files/documents/ConstrAndDemo_EquipDisposal.pdf	EPA/ Government website			Yes				Yes
Technical Summary: Refrigerant Management	Last viewed: 1/10/2021	https://www.drawdown.org/solutions/refrigerant-management/technical-summary	Project Drawdown/ industry website			Yes				

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
World's leading AC manufacturers and innovative technology companies in running for the Global Cooling Prize	11/15/ 2019	https://globalcoolingprize.org/finalist-global-press-release/	Global Cooling Prize/ industry website							
Fluorine-Gas Refrigerant Product Specifications	Last viewed: 1/10/2021	http://www.beijingyuji.com/english/product/fluorine/Refrigerants/	Beijing Yuji Science & Technology Co., Ltd./ industry website				Yes	Yes	Yes	
The Drawdown Review 2020	Last viewed: 1/10/2021	https://www.drawdown.org/drawdown-review#:~:text=Project%20Drawdown%20conducts%20an%20ongoing,a%20current%20and%20robust%20resource.	Project Drawdown/ industry website			Yes				
EPA-Certified Refrigerant Reclaimers	Last viewed: 1/10/2021	https://www.epa.gov/section608/epa-certified-refrigerant-reclaimers	EPA/ government website			Yes				
Newcomb Mechanical	Last viewed: 1/10/2021	http://www.newcombmechanical.com/contact-us.html	Newcomb Mechanical/ industry website			Yes				
Refrigerant Exchange	Last viewed: 1/10/2021	http://www.refex.com/index.html	Refrigerant Exchange/ Industry website			Yes				
RHI Refrigerant Handling Inc.	Last viewed: 1/10/2021	https://www.refrigeranthandling.com/	RHI Refrigerant Handling Inc./ industry website			Yes				
ODS Destruction in the United States and Abroad	2/2018	https://www.epa.gov/sites/production/files/2018-03/documents/ods-destruction-in-the-us-and-abroad_feb2018.pdf	EPA/ Government technical report		Yes	Yes				
Danfoss: Refrigerants for Lowering GWP	Last viewed: 1/10/2021	https://www.danfoss.com/en-us/about-danfoss/our-businesses/cooling/	Danfoss/ industry website	Yes				Yes		
Why R-32 May Be the Refrigerant of the Future	1/9/2017	https://www.achrnews.com/articles/134215-why-r-32-may-be-the-refrigerant-of-the-future	Don Prather for ACHR News/ industry blog		Yes					

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
New process could cut price of HFOs	7/4/2017	https://www.coolingpost.com/world-news/new-process-could-cut-price-of-hfos/	Cooling Post/ industry blog		Yes					
An Evaluation of R32 in the US HVAC&R Market	5/2016	https://www.optimizedthermalsystems.com/images/pdf/about/An-Evaluation-of-R32-for-the-US-HVACR-Market.pdf	Optimized Thermal Systems, Inc./ industry publication						Yes	
A Breakthrough in the Industrialization of Manufacturing Technology for New Mainstream Low-GWP Refrigerants in China	2017	https://www.engineering.org.cn/EN/10.1016/J.ENG.2017.03.001	Shuhua Wang et al. in *Engineering*/ technical report		Yes					
R470A-a potential "drop-in" alternative to R410A	12/1/2019	https://www.coolingpost.com/world-news/r470a-a-potential-drop-in-alternative-to-r410a/	Cooling Post/ industry blog				Yes			
NEC, NTT develop data center cooling system using new low pressure refrigerant	9/3/2020	https://www.datacenterdynamics.com/en/news/nec-ntt-develop-data-center-cooling-system-using-new-low-pressure-refrigerant/	Tanwen Dawn-Hiscox and Peter Judge for Data Centre Dynamics/ industry blog						Yes	
Electrification Backers, the Refrigerant Revolution Needs Your Support	5/26/2020	https://energycentral.com/c/ec/electrification-backers-refrigerant-revolution-needs-your-support	Jay Stein for Energy Central/ industry blog	Yes						
US Push to Phase Down Global Warming Inducing Refrigerants Blocked by Trump Administration, Moves to the States	4/21/2020	https://energycentral.com/c/ec/us-push-phase-down-global-warming-inducing-refrigerants-blocked-trump	Jay Stein for Energy Central/ industry blog				Yes		Yes	Yes
What Trump's Environmental Rollbacks Mean for Global Warming	9/17/2020	https://www.nytimes.com/interactive/2020/09/17/climate/emissions-trump-rollbacks-deregulation.html	Nadja Popovich and Brad Plumer for *The New York Times*/ periodical		Yes					Yes

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Refrigerant Round-up	5/1/2019	http://www.hvacrbusiness.com/refrigeration-round-up.html	Todd Washam for HVACR Business/ Industry blog		Yes				Yes	
Understanding A2L Refrigerants for Air Conditioners	8/12/2019	https://www.achrnews.com/articles/141733-understanding-a2l-refrigerants-for-air-conditioners	ACHR News/ Industry blog	Yes						
Recommended Leak Hole Size and Mass Flow Rates by System and Application Characteristics	5/2020	http://lifefront.eu/wp-content/uploads/2020/05/final_recommended-leak-hole-size-and-mass-flow-rates-by-system-and-application-characteristics-27052020.pdf	Daniel Colbourne et al. for LIFE FRONT/ EU government publication			Yes			Yes	
Institute of Heating and Air Conditioning Industries, Inc. (IHACI)	Last viewed: 1/10/2021	https://www.ihaci.org/	IHACI/ Industry website					Yes		Yes
Refrigerant and Environmental Impacts: A Best Practice Guide	9/2020	https://www.integralgroup.com/news/refrigerants-environmental-impacts/?fbclid=IwAR3Bg6wkqpC2IZXa_tiaSQVR-WdAL2T7n1i0J4SOzRD_cwkD37x2xRbwu2M	Integral Group, Inc./ industry publication			Yes			Yes	Yes
Revisiting Recovery, Recycling, Reclaim	2/27/2003	https://www.achrnews.com/articles/91665-revisiting-recovery-recycling-reclaim	Peter Powell for ACHR News/ industry blog			Yes				
Phasing out HCFC refrigerants to protect the ozone layer	7/2015	https://www.epa.gov/sites/production/files/2015-07/documents/phasing_out_hcfc_refrigerants_to_protect_the_ozone_layer.pdf	EPA/ government technical report			Yes				Yes
2. f Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer	1/1/2019	https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=_en	United Nations/ international agreement						Yes	Yes

