July 2, 2021

MARKET IMPACTS OF LOW-GWP REFRIGERANTS FOR REFRIGERATION EQUIPMENT

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1 Executive Summary

1.1 Introduction, Study Objective, and Scope

Through various commercial and industrial (C&I) energy efficiency programs, Southern California Edison (SCE) has influenced and provided incentives for many new refrigeration systems and system upgrade measures over many years. Recently, the California Air Resource Board (CARB) proposed new regulations for refrigerant global warming potential (GWP), which will affect SCE's program offerings. These regulations impact new and existing refrigeration systems with more than 50 lb. of refrigerant.

This study's objective is to understand the market impacts of low-GWP alternative refrigerants, understand how these changes will impact the refrigeration measures offered by the investor owned utilities (IOUs), and assist program implementers with developing strategies to accelerate the adoption of the low-GWP alternatives. Specifically, this study investigated the impact of the proposed CARB regulations on Commercial Refrigeration Equipment, Cold Storage, and Industrial Refrigeration.

The study comprised two phases:

- Phase 1 includes secondary research data collection and interview guide development.
- Phase 2 includes market actor interviews, assessment, and analysis of data collected in Phase 1.

This report provides key results from phase 1, full results of phase 2, and recommendations based on the results of both phases.

1.2 Methodology

Phase 1 consisted of a literature review to collect information on:

- Regulations that affect C&I refrigerants, including state and federal energy, environmental, safety, and labor regulations.
- Refrigerant technical characteristics, including their GWP, flammability, toxicity, capacity, coefficient of performance (to indicate efficiency), and other characteristics.
- C&I refrigeration systems, including application, size, leak detection methods, and phase-out dates for certain refrigerants based on regulations.

Phase 2 consisted of primarily interviews with various types of market actors. TRC interviewed 28 market actors, including refrigeration equipment manufacturers, distributors, contractors, and customers; as well as state agency staff.

1.3 Conclusions and Recommendations

The C&I refrigeration industry is rapidly evolving. As with many technologies, standard practice appears to be very different for new facilities vs. retrofits.

For new facilities, the market is primarily installing low-GWP systems—typically CO_2 with some microdistributed for commercial (including grocery stores), and primarily ammonia in industrial with some CO_2 systems.

For existing commercial and cold storage facilities, the market has various options for retrofitting systems. This includes moderate-GWP systems—defined by this study as 733 to 1,429 GWP; and low GWP systems—defined by this study as <150 GWP. Because the CARB regulations impose a weighted-facility-average GWP for existing facilities, many customers are exploring different options. Most commercial refrigeration customers reported they plan to retrofit systems to moderate-GWP systems (R448A and R449A). In addition, no interviewees reported they have retrofitted a grocery store (or other commercial facility) to a low-GWP system such as CO_2 or microdistributed. A few market actors reported they are "waiting and seeing", either what synthetic Hydrochlorofluoro-olefins (HFO) blends (which would require a less extensive retrofit) manufacturers might release, or for codes and standards to allow HFO systems (which have a lower GWP, but flammability concerns) to be allowed for use in U.S. facilities. For industrial facilities, interviewees reported they are either not retrofitting facilities (since they are already ammonia), or they are replacing with a CO2 system. While ammonia dominates industrial facilities in non-populated areas, split systems that use high-GWP (halocarbon) refrigerants are common in smaller facilities and those in more populated areas. One cold storage interviewee reported replacing their existing system with a new CO_2 system. Note that this report uses the term "retrofit" to refer to both a true retrofit (i.e., replacement of only certain components of a system), and the complete replacement of an existing system to a new system, such as to a new CO2 system.

Most market actors reported they are moving to moderate- or low-GWP systems because of regulations, although they frequently cited sustainability reasons as well.

Multiple market actors indicated they (or other market actors) had unanswered questions regarding low-GWP systems. For example, many raised questions regarding the energy performance and operational or maintenance needs of CO_2 or microdistributed systems, and many raised concerns about the lack of qualified technicians to maintain these systems. There was also interest regarding HFO blends (e.g., 454A/454C) that are yet to be released. However, market actors expressed concerns about HFO refrigerants' flammability and many unknowns (in terms of HFO refrigerants' cost, energy performance, and allowability in future building codes). This has led some market actors to adopt a "wait and see" attitude when developing a plan for meeting the upcoming CARB regulations.

Based on the findings of this study, TRC developed recommendations to address specific barriers that we identified during interviews with market actors and market research. These recommendations are organized into the following three main categories. Particularly for the GHG incentives and non-resource offerings, SCE should discuss their planned initiatives with CARB, to ensure these support CARB goals but do not duplicate CARB initiatives.

Energy Savings Incentives: which the IOUs could start implementing in the near future. These recommendations include:

1. Develop higher energy efficiency incentive rates and more comprehensive offerings (e.g., include advanced commissioning and performance monitoring) for low-GWP refrigeration system energy savings retrofit projects.
2. Eliminate energy efficiency incentives for high-GWP (>1300) refrigeration systems, but provide efficiency incentives for moderate-GWP systems (at lower levels than for low-GWP).

Greenhouse Gas (GHG) Incentives: which the IOUs could start implementing once the total systems benefit (which accounts for GHG reductions) takes effect in 2024. These recommendations include:

1. Develop incentives based on $/MTCO$_2$e reduced, focused on accelerated replacement of existing systems, with a target of offsetting 25-40% of incremental project costs. Incentivize systems with GWP below 150.
2. Explore program offerings for grocery stores replacing existing high-GWP display cases with self-contained low-GWP cases (microdistributed, propane), utilizing a $/TR of capacity replaced metric.
3. Allow customers to participate in a GHG reduction program without requiring associated energy savings calculations and engage the California Public Utilities Commission (CPUC) on appropriate baseline assumptions (the *do nothing* option).
4. Develop lower incentive rates (based on $/MTCO$_2$e) for HFO refrigerant systems or incentivize only natural refrigerants in future programs.
5. Explore emerging technologies projects associated with product development and site demonstrations of CO_2 condensing units or develop upstream program incentives directed at condensing unit manufacturers.
6. Make proper refrigerant disposal a requirement for program participation (documentational requirement).

Non-Resource Offerings: which the IOUs could start implementing in the near future, but for which they cannot claim savings. These recommendations include:

1. Develop a *Refrigerant Audit* program analogous to energy audits, where SCE or affiliated third parties survey refrigeration systems. Audit reports would offer tailored recommendations on low-GWP options, leak detection systems, and potential GHG incentive amounts as a free service to customers.
2. Develop an "early adopter" program for customers that replace existing refrigeration systems with low-GWP systems. This program could provide design assistance, advanced commissioning; and measurement and verification (M&V) services, and performance monitoring services. M&V services would include benchmarking low-GWP system performance with other customers. This could be part of GHG reduction programs or *Refrigerant Audit* programs.
3. Become a sponsorship partner for industry organization events that promote technical learning (conferences, dedicated training sessions, etc.)
4. Explore Emerging Technologies projects associated with product development and site demonstrations of CO2 condensing units, or develop upstream program incentives directed at condensing unit manufacturers.
5. Invest in the next generation of refrigeration whole building modeling simulation software (e.g., upgrade Energy Plus), with a focus on low-GWP system modeling that could be utilized by customers, industry trade allies associated with the refrigerant audits, and SCE staff engineers.
6. Provide a recognition-based program, where SCE can provide awards to customers that adopt best practices for reducing their GHG emissions via leak reduction or low-GWP conversion.
7. Explore Emerging Technologies project that targets a supermarket retrofit, to investigate feasibility of retrofitting to CO2, micro-distributed propane, or another low GWP system.

2 Introduction and Study Scope

2.1 Study Motivations and Objectives

Southern California Edison (SCE) has influenced and provided incentives for many new refrigeration systems and system upgrade measures over the years through various commercial and industrial (C&I) energy efficiency programs. SCE must continually adjust its program offerings and consider the regulatory environment and other market conditions for its programs to succeed.

Recently, the California Air Resource Board (CARB) proposed new regulations for refrigerant global warming potential (GWP) that would impact new and existing refrigeration systems with more than 50 lb. of refrigerant. The regulations would be phased in over time beginning January 1, 2022.

The objective of this study is to understand the market impacts of low-GWP alternative refrigerants, understand how these changes will impact the refrigeration measures offered by the investor owned utilities (IOUs), and assist program implementers to develop strategies to accelerate the adoption of the low-GWP alternatives.

2.2 Study Scope

TRC and VaCom Technologies (the study team) researched refrigerant properties for various refrigerants and relevant system performance characteristics; system, cost, and market impacts of moving to low-GWP refrigerants; and drivers and barriers of converting existing refrigeration systems (from high-GWP refrigerants) to low-GWP refrigerant systems. Figure 1 below provides the affected refrigeration categories, market areas, and equipment included in this study, which align with the EPA Significant New Alternatives Policy (SNAP) classifications.

Figure 1. Refrigeration Systems

Category	Covered Areas	Equipment
Commercial Refrigeration Equipment	Supermarket	♦ Air cooled and remote condensing units ♦ Multi-rack systems ♦ Self-contained walk-in cooler & freezer
Cold Storage	Cold Storage Warehouse	♦ Remote condensers and evaporators ♦ Packaged systems
Industrial Refrigeration	Food Processing, Chemical, Pharmaceutical and Plastics Manufacturing, Construction, Ice Rink	♦ Process chillers ♦ Remote condensers and evaporators ♦ Compressor packages ♦ Packaged systems

The full study was comprised of two phases:

- Phase 1 included secondary research data collection and served as a scoping study for Phase 2. Phase 1 included interview guide development and captured information regarding refrigerants' energy efficiency, toxicity, and leakage detection requirements.
- Phase 2 included market actor interviews to capture information on system design differences, costs, barriers, and feasibility for adoption. It also included analysis of deemed and custom refrigeration measures in the SCE database, a review of other programs to incentivize low-GWP refrigeration systems, and a targeted literature review.

This report incorporates information from both phases and provides conclusions and recommendations for SCE program offerings based on both phases.

The study focused on *existing* facilities. However, TRC did gather some data for new facilities (for example, several interviewees commented regarding their practices for new facilities), so this report presents those results as well.

3 Methodology

The methodology for Phase 2 primarily consisted of interviews with market actors, as well as a few interviews with SCE staff and regulators. In addition to the interviews, TRC also reviewed the SCE program databases to investigate past trends in refrigeration measure uptake, reviewed the program design of other programs that encourage customers to move to low-GWP refrigeration systems, and conducted a targeted literature review of key studies.

3.1 Market Actor Interviews

Figure 2 provides a disposition table showing the number of interviews targeted and completed by market actor type. As shown, TRC completed a total of 28 interviews with market actors, including 10 customers, 5 refrigeration equipment manufacturers, and 5 contractors. The customer interviews represented staff from six grocery store chains (including mass merchandise stores with a grocery store), three food producers and one cold storage facility.

Figure 2. Market Actor Interview Completions

Market Actor Type	Target Number	Source for Interviewees	Completed	Contacted
Refrigeration Equipment Manufacturers	3 to 5	Title 24 and Title 20 stakeholders, research team contacts, online research	5	16
Distributors of Refrigeration Equipment	3 to 5	Title 24 and Title 20 stakeholders, research team contacts, online research, referrals from refrigerant manufacturers	2	4
Refrigerant Manufacturers	3 to 5	Referrals from refrigerant manufacturers and online research	1	4
Contractors	4 to 6	Research team contacts, Title 24 and Title 20 stakeholders, referrals from distributors, online research	5[1]	9
Customers	Minimum 6, potentially 10-12	Research team contacts, Title 24 and Title 20 stakeholders, online research	10	26
Regulatory staff	3	Research team contacts and online research	2	3
SCE staff	2 or 3	SCE referrals	3	3
Total	*20 to 32*		28	65

[1] Includes one energy efficiency / sustainability consultant.

As shown in Figure 2, the research team used a variety sources to identify interviewees, including research team contacts, Title 24 and Title 20 stakeholder comments, online research, and the *snowball approach* of asking interviewees to recommend other contacts. TRC conducted the interviews via teleconference and provided a $150 gift card for market actor interviewees[2].

Interviewees described the equipment that they manufactured (manufacturers), sold (distributors), installed (contractors), or owned or managed (customers). Of those interviewed (excluding regulatory staff and SCE staff):

- **15 respondents** reported they manufacture, sell, install, or own or operate some type of **commercial refrigeration system**. For many respondents, this included refrigeration systems for grocery stores.
- **20 respondents** reported they manufacture, sell, install, or own or operate some type of **cold storage system**. While the interviewees included more grocery stores than cold storage facilities, several of the grocery store chains reported they had a separate cold storage facility, while the cold storage facility did not have a commercial refrigeration system.
- **21 respondents** reported they manufacture, sell, install, or own or operate some type of **industrial refrigeration system**. While the interviewees included more grocery stores than food processors, a few of the grocery store chains reported they had a separate food processing facility, while the food processing facilities did not have a commercial refrigeration system.

This study notes where interview results differed by market actor type or by system type.

3.2 Additional Data Collection

While the interviews represented the main data collection in this study, TRC also:

- **Analyzed the SCE program databases for trends in refrigeration measure incentive use**. The purpose of the review was to understand the types of customers using the refrigeration measure offerings and their project types, to inform whether those types of projects could continue under low-GWP refrigeration system scenarios, and to inform opportunities under low-GWP incentive offerings. TRC requested the program databases for the SCE deemed and custom programs for measures that used a refrigeration project measure code. TRC analyzed the types of refrigeration measures installed, customer types that used those measures based on North America Industrial Classification System (NAICS) code, and the energy savings associated with each measure. The data set included participants for program years 2018 to early 2021. TRC viewed the 2018 and 2019 participation years as "normal", while 2020 was impacted by Covid-19, and 2021 data was incomplete, since it only included the first few months of that year. Section 6.1 presents results.
- **Reviewed other programs that incentivize or encourage low-GWP refrigeration systems**. The purpose was to understand current offerings in the market, and to identify any strategies that could be incorporated into SCE offerings. The review included a program from Sacramento Municipal Utility District (SMUD), the California Energy Commission (CEC) Food Production

[2] TRC did not offer gift cards to regulatory agency and SCE staff. A few market actors declined the gift card, and one requested a donation be made instead to his local food bank.

Investment Program (FPIP), CARB's F-Gas program, and the U.S. Environmental Protection Agency's (EPA) GreenChill program. Section 6.2 presents results.

- **Reviewed key literature** to inform findings and recommendations. These included:
    - The DNV-GL Low-GWP HVAC Refrigerants Study[3] to identify findings applicable to C&I refrigeration. As part of our literature review, TRC examined the California Public Utilities Commission (CPUC) report to compare the key findings and trends with those identified as part of this study. The results relative to this study are included throughout Section 7.
    - The CPUC Cost Effectiveness proposed decision (PD) https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M378/K256/378256443.PDF and Avoided Cost Calculator https://www.cpuc.ca.gov/general.aspx?id=5267. An overview of the PD and the implications of the avoided cost calculations are summarized in section 5.3.
    - The "Potential Barriers to Improving Energy Efficiency in Commercial Buildings: The Case of Supermarket Refrigeration,"[4] results are included as part of Section 7.7.1.