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Update on New Refrigerants Designations and Safety Classifications	4/2020	https://www.ashrae.org/file%20library/technical%20resources/refrigeration/factsheet_ashrae_english_20200424.pdf	United Nations Environmental Program (UNEP) and ASHRAE/ industry publication						Yes	
Conversion Challenges and Applications: Adopting Alternative Refrigerants	2/2018	https://technologyportal.ashrae.org/Journal/ArticleDetail/1942 Requires subscription to access article	ASHRAE/ industry publication	Yes	Yes		Yes	Yes	Yes	
ISO+5149-3:2014 Refrigerating systems and heat pumps — Safety and environmental requirements — Part 3: Installation site	4/15/2014	https://webstore.ansi.org/preview-pages/ISO/preview_ISO+5149-3-2014.pdf Requires purchase to access full article	International Organization for Standardization (ISO)/ industry standard publication				Yes	Yes		
Research Results in Changes to Refrigerant Safety Measures	4/2019	https://www.ashrae.org/news/esociety/research-results-in-changes-to-refrigerant-safety-measures	ASHRAE/ industry publication			Yes			Yes	Yes
What's Keeping Trump from Ratifying a Climate Treaty Even Republicans Support?	2/12/2019	https://insideclimatenews.org/news/12022019/kigali-amendment-trump-ratify-hfcs-short-lived-climate-pollutant-republican-business-support-montreal-protocol/	Phil McKenna for *Inside Climate News*/ periodical							Yes
US Senate Letter to President Donald Trump about Kigali Amendment	6/4/2018	https://www.eenews.net/assets/2018/06/12/document_daily_01.pdf	US Senate/ official correspondence							Yes

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Test Report #52: System Drop-in Tests of Refrigerant Blends ARM-71a, DR-5A (R-454B), HPR2A, L-41-1 (R-446A), L-41-2 (R447A) in a R-410A Split System Heat Pump	10/9/2015	https://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_Final_Reports/AHRI_Low_GWP_AREP_Rpt_052.pdf	AHRI/ industry study	Yes			Yes			
ASHRAE confirms R466A as non-flammable A1 refrigerant	11/21/ 2019	https://www.coolingpost.com/world-news/ashrae-confirms-r466a-as-non-flammable-a1/	Cooling Post/ industry blog				Yes		Yes	
Finding the Promise in Compromise: EIA Proposal to Jumpstart California HFC Reclaim	7/27/2021	https://eia-global.org/blog-posts/20200727-proposal-california-hfc-reclaim	Environmental Investigation Agency (EIA)/ industry blog			Yes				Yes
Soft-Optimized System Test of R410A, DR-55, R32, and DR-5A in a 4-RT Unitary Rooftop Heat Pump	1/21/2016	http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_II/ACHP-III-2_Ingersoll_Rand.pdf	Ken Schultz for Trane/Ingersoll Rand/ industry study				Yes	Yes		
Performance Testing of R-466A: A Low Global Warming Potential Alternative Refrigerant	10/2019	https://wcec.ucdavis.edu/wp-content/uploads/Case-Study_Refrigerant_R466A_10_30_2019.pdf	University of California at Davis (UC Davis) Western Cooling Efficiency Center/ lab study	Yes			Yes			
Honeywell announces R410A breakthrough	6/26/2018	https://www.coolingpost.com/world-news/honeywell-announces-r410a-breakthrough/	Cooling Post/ industry blog	Yes			Yes			

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
Secret of Honeywell's new refrigerant	6/27/2018	https://www.coolingpost.com/world-news/secret-of-honeywells-new-refrigerant/	Cooling Post/ industry blog	Yes			Yes			
California's High Global Warming Potential Gases Emission Inventory: Emission Inventory Methodology and Technical Support, 2015 Edition	4/2016	https://ww3.arb.ca.gov/cc/inventory/slcp/doc/hfc_inventory_tsd_20160411.pdf	California Air Resources Board/ government publication			Yes				Yes
Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018	2020	https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf	EPA/ government technical report			Yes			Yes	
Demonstration of a Regional Strategy for ODS Waste Management and Disposal in the ECA Region	11/9/2017	https://wedocs.unep.org/handle/20.500.11822/26731	United Nations Environment Program/ UN report			Yes				
Search Reuse & Destroy: Initiating Global Discussion to Act on a 100 Billion Ton Climate Problem	11/6/2019	https://content.eia-global.org/posts/documents/000/000/979/original/RefrigerantBanks.pdf?1573061483	EIA/ Industry report			Yes				
Proposed Amendments to CARB's HFC Regulation: New Requirements for Stationary Refrigeration and Air Conditioning	12/10/2020	https://ww3.arb.ca.gov/board/books/2020/121020/20-13-4pres.pdf	California Air Resources Board/ government publication			Yes			Yes	
Performance Testing of DR-55 as a Replacement for R-410A Refrigerant	11/2016	https://wcec.ucdavis.edu/wp-content/uploads/2016/11/Trane-Refrigerant_Case-Study.pdf	UC Davis Western Cooling Efficiency Center/ lab study	Yes			Yes	Yes	Yes	

Title	Publish Date/ Date Site Last Viewed	URL	Source/ Publication Type	Data Categories						
				EE Performance	**Cost/ Economic Impact**	**Leakage/ Reclamation/ Recovery**	**Refrigerant-Only Retrofits**	**Low GWP Adoption**	**GWP, Toxicity, or Flammability**	**Policy/ Enforcement**
Everything You Need to Know About the Coming Changes in the Global, Federal, and state Refrigerant Landscape	2016	https://www.ahrinet.org/App_Content/ahri/files/MEMBER-CONTENT/EVENTS/SM2016/Industry_Session-Transition_to_Lower_GWP_Refrigerants.pdf	AHRI/ industry publication						Yes	
Refrigerants Regulation Updates	12/2019	https://www.fluorineproducts-honeywell.com/refrigerants/wp-content/uploads/2019/12/4967_RefrigerantsRegulationUpdates_Dec2019.pdf	Honeywell/ industry publication							
Refrigerant Regulations: 2020 Update	7/7/2020	https://emersonclimateconversations.com/2020/07/07/refrigerant-regulations-2020-update/	Emerson/ industry publication							
The legislation calls for cutting the use of powerful planet-warming chemicals common in air-conditioners and refrigerators	12/21/ 2020	https://www.nytimes.com/2020/12/21/climate/climate-change-stimulus.html?action=click&module=Well&pgtype=Homepage&section=Climate%20and%20Environment	Coral Davenport for *The New York Times*/ periodical			Yes			Yes	
Code Uncertainty Puts Safe Refrigerant Transition At Risk	5/5/2020	https://www.achrnews.com/articles/143110-code-uncertainty-puts-safe-refrigerant-transition-at-risk	ACHR News/ industry blog						Yes	Yes
Congress Approves HFC Phasedown Plan in Omnibus Bill	12/22/ 2020	https://www.achrnews.com/articles/144236-congress-approves-hfc-phasedown-plan-in-omnibus-bill	ACHR News/ industry blog			Yes		Yes		Yes
"Low GWP" HFO and HFO/HFC Blends: Aspects on the development of HFO and HFO/HFC Refrigerants	Last viewed: 1/10/2021	https://www.bitzer-refrigerantreport.com/refrigerants/low-gwp-hfos-and-hfohfc-blends/	Bitzer Refrigerant Report/ industry publication	Yes				Yes	Yes	

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Potential Impact of the Kigali Amendment on HFC Emissions	Last viewed: 1/10/2021	https://ww2.arb.ca.gov/resources/documents/potential-impact-kigali-amendment-california-hfc-emissions	Government Publication							Yes
Countries commit to protect the ozone layer and climate under the Montreal Protocol	11/13/2019	https://www.unenvironment.org/news-and-stories/press-release/countries-commit-protect-ozone-layer-and-climate-under-montreal	Non-profit Publication							Yes
EU legislation to control F-Gases	Last viewed: 1/10/2021	https://ec.europa.eu/clima/policies/f-gas/legislation_en	Government Policy			Yes		Yes		Yes
The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact	9/30/2020	https://ec.europa.eu/clima/sites/clima/files/news/docs/c_2020_6637_en.pdf	Government Report	Yes	Yes		Yes	Yes	Yes	Yes
SPOTLIGHT ON REFRIGERANT RECOVERY, RECLAMATION AND DESTRUCTION	11/11/2020	https://www.fluorocarbons.org/news/spotlight-on-refrigerant-recovery-reclamation-and-destruction/	Industry Publication			Yes				Yes
AB 32 Global Warming Solutions Act of 2006	Last viewed: 1/10/2021	https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006	Government Policy							Yes
The London Amendment (1990): The amendment to the Montreal Protocol agreed by the Second Meeting of the Parties (London, 27-29 June 1990)	Last viewed: 1/10/2021	https://ozone.unep.org/treaties/montreal-protocol/amendments/london-amendment-1990-amendment-montreal-protocol-agreed	International Agreement							

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				EE Performance	Cost/ Economic Impact	Leakage/ Reclamation/ Recovery	Refrigerant-Only Retrofits	Low GWP Adoption	GWP, Toxicity, or Flammability	Policy/ Enforcement
The Copenhagen Amendment (1992): The amendment to the Montreal Protocol agreed by the Fourth Meeting of the Parties (Copenhagen, 23-25 November 1992)	Last viewed: 1/10/2021	https://ozone.unep.org/treaties/montreal-protocol/amendments/copenhagen-amendment-1992-amendment-montreal-protocol-agreed	International Agreement							Y
Phaseout of Class II Ozone-Depleting Substances	Last viewed: 1/10/2021	https://www.epa.gov/ods-phaseout/phaseout-class-ii-ozone-depleting-substances	US Government Policy Document							Y
F-gas reduction incentive programs	Last viewed: 1/10/2021	https://ww2.arb.ca.gov/our-work/programs/f-gas-reduction-incentive-program/applications-received/tier-i-detailed-project			Yes			Yes		
Experience with R600a heat pumps installed at Danish hospital	Last viewed: 1/10/2021	http://hydrocarbons21.com/articles/2782/experience_with_r600a_heat_pumps_installed_at_danish_hospital	Industry Publication					Yes	Yes	
HFC PHASEDOWN	Last viewed: 1/10/2021	https://hardinet.org/advocacy/issues/hfc-phasedown/	Industry Tracker							

7.3 Appendix C: Invitation to participate and IDI guide

STATE OF CALIFORNIA EDMUND G. BROWN JR., *Governor*

PUBLIC UTILITIES COMMISSION
505 VAN NESS AVENUE
SAN FRANCISCO, CA 94102-3298

Dear Subject Matter Expert:

The California Public Utilities Commission (CPUC) is performing a study to assess the operational performance of HVAC refrigerants with low global warming potentials (GWP) and to develop a strategy to encourage the adoption of those low-GWP refrigerants. As part of the California Cooling Act, refrigerant equipment funded by energy efficiency programs overseen by the CPUC must have low-GWP refrigerants.

The CPUC's Energy Division requests your participation in a study which includes telephone interviews. The CPUC has retained DNV GL (www.dnvgl.com) and its team of consultants as the primary contractor for this work. This letter serves to authenticate their request for information. The data collected during the interview will be used for the purpose of informing the research objectives.

The purpose of this study is to:

- Identify and better understand feasible HVAC refrigerants with a GWP<750
- Identify critical barriers in converting HVAC systems to use low-GWP refrigerants and determine potential solutions for overcoming these barriers
- Analyze the hypothetical performance impacts of alternative low-GWP refrigerants on common HVAC systems
- Summarize the findings of the research tasks in a report and provide recommendations to stakeholders

Please do not hesitate to contact me at the phone number or email address shown below if you have further questions regarding the research. Thank you for agreeing to participate in this study. Your participation will help both the utilities and the CPUC better understand low-GWP opportunities.

Sincerely,

/s/Erik Johnson
California Public Utilities Commission
505 Van Ness Ave.
San Francisco, CA 94102
Direct Dial: (415) 703-1608 or email: erik.johnson@cpuc.ca.gov

7.4 Appendix D: Web survey

Low-GWP HVAC Refrigerant Survey for Subject Matter Experts

Hello,

This survey contains approximately 15 questions related to HVAC refrigerants. For the purpose of this survey, the term "low-GWP" is defined as a gas with a 100-year global warming potential, relative to carbon dioxide, below 750. Thank you for your valuable feedback.

Please click next to continue.

Which of the following best describes the industry you work in?

		Response percent	Response total
HVAC original equipment manufacturer		0%	0
HVAC distributor		0%	0
HVAC contractor		0%	0
Refrigerant manufacturer		0%	0
Environmental policy, research, consulting		0%	0
Engineer or building design architect		0%	0
Laboratory testing and research		0%	0
Government agency		0%	0
Other, please specify:		0%	0

Statistics based on 0 respondents;

What is the name of the organization you work for?

			Response total
			0

Statistics based on 0 respondents;

Are you familiar with the California Cooling Act, Senate Bill (SB) 1013?

		Response percent	Response total
Yes		0%	0
No		0%	0

Statistics based on 0 respondents;

How strongly do you agree that SB 1013 will result in most new California HVAC equipment installed after January 1, 2023, to utilize a low global warming potential refrigerant (100-year GWP <750)?