[3] DNV GL Energy, "HVAC Refrigeration: A Roadmap for Accelerating the Adoption of Low-GWP Refrigerants," May 3, 2021

[4] Klemick, Heather & Kopits, Elizabeth & Wolverton, Ann, 2017. "Potential Barriers to Improving Energy Efficiency in Commercial Buildings: The Case of Supermarket Refrigeration 1," Journal of Benefit-Cost Analysis, Cambridge University Press, vol. 8(1), pages 115-145, April.

4 Overview of Refrigerants

4.1 Overview of Refrigerant Classes and Terminology

4.1.1 Refrigerant Naming Convention

Refrigerants have traditionally been classified by their chemical make-up and comprise several different major groupings of artificial and natural refrigerants. ASHRAE Standard 34 assigns each a unique refrigerant number (typically R-###) that is used by industry, regulatory bodies, and researchers to denote accepted refrigerant products with their related thermodynamic and physical properties. Some of the unique refrigerants are recognized blends (Zeotropes and Azeotropes) of other refrigerants.

4.1.2 Ozone Depletion Potential (ODP)

With the knowledge that many artificial refrigerants were contributing to the destruction of the ozone layer, international agreements were struck, including the Montreal Agreement, that required the reduction of these refrigerants. An Ozone Depletion Potential (ODP) measures a chemical's relative amount of degradation to the ozone layer it can cause, relative to trichlorofluoromethane (R-11 or CFC-11) which has an ODP of 1.0. As a result, many older artificial refrigerants, including chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), have been banned or will be phased out by 2030 because of their high ODP.

4.1.3 Global Warming Potential (GWP)

Concerns related to global warming have brought about additional concerns on many C&I byproducts, including many refrigerants. The primary metric for global warming is Global Warming Potential (GWP). GWP measures how much energy the emissions of one ton of a gas will absorb over a given period of time (100 years), relative to the emissions of 1 ton of carbon dioxide (CO2)[5]. The larger the GWP, the more that a given gas warms the Earth compared to CO2. CO2 has a GWP value of 1.0. As an example of a legacy refrigerant, R-404A has a GWP of 3,922, meaning that one ton of R-404A is 3,922-times more powerful in warming the atmosphere than one ton of CO2. The long-term goal is to transition to low GWP refrigerants such as ammonia (R-717), propane (R-290), and CO2 (R-744).

Figure 3 summarizes the differing classifications. This figure groups refrigerants for commercial and industrial refrigeration applications into five primary classifications based on their GWP. TRC found different categorizations for "low GWP" in the literature. For example, the HVAC Refrigerants study by DNV (2021) categorized HVAC refrigerants with a GWP between 150 and 732 as "Low GWP", and HVAC refrigerants with a GWP of 3 or lower as "ultra-low GWP", as shown in the column "GWP Grouping HVAC Refrigerants Study". In contrast, CARB categories all refrigerants with a GWP less than 150 as "Low GWP", and all refrigerants with GWP ≥150 as "High GWP", as shown in the column "CARB GWP Class". **This study aligned with CARB by referring to all refrigerants with GWP < 150 as "low GWP"**, since that was generally how market actors used the term low-GWP. This study also introduces the following new categories: "Moderate" for GWP between 733 and 1,429; and "Low/Moderate" for GWPs between 150 and 732, since we believe more differentiation is needed for refrigerants with GWP > 150.

[5] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Figure 3. GWP Refrigerant Classifications

GWP Grouping, per this study	GWP Grouping, HVAC Refrigerants Study	CARB GWP Class	GWP Range	Refrigerant Types	Typical Low and Medium Temperature Refrigerants	Typical Applications / Usage
High	High- GWP	High	>1,430	CFCs, HCFCs, HFOs	R-12, R-502, R-404A, R-22	Legacy refrigerants that have already have a sunset path set for multiple applications, R-404A for medium/low temps, R-22 legacy refrigerant used in supermarket rack systems
Moderate	Not categorized: no common HVAC refrigerants in this GWP range[6]	High	733-1,429	hydrofluorocarbons (HFCs), HCFCs, HFO blend, HFC/HFO blend	R-134a, R-448A, R-449B, R-449A	R-448a for retrofitting R-404A, R-134a for medium temps, R-448A, R449A/B for ice skating rinks
Low/ Moderate	Low- GWP	High	150-732	HFCs, HFO, HFC/HFO blend	R-32, R-450a, R-513A	R-32 for replacing R-410a; R-450a for replacing R-404A and R0134a; R-513A used in ice skating rinks
Low	Not categorized: no common HVAC refrigerants in this GWP range	Low	11-149	HFCs, HFO, HFC/HFO blend	R-455a, R-454C, R-457a	Replacement for R-404A, R-22
Low	Ultra-Low- GWP	Low	0-10	Natural refrigerants, HFOs Other Types	Natural: R-744 (CO_2), R-717 (ammonia) HFO: R-1234yf, R-1234ze Others: R-290, R-600a, R-1270	Ammonia historically used in Industrial refrigeration. Various trials of new system supermarket designs including cascaded, trans critical CO_2, distributed systems, compact chillers, and secondary loop systems. These may eliminate or reduce traditional refrigeration charge.

[6] Based on Table 1-1 in DNV (2021).

4.1.4 Toxicity and Flammability

The GWP refrigerant classification is the focus of this study. However, other classifications, especially flammability and toxicity, affect policies and customer decision-making, as there are many implications including life safety and building and equipment codes beyond the GWP. ASHRAE has also classified these refrigerants in terms of toxicity and flammability. These classifications, which are explained in more detail in Section 4.2, have been used to guide building and equipment codes relative to the use of and application of these refrigerants and equipment containing these refrigerants in various buildings and applications.

Section 4.2 provides details on the specific refrigerants, while Section 7 provides more details on the market and system impacts of the current and future refrigerants.

4.2 Refrigerant Comparison

Figure 4 provides a comparison of refrigerants by the following key characteristics:

1. GWP is a measure of the total energy that a gas absorbs over a particular period of time (usually 100 years), compared to carbon dioxide.
2. *ASHRAE Safety* Classification is taken from American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 34. ASHRAE classified refrigerants based on flammability and toxicity:
    a. A: lower toxicity; B: higher toxicity
    b. 1: non-flammable, 2L: lower-flammable, 2: flammable, 3: highly-flammable
    For example, refrigerants classified as A2L are low toxicity and low flammability, and A3 are low toxicity and highly flammable. Ammonia is classified as B1 for its high toxicity and low flammability.
3. Acute toxicity exposure limit (ATEL) is the level above which there is an adverse effect that results either from a single or multiple exposure in a short space of time (usually less than 24 hours).
4. Relative cooling capacity is defined cooling capacity of the alternative refrigerant relative to the refrigerant being replaced.
5. Relative coefficient of performance (COP) is the COP of the alternative refrigerant relative to the refrigerant being replaced.
6. Leakage rate based on the nominal system design methods, detection systems, and current practice. While synthetic refrigerants generally have lower pressure compared with ammonia, ammonia typically has the lowest leakage rate because of regulation. CO2 typically has a lower leakage rate than synthetic refrigerants due to piping and joining practices.
7. Refrigerant cost is the cost per pound ($/lb) of refrigerant. This reflects only the cost of the refrigerant itself, not the cost of the refrigeration system, which is presented in Section 7.4.

The refrigerants are listed in the order of GWP ranking, with lowest GWP refrigerant (best) at the top of the figure and highest GWP (worst) at the bottom. This figure provides an at-a-glance view of characteristics for refrigerants, where:

- ● a full circle indicates that a refrigerant scores well for this characteristic
- ◖ a half-full circle indicates that a refrigerant scores medium for this characteristic
- ○ an empty circle indicates that a refrigerant scores poorly for this characteristic

TRC provides the quantitative scoring method for each characteristic below the figure. The **bolded text** indicates refrigerants that were frequently mentioned in interviews conducted for this study. In addition to those bolded below, several interviewees mentioned HFO-HFC blends but did not call out specific refrigerants within this class. The figure includes common existing refrigerants for comparison.

Figure 4. Refrigerant Characteristics

Refrigerant	Type	Substitute for	GWP [1]	ASHRAE Safety Classification Flammability [2a]	ASHRAE Safety Classification - Toxicity [2b]	ATEL [3]	Relative Cooling Capacity [4]	Relative Efficiency COP [5]	Leakage Rate [6]	Refrigerant Cost [7]
R-717	**Ammonia**	**HCFC and CFC**	●	◖	○	○	◖	●	●	●
R-744	**Carbon Dioxide**	**R-134a, R-404A**	●	●	●	○	●	●	●	●
R-1336mzz	Hydro Fluoro Olefin, HFO	R-134a, HCFC -123	●	●	●	Not found	Not found	Not found	●	Not found
R-600a	Hydrocarbon, HC	R-134a	●	◖	●	○	●	●	●	◖
R-290	**Hydrocarbon, HC**	**R-404A**	●	○	●	◖	●	●	●	●
R-1270	Hydrocarbon, HC	R-404A	●	○	●	○	●	●	●	●
R-1234yf	**Hydro Fluoro Olefin, HFO**	**R-134a**	●	◖	●	◖	●	●	◖	○
R-1234ze	Hydro Fluoro Olefin, HFO	R-134a	●	◖	●	◖	◖	●	◖	○
R-516A	HFC/HFO Blend	R-134a	●	◖	●	Not found	●	●	◖	Not found
R-457A	HFC/HFO Blend	R-404A, R-22, R-507A	●	◖	●	Not found	◖	●	◖	Not found
R-451A	HFC/HFO Blend	R-134a	●	◖	●	◖	Not found	Not found	Not Found	Not found
R-454C[7]	**HFC/HFO Blend**	**R-404A**	●	◖	●	◖	●	●	◖	Not found
R-455A	HFC/HFO Blend	R-404A	●	◖	●	◖	●	●	◖	○
R-451B	HFC/HFO Blend	R-134a	●	◖	●	◖	Not found	Not found	Not Found	Not found
R-454A[8]	**HFC/HFO Blend**	**R-404A, R-507A, R-407A, R-407F**	◖	◖	●	◖	●	●	◖	○
R-515B	HFC/HFO Blend	R-134a	◖	●	●	Not found	◖	●	◖	Not found
R-515A	Hydro Fluoro Olefin, HFO	R-134a	◖	●	●	Not found	◖	●	◖	Not found
R-446A	HFC/HFO Blend	R-410A	○	◖	●	○	Not found	Not found	Not Found	Not found
R-454B	HFC/HFO Blend	R-410A	○	◖	●	◖	●	●	◖	Not found
R-513B	HFC/HFO Blend	R-134a, R-404A	○	●	●	Not found	Not found	Not found	◖	Not found
R-447A	HFC/HFO Blend	R-410A	○	◖	●	◖	●	●	◖	Not found
R-450A	HFC/HFO Blend	R-404A	○	●	●	◖	●	●	◖	Not found
R-513A	**HFC/HFO Blend**	**R-134a**	○	●	●	Not found	●	●	◖	Not found
R-32	Hydro Fluoro Carbon, HFC	R-410A	○	◖	●	◖	●	Not found	◖	●
R-460B	HFC/HFO Blend	R-404A, R-134a	○	●	●	Not found	Not found	Not found	Not Found	Not found
R-449B	HFC/HFO Blend	R-404A, R-22, R-407	○	●	●	◖	Not found	●	◖	Not found
R-448A	**HFC/HFO Blend**	**R-404A**	○	●	●	◖	◖	◖	◖	◖
R-449A	**HFC/HFO Blend**	**R-404A**	○	●	●	◖	◖	●	◖	◖
R-463A	HFC/HFO Blend	R-410A	○	●	●	Not found	●	●	◖	Not found
R-452A	HFC/HFO Blend	R-404A, R-507A	○	●	●	◖	●	●	◖	Not found
R-452C	HFC/HFO Blend	R-404A	○	●	●	Not found	●	Not found	Not Found	Not found
R-22	HCFC (Freon)	N/A	○	●	●	◖	N/A	N/A	◖	◖
R-134a	HFC	N/A	○	●	●	◖	N/A	N/A	◖	○
R-404A	HFC	N/A	○	●	●	◖	N/A	N/A	◖	○

[7] Interviewees identified as approved for use in Europe, but not available currently in the U.S. because of code restrictions due to their flammability.
[8] Same common as for R454C on commonly used in Europe but not the U.S. flammability.

[1] GWP - Full Circle: 0 - 150 GWP, Half Circle: 150 - 400 GWP, Empty Circle: > 400 GWP
[2a] ASHRAE flammability classification - Full Circle: 1 (non-flammable), Half Circle:2 (lower flammable), 2L (flammable), Empty Circle: 3 (highly flammable)
[2b] ASHRAE Toxicity classification - Full circle: ASHRAE Classification A (lower toxicity), Empty Circle: ASHRAE Classification B (higher toxicity). While both the ASHRAE Toxicity classification and ATEL measure toxicity, the minimum toxicity to be designated as a toxic (Classification B) refrigerant by ASHRAE is very high.
[3] ATEL - Acute toxicity exposure Limit - Full Circle: High (> 0.05 lb/ft3), Half Circle: Medium (0.005 - 0.05lb/ft3), Empty Circle: Low (0 - 0.005 lb/ft3).
[4] Relative Capacity - Full Circle: ≥1, Half Circle: 0.5 - 0.99, Empty Circle: <0.5
[5] Relative Efficiency - Full Circle: ≥9, Half Circle: 0.5 - 0.89, Empty Circle: <0.5
[6] Leakage Rate - Full Circle: Low, Half Circle: Medium, Empty Circle: High
[7] Cost - Full Circle - 0-10 $/lb, Half Circle - 11-20 $/lb, Empty Circle >20 $/lb

In general, the comparison shows that many low-GWP refrigerants have comparable capacity, efficiency, and toxicity compared to current standard practice (prohibited) refrigerants. However, some low-GWP refrigerants have additional flammability potential concerns that may result in restricted applicability. In addition, as described in Section 7, the system impacts of different refrigerants—including the costs of retrofitting from one type of refrigerant to another—can be much higher for low-GWP systems.

5 Summary of Regulations and Proposed Ruling on Cost-Effectiveness Test for IOU Regulations

5.1 Prohibited Refrigerants and CARB Phase-out Schedule

As an overview, there are two levels of EPA and CARB regulations affecting C&I refrigeration systems.

- CARB Title 17 Division 3, § 95371-95377 and the U.S. EPA Code of Federal Regulations (Title 40) SNAP regulate substances and prohibit specific refrigerants in new facilities and facilities that are retrofitted.
- CARB Title 17, Division 3, § 95371-95377 provides additional requirements for existing facilities—including those that ***do not*** undergo a retrofit. As described below, for retail food facilities (e.g., supermarkets), the CARB regulations set weighted average GWP requirements that a company must meet across its existing facilities by 2030. In addition, retail food companies with more than 20 facilities must meet an interim requirement in 2026. There are also GWP limits for existing industrial refrigeration equipment that take effect in 2022.

Figure 5 shows the first type of regulations—prohibited standard practice refrigerants—based on system and replacement types, where "P" indicates it was prohibited as of January 1, 2021. The CARB regulations will take effect January 1, 2023 for new cold storage warehouse facilities. Industrial process refrigeration is not listed below, because TRC's literature review indicated that there are currently no standard practice refrigerants that are prohibited for that system type. A full list of currently prohibited refrigerants (standard practice, and less commonly used refrigerants) is referenced in Appendix 11.

Figure 5. Prohibited Standard Practice Refrigerants

CARB & EPA (SNAP) Title 17, Division 3, § 95371-95377 List of Prohibited Substances (CARB) & Title 40, § 82 Subpart G, Rules 20 and 21 (US EPA SNAP)										
Refrigerant	**Supermarket Systems**		**Remote Condensing Units**		**Stand-alone medium temperature units**	**Stand-alone low temperature units**	**Stand-alone units**	**Cold Storage Warehouse**		**Food Processing Refrigeration**
	New	**Retrofits**	**New**	**Retrofits**	**New**	**New**	**Retrofit**	**New**	**Retrofit**	**New**
HFC-134A					P					
R-404A	P	P	P	P	P	P	P	1/1/2023		P
R-407A					P	P		1/1/2023		P
R-407C					P	P				P
R-407F					P	P				P
R-410A					P	P		1/1/2023		P
R-507A	P	P	P	P	P	P	P	1/1/2023		P

As shown, many *standard practice* refrigerants are already prohibited or soon will be (in 2023), including HFC-134A and R04A.

As shown in the figures above, the regulations will impact new facilities, existing facilities that are doing remodel, and existing facilities that may not have had a remodel planned (because of the facility-weighted GWP requirement). Regulator interviewees clarified that, if a customer is adding capacity to existing facilities, they can use the weighted average approach. If they are adding new systems, those must meet the 150 GWP requirement.

Figure 6 through *Figure* 8 summarize the CARB phase-out schedule for additional refrigerants based on the proposed requirements, and they show the regulations that govern all existing facilities based on facility-weighted averages. To highlight differences in requirements for new equipment vs. existing facilities vs. new facilities, these figures show regulations for new equipment in blue, for **existing facilities in bold**, and for new facilities in plain text.

Figure 6. CARB Phase Out Schedule: Commercial Refrigeration—Supermarket, Retail Food

Equipment	Title 17, Division 3, § 95371-95377
Stationary Refrigeration Equipment containing more than 50 pounds refrigerant (New Equipment, *New Facilities)	Prohibited as of January 1, 2022: Refrigerants with a GWP of 150 or greater R-450A, R-513A, R-513B, R-448A, R-449A, R-449B, R-452A, R-451B, R-454A, R-446A, R-447A, R-454B, R-460B, R-515A, R-515B, R-463A
Companies owning or operating 20 or more retail food facilities and national supermarket chains operating in California **(Existing Facilities)**	Prohibited as of January 1, 2026: Weighted Average GWP < 2,500 or Greenhouse Gas (GHG) Potential Reduction ≥ 25% below 2019 levels
	Prohibited as of January 1, 2030: Weighted Average GWP < 1,400 or GHG Potential Reduction ≥ 55% below 2019 levels
Companies owning or operating fewer than 20 retail food facilities **(Existing Facilities)**	Prohibited as of January 1, 2030: Weighted Average GWP < 1,400 or GHG Reduction ≥ 55% below 2019 levels

*New Facilities - Title 17, Division 3, §95373. New Facilities means (1) New Construction, (2) An existing facility not previously used for cold storage, or refrigeration used in retail food, commercial, industrial refrigeration, or (3) with a replacement of 75% or more of evaporators (by number) and, 100% of compressor racks, and 100% of condensers.

Figure 7 shows requirements for cold storage. TRC did not find a requirement for existing facilities in the proposed CARB regulation, so the figure presents requirements only for new equipment and new facilities.

Figure 7. CARB Phase Out Schedule: Cold Storage

Equipment	Title 17, Division 3, § 95371-95377
Cold Storage Refrigeration Equipment containing more than 50 pounds refrigerant (New Equipment, New Facilities)	**Prohibited as of January 1, 2022:** **Refrigerants with a GWP of 150 or greater** R-448A, R-449A, R-454A, R-463A

Figure 8. CARB Phase Out Schedule: Industrial Refrigeration

Equipment	Title 17, Division 3, § 95371-95377
Chillers designed for minimum evaporator temperature > +35°F (2°C) (New Equipment)	Prohibited as of January 1, 2024: Refrigerants with a GWP of 750 or greater R-448A, R-449A, R-449B, R-452A, R-452C
Chillers designed for minimum evaporator temperature ≤ to +35°F (2°C) and > -10°F (-26°C) (New Equipment)	Prohibited as of January 1, 2024: Refrigerants with a GWP of 1,500 or greater R-452A, R-452C
Chillers designed for minimum evaporator temperature ≤ -10 °F (-26°C) and > -58°F (-50°C) (New Equipment)	Prohibited as of January 1, 2024: Refrigerants with a GWP of 2,200 or greater R-452C
Refrigeration equipment excluding chillers containing more than 50 pounds refrigerant (New Equipment, New Facilities)	Prohibited as of January 1, 2022: Refrigerants with a GWP of 150 or greater R-513A, R-513B, R-449B, R-452A
Refrigeration equipment excluding chillers containing more than 50 pounds refrigerant (New Equipment, **Existing Facilities**)	Prohibited as of January 1, 2022: Refrigerants with a GWP of 2,200 or greater
Refrigeration equipment and chillers used in ice rinks (New Equipment)	Prohibited as of January 1, 2024: Refrigerants with a GWP of 750 or greater R-448A, R-449A, R-449B, R-452A, R-452C

The proposed regulations set specific GWP limits by refrigerant for some equipment types in existing buildings as seen above. For others, the proposed regulations would not prohibit specific refrigerants, but would instead put a cap on the total weighted average GWP for a company's facilities.

5.2 Overview of Energy, Environmental, and Safety Regulations

Refrigeration systems and refrigerants abide by various state and federal regulations. Figure 9 below shows the various policies and regulations impacting specific systems and equipment types in the refrigeration market. Project type is defined as:

1. **New** - New equipment design and installation
2. **Retrofit** - Replacement of the refrigerant used in refrigeration equipment with a different refrigerant, and any related changes to the refrigeration equipment required to maintain its operation and reliability. These include the "major" and "minor" retrofit designations used in this study.
3. **Drop-In** – New refrigerant replacing original refrigerant with no other changes to existing system

The figure presents the regulations by category: Environmental, Energy, and Safety. Regulations applicable to each system and equipment type are indicated with an "x".

Figure 9. Summary of Regulations

			Environmental		Energy			Safety	
			*CARB - Title 17 State Regulation	Title 40 (2020) Federal Regulation	Title 24 (2019) State Regulation	Title 20 (2019) State Regulation	Title 10 (2020) Federal Regulation	OSHA - Title 29 Federal Regulation	International Fire Code
Commercial Refrigeration - Supermarket, Retail Food	Stand-Alone Equipment**	New	x	x	x	x	x	x	x
		Retrofit	x	x	x	x	x	x	x
		Drop-In (Refrigerant)	x	x				x	x
	Air Cooled and Remote Condensing Unit	New	x	x	x	x	x	x	x
		Retrofit	x	x	x	x	x	x	x
		Drop-In (Refrigerant)	x	x				x	x
	Multi-rack System	New	x	x				x	x
		Retrofit	x	x				x	x
		Drop-In (Refrigerant)	x	x				x	x
Cold Storage Warehouse	Remote Condensers and Evaporators	New	x	x	x	x	x		x
		Retrofit	x	x	x	x	x		x
		Drop-In (Refrigerant)	x	x					x
	Packaged Systems	New	x	x	x	x	x		x
		Retrofit	x	x	x	x	x		x
		Drop-In (Refrigerant)	x	x					x
Industrial Refrigeration - Food Processing, Chemical, Pharmaceutical, Plastic Manufacturing, Construction, Ice Rink	Process Chillers	New	x	x				x	x
		Retrofit	x	x				x	x
		Drop-In (Refrigerant)	x	x				x	x
	Remote Condensers and Evaporators	New	x	x	x	x	x		x
		Retrofit	x	x	x	x	x		x
		Drop-In (Refrigerant)	x	x					x
	Compressor Packages	New	x	x					x
		Retrofit	x	x					x
		Drop-In (Refrigerant)	x	x					x
	Packaged Systems	New	x	x	x	x	x		x
		Retrofit	x	x	x	x	x		x
		Drop-In (Refrigerant)	x	x					x

*Triggered if system contains more than 50 pounds of refrigerant in new facilities. Based on Title 17, Division 3, §95373, New Facilities means (1) New Construction, (2) An existing facility not previously used for cold storage, or refrigeration used in retail food, commercial, industrial refrigeration, or (3) with a replacement of 75 percent or more of evaporators (by number) and, 100 percent of compressor racks, and 100 percent of condensers.

**Stand-Alone equipment includes walk-in coolers and walk-in freezers.
Title 17: California Code of Regulations Public Health, Division 3, Air Resources
Title 40: Federal Code or Regulations Protection of the Environment, Chapter I (Environmental Protection Agency)
Title 24: California Building Energy Efficiency Standards
Title 20: California Appliance Efficiency Regulations
Title 10: Federal Code of Regulations, Chapter II (Department of Energy)
Title 29: Federal Code of Regulations, Part 1910 (Occupational Safety and Health Standards)
International Fire Code, Section 605 (Mechanical Refrigeration)

5.3 Proposed CPUC Cost Effectiveness Ruling and Impact on Future Incentive Opportunities

Currently, the IOUs can only claim credit for energy and demand savings, not GHG reductions. The IOUs currently must report GHG savings, and they can claim savings in 2024 when they transition to the Total System Benefit (TSB), described below.

The CPUC PD issued on April 16,2021 for Rulemaking 13-11-005 lays out a timeline for the utilization of the TSB, which is meant to replace the current portfolio energy/demand reduction goals. When fully transitioned by 2024, the TSB will consider all sources of GHG reductions, including those reductions from energy efficiency, the reductions by transitioning to low-GWP refrigerants and those due to reducing methane leakage due to lower natural gas consumption and building decarbonization. This metric will be used for ongoing program forecasting and goal determination, although energy efficiency savings will still be tracked and reported upon. The TSB metric will completely change the cost effectiveness result for measures that primarily reduce GHG emissions, but potentially save little or no energy. The change will allow the program administrators (PAs) to incentivize refrigerant retrofit and replacement measures and capture the GHG reduction benefits. (A reduction in refrigerant GWP will reduce GHG emissions, since lower GWP refrigerants have a lower GHG impact. See Section 4.1 for an explanation of GWP.) To support this change, the 2021 Avoided Cost Calculator (ACC) was updated to incorporate a separate calculator exclusively for refrigerants. The PD requires that the PAs use this new calculator for forecasts and filings and to update workpapers for the 2022 program year.

The 2021 ACC update now accommodates three different use cases:

1. **Change in electricity use:** traditional savings from energy efficiency and demand response, which now also includes a methane leak reduction factor
2. **Change in gas usage:** traditional savings from energy efficiency, which now also includes two methane leak reduction factors
3. **Change in refrigerant usage or type:** new usage case that accounts for the reduction in GHGs due to changing refrigerant and/or the amount of refrigerant used.

The third use case, which is relevant to this study, examines the case of any energy efficiency retrofit project that either changes the refrigerant type or refrigerant charge for several common refrigeration equipment types and applications. To support this new case, the overall approach now has a separate refrigeration ACC that uses system level information to quantify the avoidable costs attributed to refrigerant system changes. The avoided costs are driven by multiple factors, including the lifecycle leakage and impacts due to the refrigerant GWP for a given piece of equipment. The refrigerant part of the ACC has one table for the GWP and life of common refrigerants and is another for heating, ventilation, air conditioning, and refrigeration (HVACR) equipment. The HVACR table includes equipment lifetime, refrigerant charge, and leakage data during its life, due to topping off (adding refrigerant during its life), and at the end of life based upon equipment specific recovery practices. The approach calculates the total lifecycle refrigerant leakage based upon the equipment type and equipment refrigerant charge to determine annual leakage as well as the estimated end of life refrigerant recovery. The refrigerant leakage, along with the refrigerant GWP is used to monetize the value of the GHG impacts on an annual basis for the life of the equipment. The result is a net present value (NPV) of avoided costs for a given application. To determine the net avoided cost reduction from a refrigerant retrofit, the ACC is run both with the existing and new system and the difference is the avoided cost NPV of the refrigerant retrofit.

For measures that not only increase efficiency, but reduce refrigerant charge and/or refrigerant GWP, there will be incremental avoided cost value for both activities. TRC briefly reviewed the PD and the ACC and did not see any explicit exclusion for the potential case where the specified retrofit does not provide any GHG reductions from energy efficiency (use cases 1 and 2), but only provides GHG benefits from refrigerant changes (use case 3). The ACC is designed for the three use cases to be mixed as appropriate.

To examine the impact of refrigerant charge on ACC, TRC ran five scenarios for typical system retrofits. TRC used the ARB defaults, SCE territory and a 2022 start year for these parametric comparisons. For each scenario, TRC ran two cases, one for the "existing" system and one for the "new" system. For each scenario (Column 1) and system, TRC defined the system configuration type (Column 2), existing and new refrigerant (Column 3, 4) from the ACC provided choices, and the resulting reduction in GWP (Column 5). The results for the existing NPV for the existing system are shown in the "NPV Avoided Cost for Removal of Existing Refrigerant" Column 6, and the result for the new system NPV for the new system are shown in the "NPV Avoided Cost For New Refrigerant" Column 7. The net impact is shown in the "Net NPV Avoided Cost for Refitting from Existing to New Refrigerant" Column 8. Figure 10 below illustrates these scenarios. In general, the scenarios show that large grocery stores have large positive NPV avoided costs, for the current "drop-in" scenario, but going to transcritical or cascade CO_2 system increases the positive impact by 50%. While the cascade system can provide higher efficiency than the transcritical system, it comes at a GHG cost if the refrigerant GWP is greater than 1.0.