		Response percent	Response total
1 = strongly disagree that after 1/1/2023, most CA HVAC equipment will utilize a low-GWP refrigerant		0%	0
2 = somewhat disagree		0%	0
3 = uncertain		0%	0
4 = somewhat agree		0%	0
5 = strongly agree that after 1/1/2023, most CA HVAC equipment will utilize a low-GWP refrigerant		0%	0

Statistics based on 0 respondents;

Please indicate why you disagree with the above statement?

			Response total
			0

Statistics based on 0 respondents;

In this next question, we would like you to consider the impact of SB 1013 in the year 2025.

How strongly do you agree that SB 1013 will result in most new California HVAC equipment installed after January 1, 2025, to utilize a low global warming potential refrigerant (100-year GWP <750)?

		Response percent	Response total
1 = strongly disagree that after 1/1/2025, most CA HVAC equipment will utilize a low-GWP refrigerant		0%	0
2 = somewhat disagree		0%	0
3 = uncertain		0%	0
4 = somewhat agree		0%	0
5 = strongly agree that after 1/1/2025, most CA HVAC equipment will utilize a low-GWP refrigerant		0%	0

Statistics based on 0 respondents;

Please indicate why you disagree with the above statement?

			Response total
			0

Statistics based on 0 respondents;

What do you anticipate will be the most common refrigerant used in California residential and light commercial unitary HVAC equipment installed after January 1, 2025?

Because this question is targeting unitary equipment, we are not including CO2 as a likely fluid in the near term.

		Response percent	Response total
R-32		0%	0
R-454b (Opteon™ XL41)		0%	0
R-466a (Solstice® N41)		0%	0
R-410a		0%	0
Some combination of low-GWP refrigerants (100-year global warming potential <750)		0%	0
None of the above		0%	0
Don't know		0%	0
Other, please specify:		0%	0

Statistics based on 0 respondents;

What is the minimum lead time needed for the HVAC supply chain to successfully transition to low-GWP HVAC refrigerant technologies and installation procedures once code updates allow for a ASHRAE A2L (mildly flammable) HVAC refrigerants in California?

		Response percent	Response total
6 months		0%	0
1 year		0%	0
18 months		0%	0
2 years		0%	0
3 years or more		0%	0
Don't know		0%	0

Statistics based on 0 respondents;

The transition to new HVAC equipment utilizing low-GWP refrigerants may impact the cost paid by the end-consumers. Please provide your best estimate on how this will impact the cost of new low-GWP installations in California in 2023:

		Response percent	Response total
No noticeable impact		0%	0
Increase in price		0%	0
Decrease in price		0%	0
Don't know		0%	0

Statistics based on 0 respondents;

How much do you expect the transition to a low-GWP refrigerant will increase the price of the equipment for the California consumer in year 2023?

			Response total
			0

Statistics based on 0 respondents;

In the previous question, you provided a cost estimate for new low-GWP equipment if installed in 2023. In this question, we are interested in your best estimate for the cost impact of new low-GWP installations in 2025.

		Response percent	Response total
No noticeable impact		0%	0
Increase in price		0%	0
Decrease in price		0%	0
Don't know		0%	0

Statistics based on 0 respondents;

How much do you expect the transition to a low-GWP refrigerant will increase the price of the equipment to for the California consumer in year 2025?

			Response total
			0

Statistics based on 0 respondents;

We would now like you to consider the practicality/feasibility of retrofitting an existing HVAC equipment's refrigerant to a low-GWP alternative. Please indicate your level of agreement with the statement that "Low-GWP alternatives are practical" for retrofitting the following equipment types:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Don't know		Response total
Split-system, computer room, or portable AC units	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)		0
Residential and small commercial heat pumps	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)		0
Commercial RTUs with refrigerant charge levels - Up to 50 lbs	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)		0
Commercial RTUs with refrigerant charge levels - Over 50 lbs	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)		0
Chillers	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)		0

Statistics based on 0 respondents;

What percent of the following HVAC equipment types have the remaining refrigerant reclaimed at the end-of-life?

			Response total
Split-system, computer room, or portable AC units			0
Residential and small commercial heat pumps			0
Commercial RTUs with refrigerant charge levels - Up to 50 lbs			0
Commercial RTUs with refrigerant charge levels - Over 50 lbs			0
Chillers			0

Statistics based on 0 respondents;

Rank the following statements where 1 represents the "most effective" and 4 represents the "least effective" action taken towards California's pursuit to lower global warming impacts caused by HVAC equipment.	Most effective 1	2	3	Least effective 4	Response total
Finalize California's fire and safety codes to allow for mildly flammable (ASHRAE A2L) refrigerants in HVAC equipment.	0% (0)	0% (0)	0% (0)	0% (0)	0
Provide incentives to target the early retirement of existing HVAC equipment and replace with low-GWP HVAC equipment.	0% (0)	0% (0)	0% (0)	0% (0)	0
Improve the success rate of refrigerant reclamation and ensure proper disposal of end-of-life HVAC equipment.	0% (0)	0% (0)	0% (0)	0% (0)	0
Create a market value for reclaimed high-GWP refrigerants by allowing non-virgin or reclaimed high-GWP to be used in new equipment installations between January 1, 2023 and January 1, 2025.	0% (0)	0% (0)	0% (0)	0% (0)	0

Statistics based on 0 respondents;

Please provide one or more suggestions on how the state of California could improve the end-of-life refrigerant reclamation success rate:	Response total
	0

Statistics based on 0 respondents;

This survey aims to gather input from experts like yourself. Can you please help us by recommending colleagues who should participate in this survey? Please do so by providing the name(s) and email(s) here. Your referrals will only be contacted for participation in this survey. Alternatively you may copy/paste this URL and forward it along to people within your professional network: https://app.form.com/f/41540936/41b8/	Response total
	0

Statistics based on 0 respondents;

This concludes our survey, thank you for your participation.

7.6 Appendix E: Complete web survey open-ended responses

Please provide one or more suggestions on how the state of California could improve the end-of-life refrigerant reclamation success rate:

- *Rebates*
- *Quantities of reclaimed refrigerant by contractor should be published. My guess is that most contractors would be at or close to 0.*
- *public education campaign around the idea of "just don't send that old A/C to the landfill"*
- *The state buys back the reclaimed refrigerant*
- *Enforce Clean Air Act Section 608 requirements on technicians.*
- *More training and incentives for the reclaimed refrigerant*
- *Create an environmental reclaim fund that would pay the contractor/owner/installer the cost of replacement refrigerant plus 25% of the same value to properly turn-in equipment refrigerant reclaimed during the change over to new refrigerant or equipment. Have verifiable collection centers provide the certificate of reclaim and verified environmentally safe disposal of the reclaim refrigerant. Otherwise many will just vent it to atmosphere because there are no teeth in any of the laws to prevent it. Some will only reclaim if there is a financial incentive for them to do so.*
- *Focus efforts on the existing housing and provide new home builders a credit if they choose to implement on new projects. Older equipment always needs more attention than newer equipment.*
- *Recovery of refrigerant or reclaimation?*
- *It is unlikely anything outside of financial incentives to safely change will result in significant retrofit. Can influence new code to low GWP effecting new builds and that will gradually cut off old refrigerants just as it did on the change from R22.*
- *Market forces need to create a value to the certified contractor to 1) recover the gas responsibly under Refrigernat Management rules and, 2) deliver the "dirty" gas to a certified reclaimer. The reclaim industry must have an integrous process, certified by third parties to 1) certify the reclamation (mass balance and purity) and 2) sell the certified reclaim only through auditable channels such as OEM's and licensed wholesalers and contractors.*
- *Levy a $100/lbs tax on sales of all new refrigerants having GWP > 750.*
- *review operation and lessons learned from other nations and/or states that have EOL refrigerant reclamation systems in place today, especially for A2L refrigerants*

- *Provide incentive to reclaim*
- *Build value to incent the contractor to reclaim; support streamlined reclamation processes with contractors and distributors.*
- *More mandated training for residential and light commercial contractors who work with small unitary HVAC units.*
- *Finalize the transition date for Low-GWP refrigerants and develop the necessary fire/safety code requirements so that manufacturers can develop products. In some cases the efficiency of the Low-GWP alternatives are better than R-410a and equipment components can be largely unchanged allowing for a relatively quick transition.*
- *1. Ban virgin high-gwp refrigerants (>750) for servicing existing equipment starting in 2025 (require use of reclaim, but allow it to come from out of state until 2030 to allow ramp up in supply) 2. Tax/fee on the sale of virgin refrigerants that are >150 GWP but less than 750 GWP, use the proceeds to fund rebates for recovery and reclaim, i.e. amt of refrigerant a servicing company verified through R4 program as having recovered and delivered for reclaim gets a corresponding rebate 3. Create a robust R4 certification program for verifying recovery and emission reductions in California that includes a traceability mechanism for lifecycle of refrigerant recovered from within California and then reclaimed: i.e. an app used to scan bar codes on reusable cylinders required to be scanned and entered at points of a) initial collection/recovery b) received by reclaimer c) sold reclaim refrigerant.   4. Mandate reusable cylinders with barcodes for reclaimed refrigerant*
- *There needs to be a demand for reclaimed R410A in order to create an incentive for technicians to recover this refrigerant at the end of life.*
- *Provide an incentive to customers towards the reclaimed refrigerant or credit to be used for installing the new refrigerant.*
- *Track refrigerant inventory Create incentives for good citizens*
- *Require contractors to show receipts of reclaimed refrigerant equivalent to new system change-outs in a month or quarter.*
- *Incentivized payment for delivering end-of-life self-contained systems (room AC, dehumidifiers, refrigerators) to recycling centers with refrigerant recovery.*
- *Provide the end-user or contractor an allowance for certifying that they reclaimed the refrigerant on decommissioned equipment*
- *To effectively transition to low GWP refrigerants will require equipment manufacturers to also modify compressor technology to not only accept these new Freon's but to also keep pace with Title 24 energy codes and equipment efficiency levels. I expect there to be a variety of low GWP refrigerants used based on equipment capacity requirements. It will also be important that equipment is*

designed to make use of heat recovery in order to improve the overall system COP and further reduce greenhouse gas emissions. I also believe the use of natural refrigerants like ammonia, CO2 and propane will have a place for certain commercial applications.

- *Enforce the damn law.   Require a permit to replace major HVAC equipment, and require a building inspector to be on-site during HVAC change-outs to verify that the contractor is recovering refrigerant at end-of-life. Penalize the shit out of companies that vent, and quadruple the penalty for repeat offenders.*
- *Rebates on reclaimed equipment/refrigerant*
- *Provide HVAC refrigerant reclamation centers for HVAC contractors to bring reclaimed High-GWP refrigerants coupled with incentive payments on site much like recycling centers do for bottles and cans. Perhaps establish a California redemption value for High-GWP and place that tax on the purchase of High-GWP equipment sold in California starting in 2023.*
- *All of the proposals to date have increased the cost to the consumer either in the form of tax money being used to offset cost or in increased cost of new equipment all of which will reduce compliance. The cost to benefit ratio makes this some of the dumbest legislation in this state to date and is a great example of why people are leaving California as fast as they can.*
- *Providing incentives for proper reclamation.*
- *Training HVAC contractors and technicians on the good reclamation techniques and adding such training to their licensing and ongoing continuing education (CE) activities.*
- *From experience only the regulatory control of refrigerant management systems will force compliance. We hear too many times from technicians and contractors that since there is no 'real' control or enforcement of the requirements many contractors simply lower their prices to be hyper-competitive and "dump the refrigerant". By 'dumping' they seem to mean venting it.*
- *proper technician training; rewarding money to the end users for reclaiming the refrigerants*
- *Monetary incentives*
- *Examine the reclamation process from Mechanical Contractor to Disposal site and reduce the friction as much as possible. And/or create a market for that reclaimed material somehow.*
- *Place a tax on every new pound of gas purchased - then provide a rebate when the gas is returned (for reclaim) and validated by an approved reclaimed. Align the tax with the carbon value of the material. Collect the tax on each sale of gas in a cylinder. Tag each cylinder as it enters the system (registry) and do not allow the*

sale or use of gas that comes in from interstate commerce unless it has been verified and credentialed into your supply chain. This is a highly simplified overview meant to provide a concept but not the mechanics.