Figure 10. ACC Impacts Due to Refrigerant Modifications

Scenario Name	System Configuration Type	Existing Refrigerant	New Refrigerant	GWP Reduction	NPV Avoided Cost for Removal of Existing Refrigerant	NPV Avoided Cost for New Refrigerant	Net NPV Avoided Cost for Retrofitting from Existing to New Refrigerant
Chain Grocery Drop in Refrigerant	Large retail food refrigeration 2,000 lbs. +	R-404A (GWP =3,922)	R-448A (GWP = 1,386)	2,536	$748,465	$264,541	$483,924
Chain Grocery Retrofit CO_2 System	Large retail food refrigeration 2,000 lbs. +	R-404A (GWP = 3,922)	R-744 (CO_2) (GWP = 1)	3,921	$748,465	$191	$748,275
Chain Grocery Retrofit Cascade CO_2 System*	Large retail food refrigeration 2,000 lbs. + to A Medium retail food refrigeration 200-2,000	R-404A (GWP = 3,922)	R-717 (NH_3) (GWP = 0) (Primary) and R-744 (CO_2) (GWP = 1)	3,921	$748,465	$ 0** (Primary) and $ 37 (Secondary)	$748,427

Scenario Name	System Configuration Type	Existing Refrigerant	New Refrigerant	GWP Reduction	NPV Avoided Cost for Removal of Existing Refrigerant	NPV Avoided Cost for New Refrigerant	Net NPV Avoided Cost for Retrofitting from Existing to New Refrigerant
	lbs. (primary) and Medium retail food refrigeration 200-2,000 lbs. (secondary)		(Secondary)				
Small Grocery Drop in Refrigerant	Small retail food refrigeration 50-200 lbs.	R-22 (GWP = 1,810)	R-448A (GWP = 1,386)	424	$9,169	$7,022	$2,148
Small Grocery Retrofit CO_2 System	Small retail food refrigeration 50-200 lbs.	R-22 (GWP = 1,810)	R-744 (CO_2) (GWP = 1)	1,809	$9,169	$5	$9,164
Industrial Process Cooling Major retrofit to Ammonia	Medium industrial process cooling 200-2,000 lbs.	R-22 (GWP = 1,810)	R-717 (NH_3) (GWP = 0)	1,810	$47,779.06	$0**	$47,779.06

* The calculator does not explicitly model the CO_2 cascade system; TRC split the system into two smaller systems for the calculation. Cascade systems consist of two refrigerant stages. The primary stage consists of the high temperature refrigerant and the secondary stage refrigerant is the lower temperature one used for the low and medium temperature cases in grocery stores.

**The calculator does not contain a value for Ammonia. TRC assumed the ACC would be $0, like HFC-161 (which has zero life and GWP = 0)

6 Refrigeration Program Trends

6.1 Historic SCE Refrigeration Participation

This section provides analysis of past usage of refrigeration measure offerings by SCE customers.

SCE offers rebates and incentives to commercial, industrial, and agricultural business customers for purchasing and installing qualifying refrigeration technologies. As described in Section 5.3, SCE has (to-date) only incentivized measures based on energy efficiency, not GHG reductions, per CPUC regulations. Consequently, the database contains energy efficiency measures, such as door auto-closers, doors to refrigerated display cases, and anti-sweat heater (ASH) controls.

SCE provided TRC with their refrigeration incentive program participation database. The data included the claim year, measure code and name, incentive amount, energy savings, and facility NAICS code to indicate the types of businesses that have leveraged these refrigeration incentives.

TRC's analysis identified 22 different measure codes from 2018 through 2020[9]. The most common measures included adding doors to refrigerated display cases, installing cooler ASH controls, and auto-door closers for main and walk-in coolers and freezers. However, the most common measures did not necessarily generate the most energy savings. Measures that provided the most savings included installing ASH controls to cooler and medium temperature display cases, adding doors to open vertical refrigerated display cases, and adding on variable frequency drives to evaporator coil fans and to screw compressors. Figure 11 shows the measures with kW, kWh, or therm savings of 5% or more of the total savings along with their measure codes starting with RF. Most measures provided electricity and demand savings, but not natural gas savings. A TRC team subject matter expert notes that that ASH have become industry standard practice, and could be considered for phasing out of program offerings.

[9] 2021 included only one measure "Vertical Ref Case, Med. Temp w/Night Covers: Open to Closed with LED" at time of analysis.

Figure 11. kW Savings by Measure Type 2018 – 2020 SCE Projects

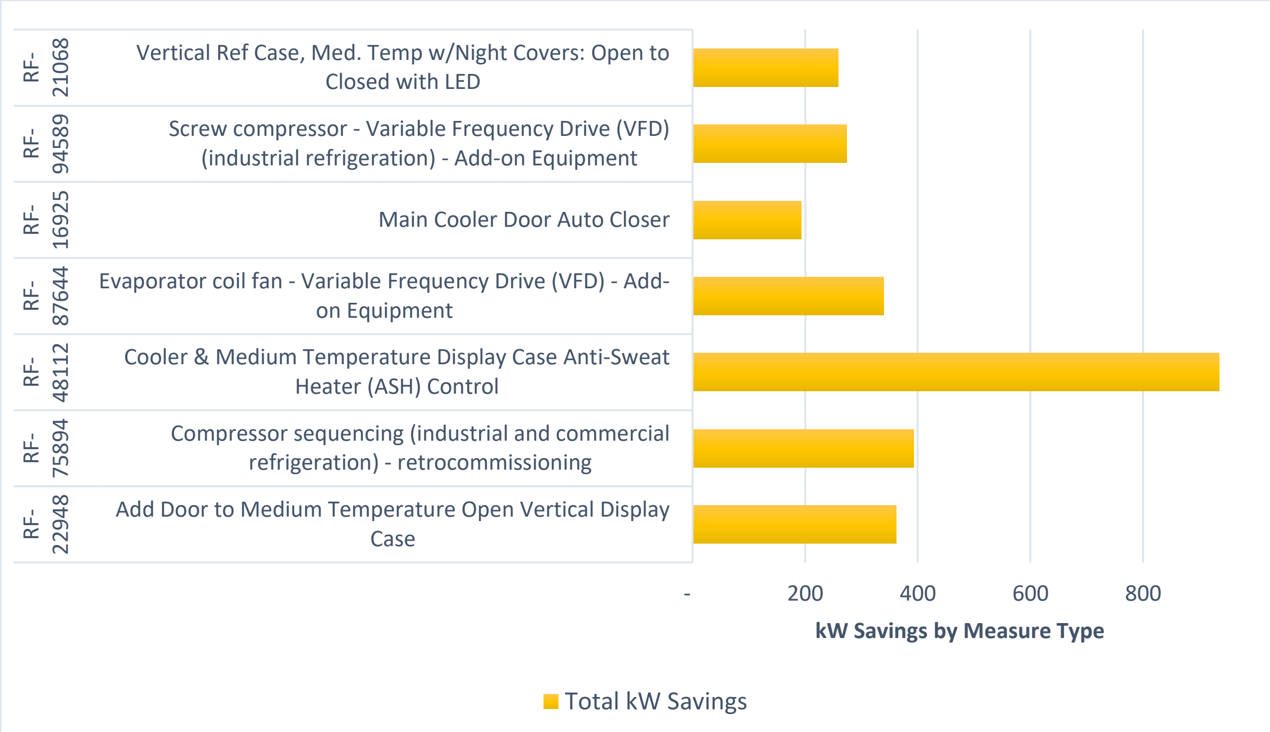


Figure 12. kWh Savings by Measure Type 2018 – 2020 SCE Projects

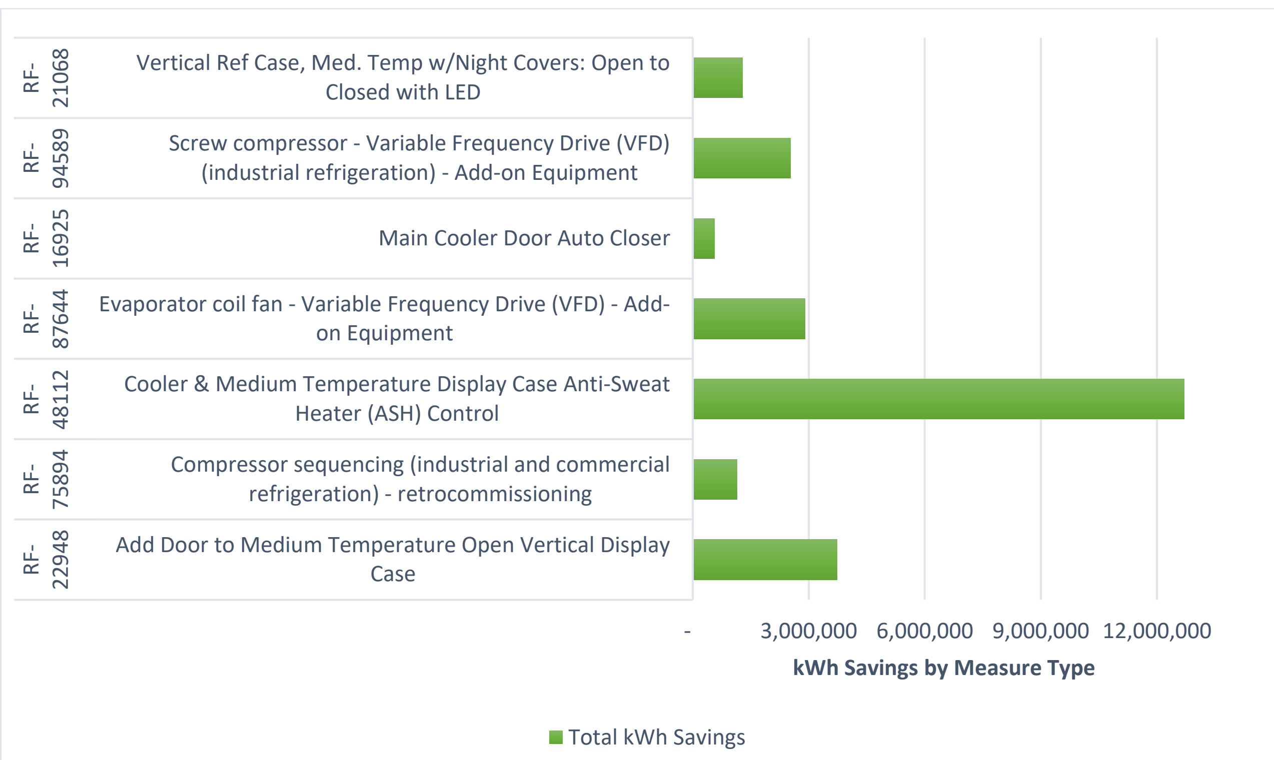
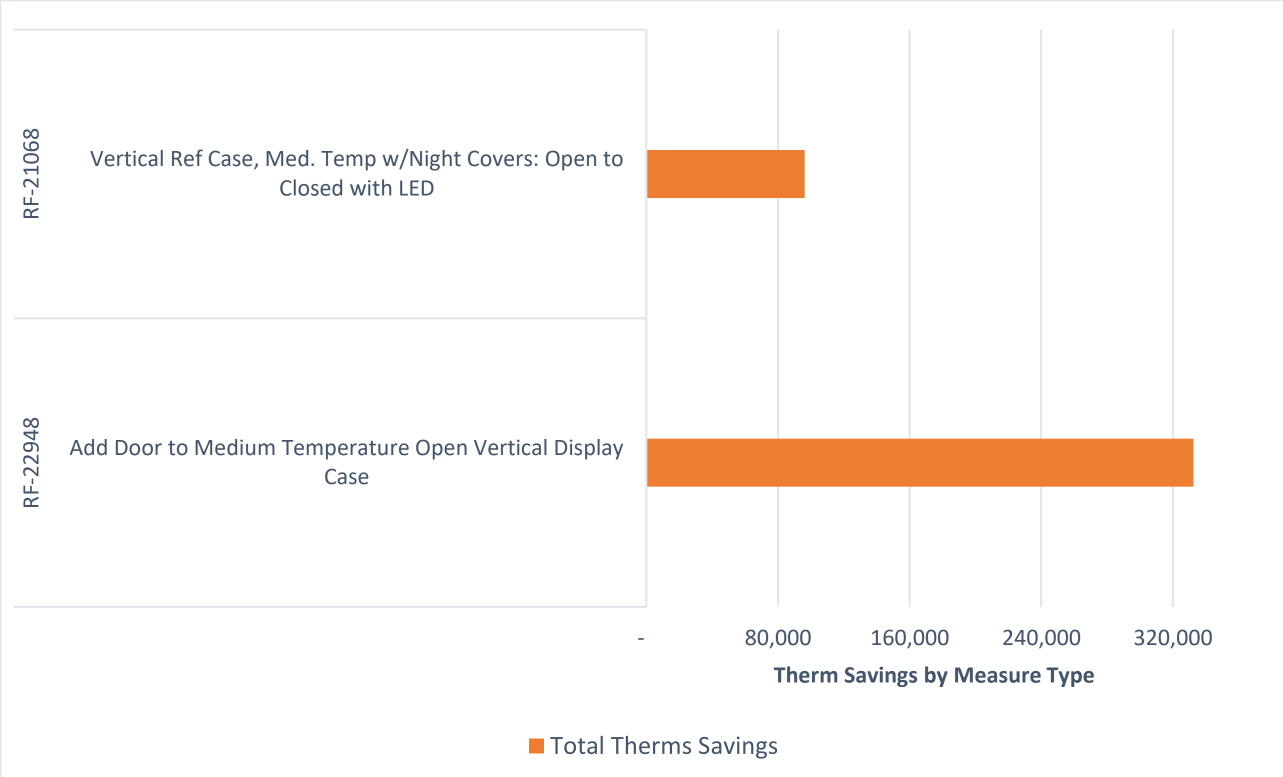


Figure 13. kWh Savings by Measure Type 2018 – 2020 SCE Projects



TRC also analyzed differences in measures by year. Projects in 2018 included three measures that were not found in 2019 projects. These three measures were "Efficient Refrigeration Condensing Unit", "High Efficiency Refrigerated Display Case", and "Process Multiplex Floating Suction Pressure Control". Projects in 2020 included 8 measures not found in previous years, while 18 measures found in 2018 and 2019 were not found in 2020 projects. This may be because of new program offerings and measures phase-outs, changes in customer practices due to Covid-2019, or other reasons.

To determine the types of facilities participating in the SCE incentive offerings, TRC analyzed each unique NAICS code and identified the different industries, sub-industries, and categories. The team identified a total of eleven industries based on the first two digits of the NAICS code (see below).

Figure 14. Industries based on NAICS Code (First 2 Digits)

Industry	NAICS Code (2 Digits)
Retail Trade	44 & 45
Manufacturing	31
Transportation and Warehousing	49
Accommodation and Food Services	72
Wholesale Trade	42
Finance and Insurance	52
Real Estate Rental and Leasing	53

Industry	NAICS Code (2 Digits)
Other Services (except Public Administration)	81
Arts, Entertainment, and Recreation	71
Professional, Scientific, and Technical Services	54
Non-classifiable Establishments	99

The retail trade industry had the highest participation as well as the highest energy savings. Within retail trade, grocery stores were the main energy savers followed by department stores[10]; they accounted for 89.4% and 9.4% of the kWh savings, respectively. Grocery stores were the only category that generated therm savings[11]. Manufacturing also provided a significant amount of energy savings with frozen specialty food, cheese, fluid milk, and ice manufacturing providing the most kWh savings. The accommodation and food services industry had the second highest participation and generated a significant amount of kWh savings, especially in the full and limited service restaurant category. **Error! Reference source not found.** below shows the top five industries with the highest kWh savings.