7.7 Appendix F: Stakeholder comments and evaluator responses

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
1	Terminology	PG&E	3/25/21	Over-arching	Over-arching	The use of the terms "low-GWP" and "lower-GWP" throughout the report is confusing and sometimes inconsistent. It appears that "low-GWP" is sometimes used to refer to both low- and lower-GWP refrigerants. Can you please clarify when you are refering to all refrigerants <750 GWP and when you are referring only to refrigerants <150 GWP?	We understand the confusion around this. Much of this stems from the definition CARB gives of low-GWP refrigerants being refrigerants with a 100-year GWP level below 150 where the HVAC industry commonly refers to refrigerants with 100-year GWP levels below 750 as low-GWP refrigerants. Given CARB is responsible for defining the high-GWP phasedown of refrigerants prescribed in SB1013, we attempted to acknowledge the distinction by defining refrigerants with GWP levels above 150 and below 750 as lower-GWP refrigerants. This being said we still use the term low-GWP in the title and in the web-survey to refer to all refrigerants with a 100-year GWP level below 750. To clarify things we chose to remove the term lower-GWP from the report entirely and define low-GWP as anything with a 100-year GWP below 750 and anything with a 100-year GWP below 10 as an ultra-low-GWP. Ultra-low-GWP was added to the list of definitions.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
2	Mildly flammable refrigerants	PG&E	3/25/21	Over-arching	Over-arching	The report repeatedly offers mildy flammable refrigerants as a near-term solution and only seems to offer up natural refrigerants as a long-term option. The research also indicates that it will be a few years at least before mildly flammable refrigerants are a viable choice in most situations. Are the strategies that could accelerate adoption of natural refrigerants so that mildly flammable refrigerants are not needed as a stepping stone, at least in certain applications?	Both mildly flammable HFC refrigerants and natural refrigerants are very limited in where they are permitted to be installed but pending code updates will likely allow mildly flammable refrigerants in most applications within two years. Natural refrigerants with properties similar to current refrigerants are either highly flammable, which includes the hydrocarbons r-290 (propane) and r-600a (isobutane) or are toxic which is the case for r-717 (ammonia). Hydrocarbons will remain extremely limited in where they are permitted to be installed until US code allows systems to have a charge over 150 grams. The one area where natural refrigerants are gaining traction is r-744 (Carbon Dioxide) systems installed in process cooling settings that can also leverage r-744 to assist with space conditioning to some extent. It's fairly complicated but economically viable when designing new grocery stores or process cooling systems. The more success and demand for these systems the more other opportunities will open up outside of this setting as technology develops. The California Air Resources Board offered $1M in funding grants to participants of their F-gas Reduction Incentive Program in the fall of 2020. That program was over-subscribed in less than 2-months. Most applications involved CO_2 refrigeration systems. The IOUs could look to offer similar programs in their respective territories. One of the anecdotes we heard in our in-depth interviews about the mildly flammable refrigerants was this is a necessary step to show standard HVAC equipment can safely operate with mildly flammable refrigerants. The more prevalent these systems become the more opportunity highly flammable hydrocarbon refrigerants to be taken seriously. The likelihood is mildly flammable HFCs will dominate the unitary HVAC market for a decade or more before technology and code acceptance on natural refrigerants enables widespread adoption. HFOs may have a brief moment in the spotlight as well before natural refrigerants really take off.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
3	Refrigerant avoided cost calculators	PG&E	3/25/21	1.2 Summary of Key Findings	11	The study references the CPUC's Refergerant ACC and DNV's own ACC. Where can these calculators be accessed? Can you please provide a link within the document?	The DNV add-on calculator is still being vetted by the CPUC. The current CPUC Refrigerant Avoided Cost Calculator is found here: ftp://ftp.cpuc.ca.gov/gopher-data/energy_division/EnergyEfficiency/CostEffectiveness/Refrigerant%20Calculator.xlsx
4	Mildly flammable refrigerants	PG&E	3/25/21	1.2 Summary of Key Findings	12	The study states that "mildly flammable HFCs are the near-term solution", however the graphic indicates that low-GWP refrigerants and mildly flammable refrigerants were both selected by the same number of respondents (35% each), which implies that these are equally viable near-term solutions. Should this instead say that both mildly flammable HFCs and low-GWP refrigerants are near-term solutions?	The figure being cited refers to the responses to question 9 in the web survey. Option E was listed as "Some combination of low-GWP refrigerants (100-year Global Warming Potential <750)." The full list of options were: a. R-32 b. R-454b (Opteon™ XL41) c. R-466a (Solstice® N41) d. R-410a e. Some combination of low-GWP refrigerants (100-year Global Warming Potential <750) f. None of the above g. Don't know The respondents were told previously in the survey the term "Low-GWP" refers to refrigerants with a 100-year GWP value below 750. The only potential near-term refrigerant options for most system types with a 100-year GWP level below 750 is R-466a but none of the 55 respondents who answered that question indicated they believed R-466a would be the most common. Mildly flammable HFCs are low-GWP refrigerants the way the web-survey was presented. The 35% of respondents saying some combination of low-GWP refrigerants were most certainly referring to mildly-flammable HFCs being at least part of the mix. It's important to make the step in the direction of flammability if we want to lower greenhouse gas impacts and maintain refrigerant energy performance.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
5	Mildly flammable refrigerants	PG&E	3/25/21	1.2 Summary of Key Findings	12	The study recommends that PAs should require the use of mildly flammable HFCs, but elsewhere the report reinforces the fact that these refrigerants are not currently allowed in the majority of applications. Would it be more sensible to recommend that PAs should incentivize the use of any lower- and low-GWP refrigerant, including natural refrigerants?	Please note the full sentence in the recommendation reads: "PAs should begin including a requirement for the use of mildly flammable HFCs into their HVAC incentive programs where these refrigerants are currently permitted." See responses above for more info on natural refrigerant promotion strategies.
6	Natural refrigerants	PG&E	3/25/21	1.2 Summary of Key Findings	13	The study states that "natural refrigerants are the long-term solution." Given that this is the case, it seems that PAs should be facilitating the move to natural refrigerants wherever this technology is viable instead of pushing first for mildly flammable refrigerants.	That's a fair question and one that we asked during the in-depth interviews. The fact is there is a wide array of HVAC equipment that require the use of refrigerants. For central residential and many commercial unitary HVAC systems it may be more than a decade before natural refrigerants are available solutions. Industry experts we spoke with cited the safe use of mildly flammable refrigerants in these systems during the interim will only help expedite the viability of natural refrigerants in the long run.
7	Drop-in refrigerants	PG&E	3/25/21	1.2 Summary of Key Findings	14	The study states that refrigerant change-outs are only viable for large commercial applications. Is there an opportunity to utilize thermorefrigeration in smaller HVAC applications?	The anecdotal feedback we got in interviews about refrigerant only change-outs was that it would be too labor intensive and potentially code prohibitive to perform on smaller equipment that could just as easily be replaced with newer, more efficient, units that operate on lower-GWP refrigerants. From what we know about thermorefrigeration that would only add more complexity to the retrofit making it an even less cost-effective strategy.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
8	End-of-life emissions	PG&E	3/25/21	1.2 Summary of Key Findings	14	The study recommends that PAs both require and incentivize safe recovery of refrigerants but offers no solutions for monitoring or enforcement of these rules. If bad actors already vent refrigerants at end-of-life, how will PA incentives prevent them from doing so? Would they not simply continue this behavior while pocketing the incentive? The root-cause of the issue is lax enforcement of regulations that exist outside of the jurisdiction of the PAs, and it should fall to those governing bodies to improve their own enforcement.	EPA 608 laws banning intentional venting are more often incapable of levvying fines because it's so difficult to prove someone "intentionally vented" refrigerant from smaller equipment on rooftops or even on the side of a house. In the orchard of measures to fight global warming, improving EOL refrigerant recovery is an abundant and very low hanging fruit. The PAs should look for measures they can consistently track and document the following info, EOL equipment nameplate photo, the site location, and the account number for every claimed safe recovery. In the web survey we polled respondents for open ended recommendations on how the state could improve reclamation rates and far and away the most common suggestion was incentives. The top 7 of 39 comments received can be found in section 5.2.1. Also, PAs can play an important role in refrigerant recovery by providing some incentive preventing venting and documenting the safe recovery and reclamation. The incentive has to be large enough that it is worth the technician's time to recover the refrigerant and transport it to a reclamation facility. PAs provide incentives for replacing old inefficient equipment with energy efficient equipment and they are best suited to incorporate requirements for disposal of the old equipment, including refrigerant recovery and reclamation. As for the enforcement aspect of refrigerant recycling and recovery, CARB can work with PAs to develop some strategies. Some to consider include requiring receipt for refrigerant delivered to a certified reclaimer within a few days of installing the new equipment, required the use of reclaimed refrigerant only for servicing existing systems, reporting/recordkeeping requirements for technicians/contractors to track refrigerant added and recovered per system. PAs have historically had programs for recycling residential refrigerators and some of the lessons learned/challenges can be used to develop a successful program.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
9	Leakage mitigation	PG&E	3/25/21	5.2 Refrigerant leakage, recover, reclamation, and reuse	47	The sentence at the end of the second paragraph is incomplete: "For smaller equipment, older equipment, or on equipment when the leaks were too difficult to find, HVAC SMEs reported that often they would either replace the component that contained the leak." Did SMEs indicate a second strategy for servicing this equipment?	Thanks for catching that oversight. We revised the report so that the sentence now reads: "For smaller equipment, older equipment, or on equipment when the leaks were too difficult to find, HVAC SMEs reported that often they would either replace the component that contained the leak or replace the unit entirely because it was the most cost effective solution."
10	Refrigerant timeline	PG&E	3/25/21	5.3 Current and future low-GWP refrigerant alternatives	55	Is this chart the result of DNV's own analysis? If so, what data was used to inform the forecast?	Yes, the chart is based on the culmination of the research DNV performed during this study. It is an approximation of HVAC refrigerant installation rates by year and is provided to show the historic, present, and likely future trends. Please refer to appendix A for the data sources.
11	Findings and Recommendations	SDG&E	3/23/21	Overarching	Overarching	The study should provide a spreadsheet listing all the recommendations similar to impact evaluations "RTR". Those suggestion should be handed over to the CPUC staff ex-ante team for review for final determination and DEER Resolution adoption.	Appendix A: IESR - Recommendations resulting from market research was added to address this comment.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
12	Findings and Recommendations	SDG&E	3/23/21	Findings and Recommendations	Overarching	The draft study report recommends "PAs should provide incentives" for reclaiming high GWP refrigerants and for new HVAC system with low-GWP. The current CPUC cost effectiveness model and CEDARS CET tool is not set-up for PA cost recovery of low-GWP avoided cost calculation. CPUC policy needs to established policy and guidance similar to what occurred with the 3-Prong Fuel Substitution Test migration to CEDARS Cost Effectiveness Tool (CET). The study needs to provide a solution on how to incorporate (CPUC) low-GWP avoided cost calculator so its seamlessly integrated with CEDARS CET, given that each PA (IOUs/POU/RENs) has their specific avoid cost records "The 2021 Avoided Cost data from the CET" (refer to CEDARS URL https://file.ac/W1JDsjbKXOU/).	This is a goal DNV is working towards providing with the add-on calculator being vetted by the CPUC. The CPUC will be providing guidance on this moving forward.