Figure 15. kWh Savings by Facility Type

In general, the database analysis indicates that **grocery stores and food processors were the major participants in the SCE refrigeration incentive program**. The refrigeration **measures used are primarily add-on features** such as variable frequency drive installations on evaporator fan coils and screw compressors and defrost and subcooling refrigeration controls. SCE staff reported there are currently no offerings for major equipment such as compressors or for complete system retrofits (such as would occur moving from a CFC-based refrigerant to a low GWP refrigerant). This is likely because IOU

[10] Therm savings did not account for interactive effects.

[11] TRC identified department stores as stores that sell clothing, houseware, and other consumer goods.

incentives for GWP-based savings are currently not allowed under CPUC rules, although this will change as the TSB rules take effect in 2024. Also, these add-on features could be used on any type of equipment, regardless of the refrigeration system (high-, moderate-, or low-GWP refrigerant).

6.2 Other (Non-IOU) Programs for Low-GWP Refrigeration

6.2.1 CEC Food Production Investment Program

The Food Production Investment Program (FPIP) was established by the CEC in 2018, and it was funded through the California Climate Investments Program (cap-and-trade). The program received approximately $117 million dollars in funding that was distributed over three separate grant solicitations in 2018, 2019, and 2020.

The purpose of the program was to incentivize food and beverage producers located in California to invest in projects that reduce GHG emissions of their facilities. Allowable projects were determined from a pre-set list of eligible technologies that targeted both direct emissions (natural gas reduction, low-GWP refrigerants) as well as indirect emissions (electricity savings). Key examples of eligible technologies included refrigeration system optimization, compressed air system optimization, boiler economizers, waste heat to power, solar thermal, microgrids, and low-GWP refrigerant conversions.

The main quantitative metric used in scoring the grant applications was dollars of CEC grant funding per metric ton of CO_{2e} reduced annually ($/MTCO$_2$e/yr), allowing the CEC to compare cost effectiveness across all applications regardless of the technology. When quantifying the GHG reduction from eliminating high-GWP refrigerants, a default refrigerant annual leak rate of 12.5% was allowed. Actual leak rates were estimated based on refrigerant purchase data when available.

Grant awards were determined based on a percent of eligible project costs as opposed to estimated project outcome. Eligible cost categories and grant award sizes are summarized in the table below.

Figure 16. FPIP Grant Award Summary

Technology Category	Award Size	% of Eligible Costs Awarded	Eligible Cost Categories
Tier I (commercially available, “drop in” equipment and systems, including low-GWP refrigeration systems)	$100,000 - $6M	65%	Equipment, M&V (by third party only)
Tier II (emerging technologies, including microgrids)	$2M - $8M	85%	Equipment, M&V (by third party only), engineering design

Approximately 10% of the total projects that were awarded funding across the three solicitations (5 of 52) included low-GWP refrigerant conversion scope, totaling approximately 13% of the total award funds ($15M). The program did not discriminate between natural refrigerants and low-GWP HFO refrigerants. However, only projects with natural refrigerants were proposed and awarded (three transcritical CO_2, one low charge ammonia, and one unknown).

6.2.2 SMUD Pilot Natural Refrigerant Incentive Program

In 2017, SMUD launched a pilot incentive program that offered incentives to C&I customers who utilize natural refrigerants (defined as CO_2, ammonia, or hydrocarbons). Eligible projects included both new construction and existing facilities, and it included either total system replacement or retrofitting of existing systems.

The program was designed similar to existing custom retrofit programs and savings by design programs, where energy efficiency incentives were calculated based on a per kWh rate of energy saved as compared to baseline or existing conditions. However, an additional incentive was included that was calculated based on the direct emissions saved from switching to a low-GWP refrigerant. The pilot program incentive rates for both indirect emissions (electricity savings) and direct emissions (low-GWP refrigerants) are summarized in the table below. Bonus incentives were provided for customers located in disadvantaged communities as defined by the top 25% of census tracts according to CalEnviroScreen 3.0 (https://oehha.ca.gov/calenviroscreen/sb535).

Figure 17. SMUD Pilot Natural Refrigerant Incentive Program Rates

	Direct Emissions	Indirect Emissions
Incentive Rate	$25/MTCO$_2$e	$0.15/kWh/yr
Incentive Cap	Minimum of 30% project cost up to $150,000	Minimum of 50% project cost up to $150,000
Combined Incentive Cap	50% project cost up to $250,000	
Bonus Incentive	25% of direct emissions incentive (disadvantaged communities only)	None

Critical in defining the direct emissions reduction and subsequent incentive is the direct emissions baseline. The SMUD pilot program developed the following baseline for new construction and retrofits based on a 2015 study performed by the American Carbon Registry, which utilized data collected by the EPA, as shown in Figure 18. .

Figure 18. Commercial Refrigeration Equipment Baseline

	New Construction	Retrofit/System Replacement
Baseline Refrigerant GWP	2107 (based on R-407A)	Existing refrigerant GWP
Annual Leak Rate	20%	20%
Refrigerant Charge	2.56lbs per 1000 Btu/hr of cooling capacity	Published charge ratings

Figure 19. Standalone Commercial Refrigeration Equipment Baseline*

	New Construction	Retrofit/System Replacement
Baseline Refrigerant GWP	2676 (based on 50% R-404A, 50% R-134a)	Existing refrigerant GWP
Annual Leak Rate	8%	8%
Refrigerant Charge	0.5kg per unit	Published charge ratings

**Stand-alone equipment is defined as a single display case with all refrigeration system components integrated into a single piece of equipment. All other equipment was classified as "Commercial Refrigeration Equipment".*

The equation below shows how the direct emission reduction is calculated. It should be noted that the calculated $MTCO_{2e}$ reduced was a total life cycle value based on the total expected or remaining useful life of the high-GWP system, as opposed to an annual savings rate.

$$Direct\ GHG\ Reduction\ (tCO2e) = Expected\ or\ Remaining\ Life * [(GWP_{Baseline} * Charge_{Baseline} * Leak\ Rate_{Baseline}) - (GWP_{new} * Charge_{New} * Leak\ Rate_{New})]$$

Although the program was offered for industrial customers as well, there was no published industrial system refrigerant baseline provided in the SMUD program marketing materials.

While the pilot program was advertised as an additional incentive to energy efficiency incentives, customers had the option to apply solely for the direct emissions reduction incentive. Thus, even if a low-GWP system was expected to consume more energy than a baseline R-407A system, the low-GWP incentive was still made available without requiring an energy analysis.

6.2.3 EPA GreenChill Program

The GreenChill program was established in 2007 by the U.S. EPA to promote market actors in food retail (i.e., supermarkets, grocery stores, co-ops, wholesale clubs) to reduce their GHG emissions from high-GWP refrigerant leaks and curb ozone depletion as a result of emissions of high ozone depletion potential (ODP) refrigerants (i.e., R22). Unlike other programs described in this report, the GreenChill program does not provide economic incentives for reducing the impact of environmentally harmful refrigerants. Instead, GreenChill functions as a partnership program, providing owners, operators, and manufacturers education materials and guidelines on how to best reduce their system leak rate and transition to lower GWP refrigerant alternatives.

Key elements of the program include the Store Certification Program, which recognizes environmentally friendly stores based on certain refrigeration system criteria, and provides customized refrigerant management data reports, prepared by the EPA, to help food retailers track their performance relative to peers in the industry.

The EPA cites an industry standard leak rate of 25% for commercial refrigeration systems. The figure below summarizes the target leak rate and other system criteria necessary to obtain certification through the Store Certification Program.

Figure 20. Store Certification Program Standards

	Platinum	Gold	Silver
Refrigerant Type	Any refrigerant with zero ODP and approved in SNAP	Any refrigerant with zero ODP and approved in SNAP	Any refrigerant with zero ODP and approved in SNAP
Refrigerant Quantity	0.5lbs per 1,000Btu/hr of total evaporator cooling capacity	1.25lbs per 1,000Btu/hr of total evaporator cooling capacity	1.75lbs per 1,000Btu/hr of total evaporator cooling capacity
Leak Rate	< 5%	< 15%	< 15%

While the requirements for certification were useful in phasing out high ODP substances and reducing leakage, they are not aggressive in terms of requirements for the GWP of the refrigerants, since the only requirement is to meet SNAP requirements.

6.2.4 Key Aspects of Low-GWP Programs

The FPIP and SMUD pilot program have key differences in their approach that should be considered in developing a new low-GWP program for SCE customers. The first key difference is the incentive rate calculations. The FPIP utilized a grant award calculation based on 65% of equipment cost of the project, with a grant award cap of $6M. This percentage and high maximum award cap ensured that a large portion of the capital cost would be offset to provide sufficient economic influence to proceed with the refrigeration system replacement. However, this was balanced with a cost effectiveness assessment utilizing program dollars per $MTCO_2e$ reduced annually to ensure overall GHG reduction targets were still being met through responsible use of grant funds. The SMUD pilot program utilized a more traditional utility incentive structure, calculating the incentive amount based on a prescriptive $/$MTCO_2e$ reduced over the project life cycle for a given system charge. Both approaches scale with system size, as larger systems will have a higher baseline charge and have higher equipment costs. However, the SMUD program did not take into account that the incremental cost associated with selecting a low-GWP refrigeration system for a new construction project is likely to be significantly lower than what is considered for an existing system, which may have resulted in an incentive rate that was too low for existing systems. The SMUD pilot program also had a much lower incentive cap at $250,000, which would limit the ability to properly incentivize conversion for existing systems. Additionally, because the FPIP was focused on existing food production facilities with higher associated incremental costs, the grant award size of 65% likely overestimates what would be required to incentivize a facility to develop low-GWP refrigerant system design plans for a new construction project.

The second key difference is eligible refrigerants. While the FPIP did not disallow projects involving low-GWP HFO refrigerants, the SMUD pilot program specifically allowed only natural refrigerants due to concerns of the toxicity of HFOs in the water supply.

One similarity between the two programs was a de-emphasis on requiring energy savings calculations in favor of prescriptive GHG reduction calculations based on system charge and documented industry average leak rates. The lower leak rate utilized for the FPIP of 12.5% is reasonable given the targeted system types were largely industrial, as compared to the commercial focus of the SMUD program, which had higher leak rate assumptions that are appropriate for commercial refrigeration systems.

The EPA GreenChill program provides recognition and data reports but does not provide incentives. Also, the GreenChill program focuses on phasing out high ODP substances, reducing the amount of refrigerant, and reducing leaks, rather than on encouraging low-GWP refrigerants. This presents an opportunity for a state agency (e.g., CARB) or the IOUs to recognize facilities for best practices in terms of low-GWP refrigerants.

7 System and Market Impacts of Current and Alternative Refrigerants

7.1 Overview of C&I Refrigeration Practices

This section provides an overview of historical C&I refrigeration practices and current trends.

Ammonia has been standard practice in large industrial applications. Ammonia is highly toxic so has additional permitting requirements, and it might not be permitted near residential areas depending on the local building and fire authorities. Smaller industrial facilities have often used packaged systems, including high-GDP CFC or HCFC systems.

Indirect refrigeration systems may be employed to reduce charge and keep the primary refrigerant charge out of occupied spaces. This provides a means to use refrigerants for which regulations limit use in commercial occupancies, such as ammonia, hydrocarbons and, currently, A2L blends. The primary refrigeration system cools and circulates a secondary heat exchange fluid to the refrigeration loads. This allows for primary refrigerant charge to be restricted to the roof or enclosed in a compressor room. Secondary fluids include glycol, phase change CO_2, chilled water, and brines. Indirect systems incur a thermodynamic penalty due to the use of a heat exchanger and the need for a pump to circulate the secondary fluid, although CO_2 indirect systems can approach efficiency of direct systems due to superior heat exchange and low piping losses.

Historically, many retail facilities (including grocery stores) used R-22, but it has been largely phased out because of its high ODP. Facilities then moved to other high-GWP refrigerants, including CFCs and HCFCs like R-404A, some of which have a higher GWP (but a lower ODP ranking) than R-22.

Interviewees unanimously reported that transitioning an existing facility from a high-GWP refrigerant like a CFC or HCFC to a natural refrigerant such as CO_2, ammonia, or propane, requires an entire system change-out (complete retrofit[12]). In comparison, moving to a moderate-GWP system such as an HFO or HFC/HFO blend can sometimes be accomplished through replacing specific components (e.g., the compressor) but leaving the existing piping and other components intact. Consequently, retrofitting from a high-GWP system to a low-GWP system is more expensive than a *drop-in* replacement of another high-GWP system, and it is typically more expensive than a retrofit to a moderate-GWP refrigerant system.

Manufacturers are developing new products, including synthetic blends, with lower GWP. However, it is challenging to develop the *magic bullet*, since many have flammability concerns or other issues.

The remainder of this section provides more details on the information above, including:

- Refrigeration systems in existing systems,
- Retrofitted refrigeration systems installed – both recent and planned,
- Refrigeration systems for new facilities,
- Cost implications of different refrigeration systems,

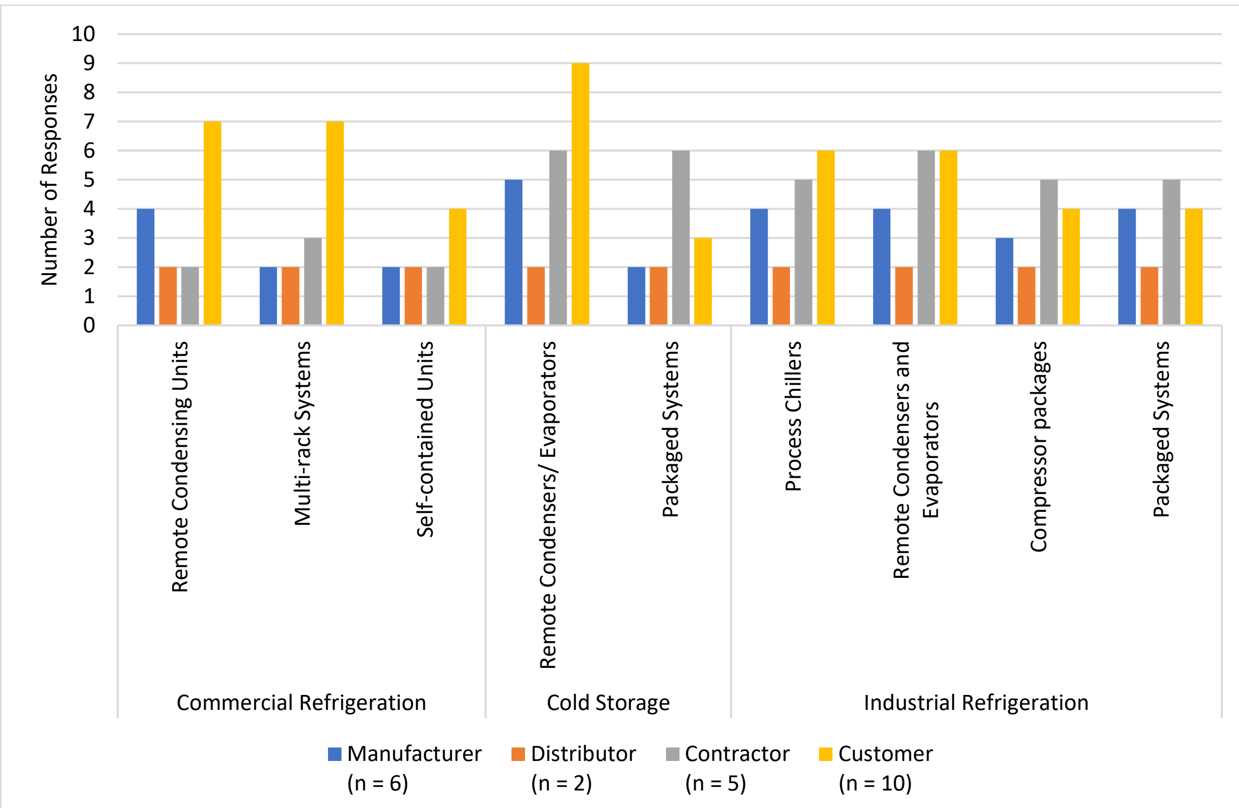
[12] Note that this report uses the term "retrofit" to refer to both a true retrofit (i.e., replacement of only certain components of a system), and the complete replacement of an existing system to a new system, such as to a new CO2 system.

- Energy impacts of low-GWP systems, and
- Market impacts of low-GWP systems

7.2 Existing Systems and Recent Retrofits

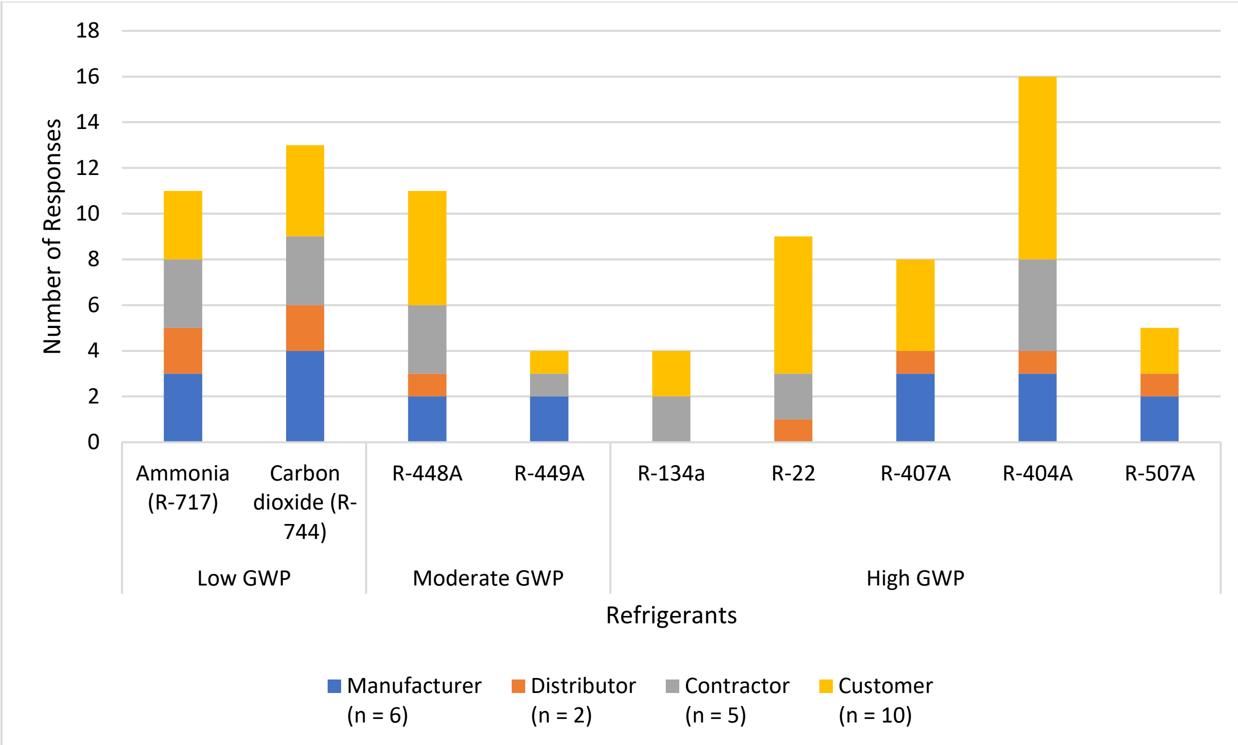
TRC asked all interviewees about the equipment they manufacture, sell, install, own, and operate. Figure 21 summarizes the results, grouped by the three main categories of commercial refrigeration (including retail grocery stores), cold storage (i.e., refrigerated warehouses), and industrial (including food processors). Multiple responses were allowed, and most interviewees manufactured, sold, installed, owned, or operated multiple system types, as shown in Figure 21 below.

Figure 21. Distribution of Interviewees' System Types



TRC asked interviewees about the refrigerants they currently use in the equipment they manufacture, sell, install, own, and operate. Figure 22 summarizes responses for existing facilities. Multiple responses were allowed, and many reported they manufactured, sold, installed, or owned a mix of system types across both new and existing facilities.

Figure 22. Refrigerants in Systems Currently Manufactured, Sold, or Installed



Based on the response from all market actors, TRC observed that

- **Industrial: ammonia is the most common application, but some use CO2 or high-GWP (halocarbon) systems**. Many interviewees described ammonia as standard practice for large systems in non-populated areas. CO_2 was also noted a few times for industrial application. One interviewee noted that many small and medium food distributors, institutional, or food plants with various cooler and freezer spaces, can use a few to a few dozen halocarbon (high-GWP) split systems.
- **Cold storage: R-404A is common** in cold storage applications. CO_2 was noted a few times primarily for cold storage and industrial (food processing) applications, including transcritical CO_2 systems. One interviewee noted that some refrigerated warehouse operators prefer halocarbon split systems; as an example, he noted two examples in California with 30 to 60 split systems, each of which contain around 200 lbs. of R-404A.
- **Retail: R-404A and other types of high-GWP refrigerants**, as well as some moderate-GWP refrigerants, are common in retail (including grocery store) applications. **The study team did not identify any low-GWP refrigerants in existing (outside of newly constructed[13]) retail facilities (including grocery stores).**

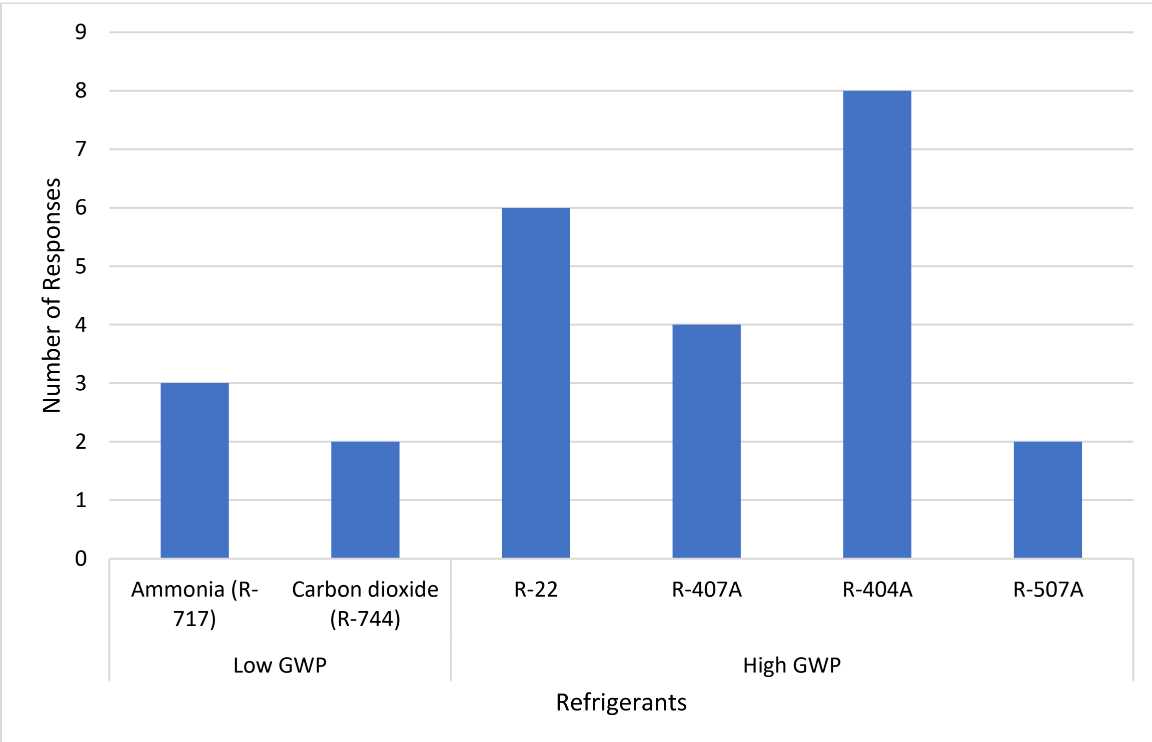
One respondent noted how the age of the facility drives the legacy refrigerants—older facilities will have R-404A and more recent facilities will have R-407A.

Figure 22 includes a combination of refrigerants in available systems (as reported by manufacturers, distributors, and contractors), and installed (as reported by customers). To better understand

[13] As described in section 7.4, many newly constructed facilities use CO_2 or other low-GWP refrigerants.

refrigerants in equipment that are installed, TRC analyzed results as reported by customers only. Figure 23 shows customers' existing equipment that has *not* been recently retrofitted, to illustrate older existing stock, and the types of facilities that customers may consider retrofitting in the near future.

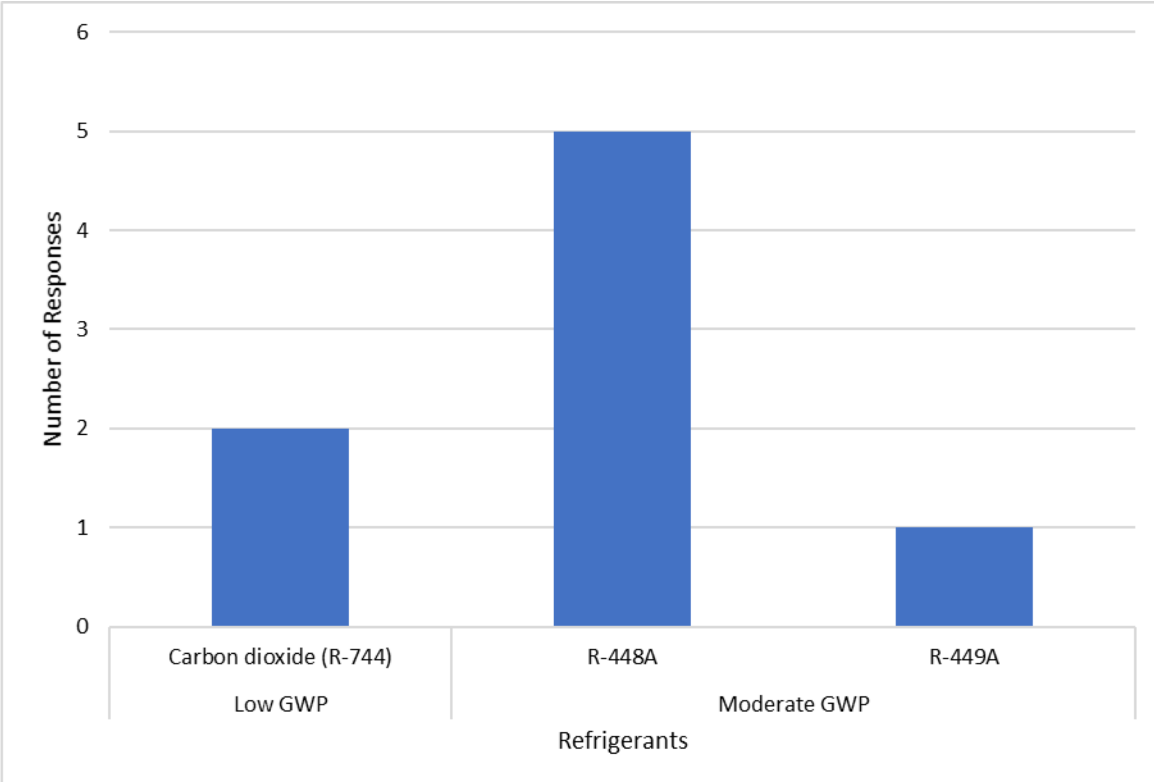
Figure 23: Refrigerants in Equipment as Reported by Customers—Existing Facilities, Not Recently Retrofitted



As seen from the graph above, R-22 and R-404A systems are commonly used in existing facilities. Ammonia is common for industry customers and CO_2 systems were cited for use in existing facilities by one industrial customer and one old storage application. No natural refrigerants were identified for existing retail facilities (including grocery stores), beyond those newly constructed. Some high-GWP refrigerants that are cited by customers include R-134a, R-441A, R-442A, R-408A.

Figure 24 shows refrigerants in customers' existing equipment that has been recently retrofitted (past five years) to illustrate retrofit trends. Also based on several interviewees' comments, customers do not plan to retrofit the recently retrofitted facilities again soon, unless regulations require them to do so.

Figure 24. Refrigerants in Equipment as Reported by Customers—Existing Facilities Recently Retrofitted



As can be seen from the graph, R-448A is common for recent retrofits made by customers to replace legacy refrigerants like R-22, R-404A, R-407A. **The two customers that reported using a CO_2 system were both food processors (industrial).** TRC did not identify any retail (including grocery store) retrofit that uses CO_2.

7.3 Planned Retrofits

To investigate the impacts of CARB regulations, TRC asked all interviewees how the refrigerants they currently use will change with new regulations. The impacts varied more by sector than by specific equipment type.

Industrial / Food processing: Interviewees that are mostly in the industrial refrigeration sector did not anticipate changes as most are already using low-GWP refrigerants (ammonia, or CO_2 in a few cases).

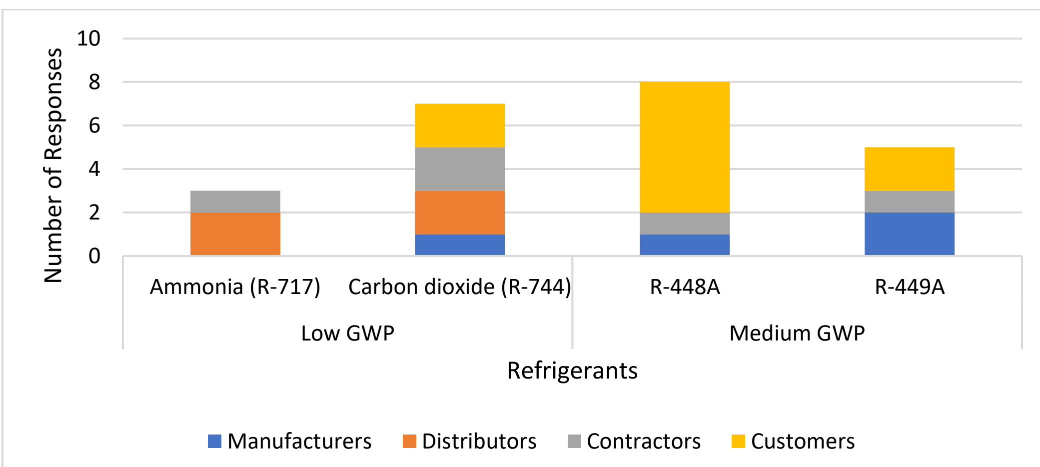
One interview indicated that wineries have switched from R-22 to R-442D, when the conversion was incentivized. Many central chiller packages now use R-438A instead of flooded R-422D systems. The same interviewee even indicated that switching to natural refrigerant from R-22 will require a complete system replacement.