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
13	Terminology	SDG&E	3/23/21	5.7.5	Pg. 70	Section 5.7.5 Early replacement (ER) vs. replacement on burnout (ROB). The use of these terms have been phased out by previous 2020 DEER Resolutions E4952 for new Measure Application Type. For most cases ER was replaced with Accelerated Replacement (AR) and ROB was replaced with Normal Replacement (NR).	Thanks for bringing this to our attention. The use of these terms has been updated in all instances of the report with the exception of the phrasing of the question used in the web survey. That was kept as-is for the posterity of the web survey results.
14	Avoided Cost Calculators	SDG&E	3/23/21	5.7.6	Pg. 71-72	Section 5.7.6 Comparison between existing refrigerant ACC and DNV GL's prototype calculator. The reader and audience needs to know where to download the two calculators if they are open source and available to the public. Suggest making the inputs and assumptions available to the reader for duplicating the results shown on Figure 5-18. Comparison between existing calculator vs. DNV GL calculator.	The DNV add-on calculator is still being vetted by the CPUC. The current CPUC Refrigerant Avoided Cost Calculator is found here: ftp://ftp.cpuc.ca.gov/gopher-data/energy_division/EnergyEfficiency/CostEffectiveness/Refrigerant%20Calculator.xlsx

Comment #	Subject	Entity	Date	Section	Page	QUESTION or COMMENT	Evaluator Response
15	Findings and Recommendations	SDG&E	3/23/21	Findings and Recommendations	Pg. 78-79	On page 80, if applicable with the recommendations for measure offerings, the measure would only be limited to refrigerant-only retrofits on commercial large HVAC equipment such as chillers and RTUs?	That is our recommendation based on the findings from this research study. Please refer to section 5.5 of the report for a full rational behind this recommendation.
16	Findings and Recommendations	SDG&E	3/23/21	Findings and Recommendations	Pg. 80	Recommendation includes stop funding refrigerant charge adjustments. Would this influence any existing approved workpapers in 2021 and beyond? When does this go into effect? Any impacts to the upcoming DEER Resolution? If so, collaboration amongst the research team and the ex-ante teams from the CPUC would help with compliance and timing.	Since RCA is a DEER measure, any changes would be made through the DEER Resolution. Our research team relayed the findings from this study to the DEER team for them to take appropriate action.
17	Findings and Recommendations	Proctor Engineering Group	3/15/21	Findings and Recommendations	N/A	Unfortunately, the draft report strays beyond the scope of low GWP refrigerants and makes unsubstantiated and unscientific claims and recommendations related to HVAC system maintenance. We recommend that the following "Key Finding" and recommendation be	A review of recently vetted impact evaluation reports on RCA measures was performed to document the evaluated measure realization rates. These report findings were arrived at using scientifically vetted methodologies using empirical data on systems receiving RCA adjustments. The average residential RR is 33% and the average commercial is 47% (see table below for a complete realization rate summary). These low evaluated savings rates also do not consider the negative GWP impacts the measure includes from de minimis leakage and perpetuating high levels of operational leakage caused by proactively adding