Supermarkets / Retail: Some responses indicated that supermarkets are already switching the standard refrigerants with R-448A for existing systems and the upcoming CARB regulations will accelerate the switch to R-448A and R-449A in the short term. Retrofitting existing systems with R-448A/R-449A will require replacement of expansion valves and elastomers in some cases. Some interviewees indicated that HFC/HFO blends like R-513A can be used as a replacement for R-134a in medium temperature applications. Some customers are choosing a hybrid option by retrofitting part of the systems to natural refrigerants like CO_2 and other part to HFO blends to get the benefits of the low-GWP CO_2 systems without the added financial burden. Some interviewees indicated that hydrocarbons like propane can be used in small self-contained refrigeration systems in limited quantity due to flammability concerns. Some indicated that microdistributed hydrocarbon systems can also be installed, which are more flexible to design; however, they require additional maintenance, are not as energy efficient, and are more expensive. One interviewee for a grocery store chain reported a barrier of microdistributed systems is that a facility's energy management system does not interface with the controls for the microdistributed systems. Another interviewee indicated that Europe has approved R-454A and R-454C for new equipment. These are A2L refrigerants which can be used in California once building codes and regulation are in place. One interviewee mentioned they plan to keep using the high-GWP refrigerants as permitted, while another was unclear of available alternatives.

Cold Storage facilities and refrigerated warehouses will likely change to natural refrigerant systems. Some facilities have already made the change to trans critical CO_2 systems.

In comparison to findings from the heating, ventilation, and air conditioning (HVAC) study[14] the specific refrigerants considered in this study differ, but both the HVAC study and this study identified a trend towards refrigerant blends and natural refrigerants for retrofits in HVAC and refrigeration systems. The most popular refrigerants based on the responses are listed in Figure 25 below. As shown, while most distributors and contractors plan to retrofit systems to low GWP systems (ammonia and CO2), **most commercial refrigeration customers reported they plan to retrofit systems to moderate-GWP systems (R448A and R449A)**.

Figure 25. Refrigerants Planned for Future Retrofits



7.4 New Facilities

Because the CARB regulations require new facilities to use refrigerants < 150 GWP, all new facilities will need to use some type of low-GWP refrigerants. While new facilities were not the focus of the study, a few interviewees described their current or planned refrigeration practices for new facilities.

[14] DNV GL Energy, "HVAC Refrigeration: A Roadmap for Accelerating the Adoption of Low-GWP Refrigerants," May 3, 2021

- **Industrial:** Industrial facilities have been using ammonia refrigeration systems for several years and will likely continue to use ammonia systems for more remote locations. New facilities that are in densely populated areas will shift to using CO_2 systems.
- **Supermarkets:** For new facilities, most interviewees cited that they will shift to CO_2 systems like transcritical systems. One supermarket chain reported they are installing microdistributed systems for new stores with either propane as a refrigerant or other HFO blends.

7.5 System Cost Implications

This section provides system cost implications for different types of refrigeration systems, organized by first cost (installation of a new or retrofitted system), indirect costs (such as training, permitting, and other ancillary costs), and the cost of the refrigerant.

7.5.1 First Costs

To estimate relative system type cost impacts, TRC asked interviewees for the relative cost of each system type. TRC received 22 responses for the question. Based upon some of the responses, TRC observed that there are multiple drivers to the incremental first costs for retrofit systems. These drivers include the sector, new system type, type of new refrigerant and size of the facility being retrofitted. We noted similar trends for operating costs as well, but we got more solid and consistent responses for first costs rather than operational costs. Based upon TRC's review of the responses, most system first cost data were provided for retail/ supermarket systems. A couple of responses were made relative to completing a retrofit with natural refrigerants instead of interim "blend" solutions, which would require future retrofits. While cost impacts were noted as part of the HVAC study, most of the focus of that report was on cost effectiveness.

Industrial: TRC received five responses related to the industrial sector costs. TRC observed mixed, and in some cases conflicting responses, in part due to the likely variation in project types and respondent's involvement in this sector. Respondents generally noted that for industrial retrofits, the systems are usually custom built and lose the cost benefits of standardization.

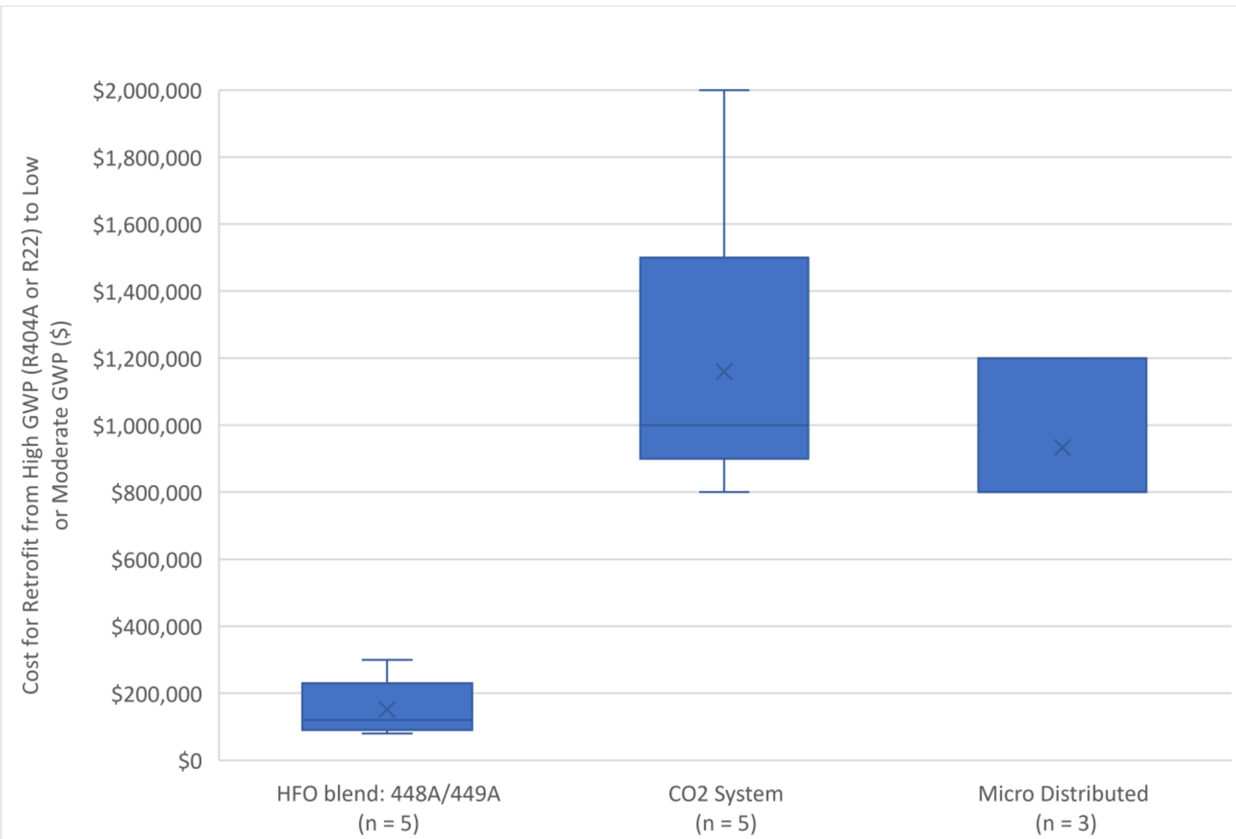
For large system industrial retrofits, one respondent noted there is typically no first cost impact, because most systems use ammonia (R-717) already. As one interviewee noted, "Ammonia is used primarily with large industrial and is typically the standard practice." Another indicated that ammonia is about 12-15% less expensive than CO_2.

Another respondent noted that at larger size ranges, HFCs are costlier than natural refrigerants. One respondent indicated that CO_2 is about 15-20% more expensive than halocarbon systems due to piping and conversely halocarbon systems are about 20% less than CO_2 systems due to standardization.

Two interviewees indicated the value of heat recovery for the right facility types with a CO_2 system, which is a cost benefit that was not quantified.

Grocery / Retail: Figure 26 shows interviewees' responses of cost estimates for a grocery store to retrofit an existing system that uses high-GWP refrigerants (e.g., R-404A or R22) to a moderate or low-GWP refrigerant. The results indicate **there is approximately a 10:1 cost difference between a complete retrofit grocery store CO_2 refrigeration system and a drop-in type of retrofit.** Two respondents replied the same on a percent basis without citing specific dollar values. Based upon TRC's review of interview responses for supermarkets, the average price to do a drop-in style retrofit from R-404A or R-22 to R-448A/R449A was on the order of $80k- $300k/ store. The same data indicated to perform a complete system replacement to CO_2, the cost for the same store was approximately $800k-$2 million/store. One respondent noted that a similar microdistributed system, with many separate units, would vary from $800k-$1.2 million/ store and another indicated $800,000. As indicated in Figure 26 below, the thin lines indicated the outliers the interviewees provided in costs for chain supermarkets, which could be driven by store size and the corresponding amount of refrigeration. The "x" marks the mean values, while the blue band indicates mid two quartiles of the responses. Some, but not all, respondents provided cost estimates for both drop in and complete retrofits. Results for each specific respondent were generally consistent on a relative percentage basis.

Figure 26. Cost Comparison for Grocery Store Retrofit Options Based on Interview Responses



Although not quantified, one of the respondents mentioned that the cost for transcritical systems is less than more complicated CO_2 systems, presumably because the system design is simpler and has fewer components. Two respondents noted that water cooling for smaller CO_2 systems where air cooled options were not available is a challenge, which likely drives some of the initial costs. Multiple interviewees noted that the costs of low-GWP systems like CO_2 and microdistributed systems may decline over time as adoption increases and manufacturers standardize production of components.

Other Commercial Facilities: TRC received less clear input on the other commercial retrofit costs. One respondent noted that much of the cost was going from a commercial to industrial grade system, which is usually longer lived and has costlier components such as thicker pipes and imported valves. Another respondent indicated that many of the components are new and not standardized to the extent that the legacy refrigerant components have been. This interviewee predicts that costs of these components may decline over time as adoption increases and manufacturers standardize production of components.

Cold storage: One respondent reported that low charge packaged Ammonia (R-717) systems used for cold storage may have slightly lower first costs than R-717 central plant systems as the installation is lower and less copper is used. Another cold storage respondent indicated there was a 20% increase for a new system vs a standard one.

New facilities: While not the focus of this study, TRC received several responses apparently relative to completely new construction. As noted above for one response, for large industrial facilities, ammonia is standard practice so there is no incremental cost. For new construction grocery stores, based on responses from four interviewees, the incremental cost to shift to Low-GWP systems (typically some type of CO_2 system) is 0 to 20%. (The four responses were No incremental cost, 5-10%, 10-20%, and 20%).

7.5.2 Indirect Costs

TRC asked interviewees about indirect costs (e.g., additional permitting fees) and operational costs (excluding energy costs, which are noted in Section 7.6.) from retrofits. TRC received 23 responses for this question that focused on operational costs, along with likely cost impacts due to reporting requirements.

Responses for incremental operational costs varied much more than first costs, so TRC could not definitively determine whether low-GWP systems have a higher, lower, or about the same operational cost as high-GWP systems.

Additional indirect or operational costs for high-GWP systems included the following:

- Several respondents reported higher operational costs for the drop-in solutions. Among the factors noted for drop-in issues were increased leaks, existing dirt in the system, dried-out O-Rings, and clogged glide valves, that would not be present in new systems.
- Respondents reported increased reporting requirements for high-GWP systems, including for refrigerant leakage reporting to CARB. Three respondents noted more quantifiable costs due to related sensor requirements.
- One respondent cited ongoing commissioning costs of existing systems as an operating cost factor.

Additional indirect or operational costs for low-GWP systems included the following:

- Several respondents noted new training costs for low-GWP systems—particularly CO_2. This was referenced primarily for the more complex/newer systems. One respondent provided a high-level estimate of 10% for training and additional fees. Another respondent noted that training needs occur at multiple levels, including fabrication, design, construction, and operations.
- Another respondent reported that microdistributed systems would also have higher operating costs as they would have a water-cooled loop and many more units to maintain. Multiple respondents indicated the need for water cooling and the associated environmental regulations were concern related to operational costs. The need to add water cooling systems, including adiabatic cooling required for CO_2 systems, is recognized as a significant cost adder, and it was

cited by two participants as contributing to increased operational costs, and it likely impacts first costs as well.

- Respondents' perception is that current building codes do not allow mildly flammable gases, and that CO_2 is currently unregulated. (TRC notes there are requirements for CO_2 systems in the proposed 2022-Title 24, Part 6 code language changes, with final adoption to be finalized in 2021. Additionally, CO_2 safety requirements are listed in ASHRAE 15, which is referenced by California mechanical code.) However, the responders reported that:
  - Code and equipment standards development work is underway to address usage of Mildly Flammable refrigerants, such as A2L. This was also noted in the HVAC Refrigerants study.
  - CO_2 is being reviewed relative to building code updates. There are costs owing to these future impacts relative to the permitting process that are unknown at this time and were not directly cited.
- While CO_2 systems generally have lower reporting costs[15], ammonia systems have similar or higher regulations due to safety reasons. As summarized by one respondent: "CARB is pushing them towards natural refrigerants, but reporting - OSHA, PSM paperwork - is pushing them away from ammonia – because of more regulations." From one respondent, CO_2 appears to have fewer regulation in place and thus no incremental reporting requirements. Another respondent mentioned that ammonia usually has safety-related reporting requirements, but these vary by code and system size and referenced the RMP. For California, a refrigerant management program (RMP) is required for refrigerants with more than 50 pounds of high-GWP refrigerant (≥ 150 GWP). The RMP consists of multiple efforts including leak detection, leak mitigation, recordkeeping, reporting, and specific service practices. Transitioning from high-GWP to low-GWP refrigerants removes this cost. One respondent noted that smaller business will likely need to subcontract these efforts as they would typically not have in house expertise to do this work.