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						removed from the report: • Refrigerant charge adjustments cause emissions to increase. • Stop funding refrigerant charge adjustments. Pretending that a problem will cease to exist if we simply stop looking for it is not an effective solution. Ignoring a problem does not make it go away, it only allows it to grow. The report presents no scientific evidence supporting the claim that correcting refrigerant level deficiencies causes refrigerant emissions to increase by any significant amount compared to ignoring the problem. It presents no scientific evidence that competent HVAC contractors following appropriate refrigerant charge verification and remediation procedures cause greater refrigerant emissions than are prevented by detecting and repairing leaks before the entire refrigerant volume has been lost. On the other hand, there is an extensive history of scientific documentation that incorrect refrigerant	refrigerant to leaky systems. If these emissions were added to the impact analysis the realization rates would potentially go negative. Our experience evaluating RCA programs is they trigger pro-active refrigerant charge adjustments which often add refrigerant to systems that are either a, not undercharged at the time of adjustment, or b, are marginally undercharged and adding charge only increases the rate of leakage. One simply needs to review EPA and CARB HVAC operational emissions to understand this point. Any occurrence of refrigerant being added to a system also includes some level of de minimis leakage. If PAs stop funding these historically under-performing programs it does not mean contractors can't correct under-charges systems where they are clearly found in the future. It simply means this action will be paid for entirely by the equipment owner. The workpapers and DEER measures detailing the energy and demand benefits of RCA adjustments do not consider the impacts of increased refrigerant emissions stemming from refrigerant being added to leaking systems. For a program to be successful it has to be cost effective.

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						levels reduce air conditioner efficiency and increase peak demand. It is also well known that air conditioning is the cause of afternoon and evening demand peaks on hot days, and that demand is primarily met by fossil fuel generation. For example, the following figure shows supply generation sources on August 14, 2020. This is a day that California experienced rolling blackouts due to excessive evening demand largely attributed to air conditioning as described in the January 13, 2021 CPUC, CEC and California ISO joint report “Root Cause Analysis, Mid-August 2020 Extreme Heat Wave”. It is obvious from this data that air conditioner energy use on hot afternoons and evenings is predominantly supplied by fossil fuel generation. Source: California ISO Ignoring easily correctable problems that have been scientifically proven to	

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						contribute to afternoon and evening energy use is bad policy. It increases reliance on fossil fuel generation, increases greenhouse gas emissions, and increases the probability that California will suffer rolling blackouts or other energy system failures during extreme weather events. While the topic of HVAC system maintenance is really not within the scope of a low GWP refrigerant study, it would be highly worthwhile to conduct an honest and unbiased investigation into the ongoing failure of HVAC programs implemented by the IOUs under the direction of the CPUC to produce energy savings and quality work. We suggest starting with a review of the CPUC decision a decade ago to redesign the HVAC programs according to requests from HVAC industry lobbyists and excluding advice from energy efficiency experts with HVAC expertise. The resulting programs, based on HVAC industry	

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						standards that are not and have never been designed to address energy efficiency, were quickly demonstrated to be: • Costly, with the majority of effort and expenses driven by activities unrelated to saving energy. • Fraught with implementation failures. • Lacking even the most fundamental quality assurance procedures including a failure to implement or enforce standards that would prevent refrigerant loss through the use of appropriate tools and practices. • Ineffective, with energy savings determined to be near zero. Despite these findings, the programs have been allowed to continue for the past decade with only superficial changes. For reference, Appendix A includes Proctor Engineering Group comments on the 2010-12 program evaluation study. The same comments still apply today since the CPUC has not taken	

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						meaningful action to correct the mistakes made 10 years ago. Proctor Engineering Group appreciates the opportunity to provide comments on evaluation documents that may inform critically important policy decisions. The California electrical grid failures of 2020 clearly demonstrate that the problems of air conditioning energy use and peak demand are too important to continue the pattern of neglect we have observed over the past decade. To address these problems, policy must be based on science and not on politics or unscientific claims by industry advocates. The contribution of air conditioning to peak demand must be appropriately valued, and program administrators must be held accountable for implementing effective solutions. This means distinguishing between technical savings potential and program implementation failures,	

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						and not causing HVAC measures to be discontinued when evaluations find low savings resulting from a failure to implement effective programs rather than a technical deficiency of the energy efficiency measure.	
18	Findings and Recommendations	IESR	3/5/21	Findings and Recommendations	N/A	On behalf of the SW Response to Recommendations (RTR) Policy Team, we'd like to request that the recommendations be put in a table following the CPUC Energy Division Impact Evaluation Standard Reporting Guidelines (even for non-impact evaluations). Thank you! https://pda.energydataweb.com/api/downloads/1399/IESR_Guidelines_Memo_FINAL_11_30_2015.pdf	Appendix A: IESR - Recommendations resulting from market research was added to address this comment.

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Evaluation Title	Program Years Covered	Res/Non Res	IOU	tion Rate
06-08 Government Partnerships Programs Direct Impact Evaluation Report	2006-08	Non-Res	SCE	7%
06-08 Government Partnerships Programs Direct Impact Evaluation Report	2006-08	Res	SCE	14%
Vol_1_HVAC_Spec_Comm_Report	2006-08	Res	PG&E 2000	28%
Vol_1_HVAC_Spec_Comm_Report	2006-08	Res	PG&E 2078	38%
Vol_1_HVAC_Spec_Comm_Report	2006-08	Res	SCE 2502	45%
Vol_1_HVAC_Spec_Comm_Report	2006-08	Res	SCE 2507	45%
Vol_1_HVAC_Spec_Comm_Report	2006-08	Res	SDG&E 3035	33%
Impact Evaluation of 2015 Commercial Quality Maintenance Programs (HVAC3)	2010-12		Not evalualuated as an isolated measure	
HVAC4_Year3_Report	2015	Com	PG&E Commercial QM	36%
HVAC4_Year3_Report	2015	Com	PG&E AirCare Plus	37%
HVAC4_Year3_Report	2015	Res	Residential QM	123%
HVAC4_Year3_Report	2015	Com	SDG&E Deemed Incentives - Commercial HVAC	81%
HVAC4_Year3_Report	2015	Com	Commercial Direct Install	32%
Group A Residential HVAC PY2019	2019	Res	PG&E	5%
Group A Residential HVAC PY2019	2019	Res	SDG&E	2%
Totals:				
Residential Average Realization Rate	**2006-2019**	**Residential Average**	**Statewide**	**33%**
Commercial Average Realization Rate	**2006-2019**	**Commercial Average**	**Statewide**	**47%**