7.5.3 Refrigerant Costs

TRC asked interviewees two questions about refrigerant costs for both existing high-GWP and for newer refrigerants. TRC received 23 and 22 responses for each respective question. Multiple respondents reported that, while there is a wide variation in refrigerant costs, **the overall impact of new refrigerants is small relative to the overall system cost**. Over 10 respondents noted that natural refrigerants are the lowest cost of ~$1-$2 a pound. One respondent noted that as more GWP regulations come into the market, legacy refrigerant prices are expected to rise. This occurred in Europe and in the U.S. for R-22 (after it was phased out due to its ozone depleting effects). Similarly, newer, low-GWP refrigerant prices are expected to fall. Several other respondents had similar comments relative to refrigerant pricing over time. As discussed in Section 8.1, a few interviewees anticipated a three-fold increase in high-GWP refrigerants cost in the coming years, and they noted this as a driver to low-GWP refrigerants. However, regulations and sustainability were cited much more frequently as drivers to low-GWP refrigeration

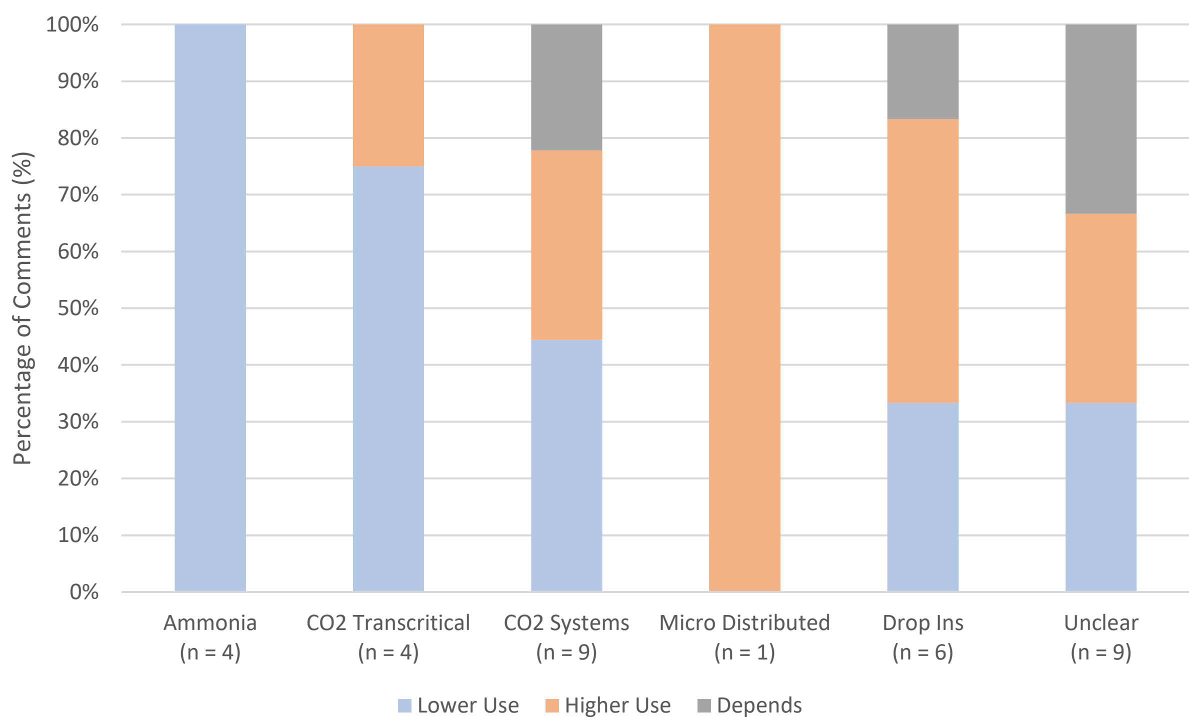
[15] The global warming implications of CO_2 systems leaking is much less than for high-GWP systems, because the GWP of CO_2 is so much lower than for high-GWP refrigerants. Consequently, under the Refrigerant Management Program (RMP), CARB requires facilities with for high-GWP systems to register the system, conduct periodic leak inspections, and provide annually reporting. Low-GWP (<150 GWP) systems including CO_2 are not subject to RMP, so do not have to pay those costs.

systems. This highlights the finding that the cost of refrigerant is low relative to the cost of a system retrofit, so refrigerant cost is typically not the primary driver when deciding what type of system to install.

7.6 Energy Impacts

Respondents provided differing opinion regarding the impacts of retrofits on energy usage as shown in Figure 27. The interviewees provided mixed comments relative to system type and/or refrigerant, including one that indicated it is not just about the refrigerant, but the system design. For the respondents that provided comments, many of them provided multiple comments about different systems and/or refrigerants. Some provided general comments that could not be tied to a specific system and/or refrigerant type, while others tended to blend multiple refrigerant types together ("low-GWP refrigerant"). Transcritical CO_2 systems have clear savings compared to high-GWP systems.

Figure 27. Energy Use Impacts



In general, **retrofits to ammonia systems are generally considered to be the best option in terms of energy efficiency.**

One respondent indicated, "if done right", new systems could save energy, but peak demand generally increases for new systems. For transcritical CO_2 systems, there are a variety of energy efficient design options that will improve system performance relative to traditional HFC systems. These include adiabatic gas coolers, parallel compression, gas ejectors, and utilization of heat reclaim. For ammonia systems, a high degree of energy efficiency can be achieved by following Title 24, Part 6 code requirements. Additional energy savings can be obtained through variable speed control of fans serving process loads (e.g., spiral freezers, blast freezers).

As with any retrofit, energy savings from refrigeration is a function of how well the retrofit was done. This is especially true of the drop in replacements that are currently done in the supermarket segment. One respondent said that R-404A, a candidate for replacement in supermarkets, is not an efficient refrigerant, so any retrofit should have lower consumption. Several respondents noted factors such as refrigerant choice, quality of oil/seals replacement, and cleaning of the existing system, along with controlling/fixing existing leaks, which will have significant impacts both on maintenance and energy consumption. Somewhat related to energy is the unit capacity. Multiple respondents indicated concerns about capacity for these types of retrofits.

For all major retrofits, considerations that include system sizing will impact both meeting the load and energy usage. For more comprehensive retrofits, including many of the CO_2 systems, both the system type and the operational ranges impact the savings. One respondent implied that CO_2 transcritical systems will experience loss of performance when the condensing temperatures are over 87° F. In general, during cooler periods, these systems will experience efficiency gains when the system is operating at a subcritical state. More complex CO_2 systems, including cascaded systems, circumvent this limitation by having two stages, and use a different refrigerant for the higher temperature stage (primary). This ensures that the CO_2 system (secondary) is always subcritical, and thus operates most efficiently.

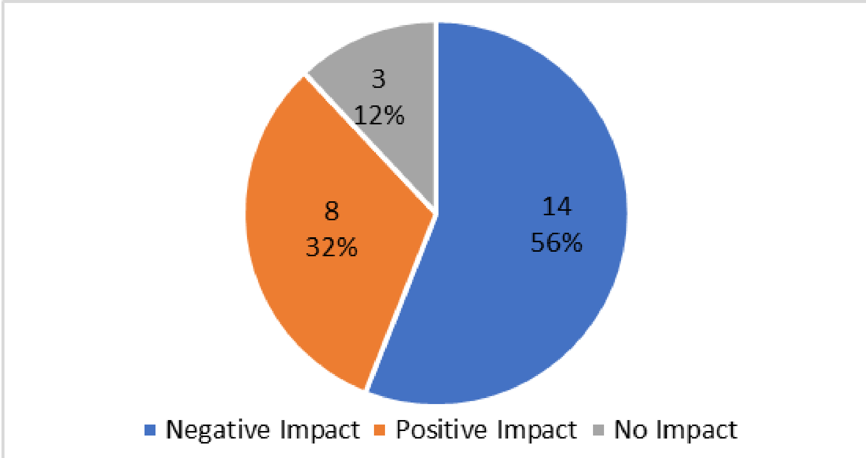
To supplement information from market research and interviews with market actors, TRC collected modeling data from the Title 24, Part 6 Codes and Standards Enhancement (CASE) team in order to compare the performance of a large supermarket building prototype using a typical baseline HFC rack refrigeration system versus a transcritical CO_2 system. Both models assumed the use of adiabatic condensers for heat rejection. The comparison of results showed that the CO_2 system prototype consumed approximately 3-8% more energy on an annual basis compared to a 404A system prototype depending on the climate zone. However, it should be noted that the two prototype models being compared were not originally developed for the purpose of direct comparison. Additionally, there are energy efficiency measures available for transcritical CO_2 systems such as lower minimum saturated condensing temperature setpoint, parallel compression, and gas ejectors that would likely result in a transcritical CO_2 prototype consuming equivalent or less energy than a 404A prototype. Parallel compression alone, which is the use of a dedicated compressor to handle non-productive flash gas at higher suction pressures, can result in an overall COP improvement of 5-10%. Further analysis and study is recommended to best determine CO_2 system performance relative to HFC system performance under a variety of different climate and load conditions.

7.7 Market Impacts

7.7.1 Impacts to Businesses

TRC asked all the interviewees about the impact of CARB regulations on their business. Figure 28 below summarizes results.

Figure 28. Impact on CARB Regulations on Businesses



In general, interviewees reported there will be more impact for commercial refrigeration compared to industrial refrigeration. This is because it is standard practice to use ammonia in industrial refrigerants, so these will not be impacted by the CARB regulations. This section provides detailed responses by type of market actor, from the top of the supply chain down.

Manufacturers: Most (4) refrigerant equipment manufacturers interviewed already have CO_2 and ammonia refrigeration equipment and reported that part of their business will grow. Two manufacturers (for both C&I equipment) indicated that they would shift towards more CO_2 equipment in response to the CARB regulations. One manufacturer did not currently have or plan to introduce any equipment that will meet the new regulations, so they expect "a big hit" on their business.

The one refrigerant manufacturer interviewed reported his company will be able to "get supermarkets below the 1,400 GWP mark in the most economical way possible", by replacing the refrigerants in the existing equipment.

Distributors: One distributor reported there are solutions available for large systems, but not for smaller systems (condensing units) to switch to CO_2.

Contractors: Three contractors are already seeing increased requests for new low-GWP refrigerant systems. They have clients requesting remodeling of high-GWP systems to comply with the new regulations. One contractor reported that projects might slow down if the budgets do not allow for these upgrades. This contractor reported that customers in densely populated areas will likely prefer CO_2 over ammonia systems, and contractors will need training on the new technology. Two contractors said it will be very difficult for their clients to retrofit or replace systems to meet the new regulations and that the variety of system they install will be restricted due to the new regulations. They expect some customers might defer upgrades/retrofits as long as possible and continue using the existing systems.

Customers: Several customers reported the regulations will hurt customers as they will delay projects until there is a more economical solution available. It will also add significant financial burden on customers. The replacements that can be accommodated through more minor retrofits (such as 448A) are expensive and will have higher maintenance cost due to higher leak rates. Most commercial refrigeration customers will choose natural refrigerants like CO_2 for new systems. They will need considerable retrofits to meet 2030 GWP goals. Two customers reported they are trying to stay ahead of the curve and remodeling some facilities to CO_2 systems. However, it will be a slow transition to avoid disruption and downtime.

TRC asked the interviewees if the regulations will have any impacts on the product availability, design of systems and equipment, equipment selection process or approach to refrigerant recharging. Of the 16 interviewees that responded, half reported that the regulations will have an impact and the other half said that there will be no impact. Reasons cited for the regulations impacting the market included the following:

- Three contractors believe that it will impact project timelines because of limited component availability for the next few years. They noted that copper pipes for CO_2 systems may take longer to obtain, and the pandemic is currently impacting raw material availability. Also, more systems will have to be customized, so pre-packaged systems will not work in some cases. It will take time to develop means to manage and monitor charge beyond simple leak detection and develop methods to detect low charge. One contractor said there will be a minimum 10% increase in evaporator and condenser coil costs, due to the use of steel for some natural refrigerant systems.
- One manufacturer did not have any products available or in design to support low-GWP refrigerants but believes the A2L refrigerants (which are not yet allowed by building codes) can be used in their current equipment.
- One distributor says lead times are approximately 60% higher for CO_2 systems vs. standard refrigerant system. This respondent reported that lead times will decline as the CO_2 market picks up.

Reasons cited for the regulations ***not*** impacting the market included the following:

- Most manufacturers interviewed (4) have low-GWP refrigerants products available (CO_2 and ammonia) and do not expect to have any impact on product availability. The lead times may be slightly longer, but they expect to find a way to meet demand. Some contractors do not expect significant impacts because they are already proposing low-GWP solutions.
- One contractor is currently installing equipment that does not meet the upcoming regulations. This contractor reported they might look for new products in the next 1.5-2 years but expect regulations to change in the next 1.5 years. (Based on TRC's review of the regulations, it does not seem likely that the CARB regulations will change.)

Some other market impacts identified by the interviewees are listed below:

- The regulations will hurt smaller facilities most because these facilities will need to move from packaged, high-GWP refrigerant systems to custom, low-GWP systems. Both the move from custom to packaged, and the complete retrofit from high-GWP to the low-GWP, will have cost and market impacts. (In contrast, most large facilities already use custom systems.)
- Manufacturers have limited supply of equipment available, which can increase costs of products.
- Higher GWP refrigerants costs are expected to increase due to regulations.
- There are limited technicians who can work on these new systems, which will increase the cost of doing business. There will be a need for more HVAC technicians with CO_2 systems experience. The North American Sustainable Refrigeration Council (NASRC) is working on adding CO_2.

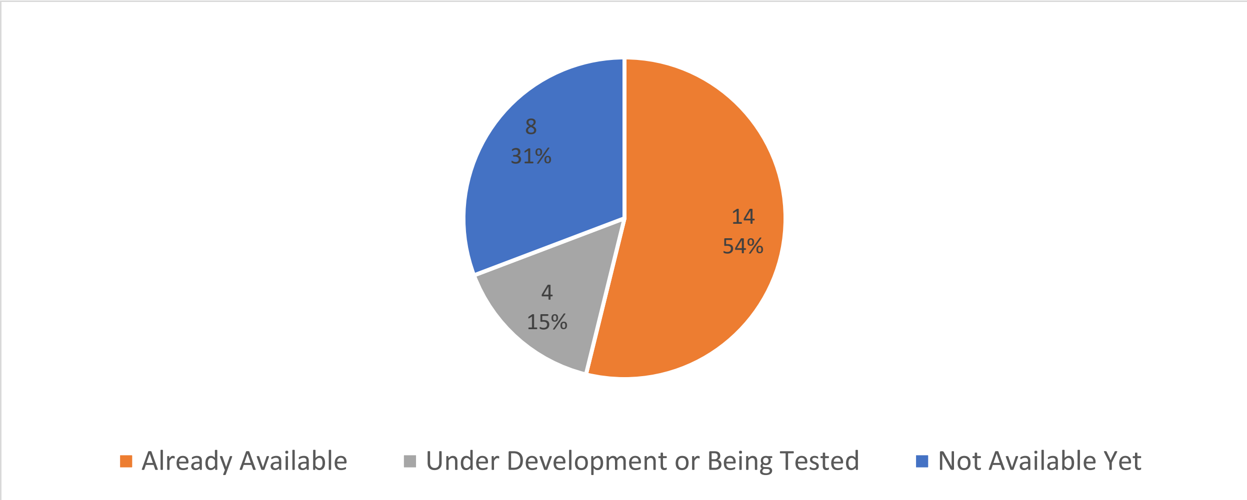
training curriculum in some venues, including community colleges. Manufacturers can provide onsite training to contractors that use their equipment.

- There are HFO blends in development that have lower GWP than freons. But these are untested so raise various questions for new and retrofitted systems.
- There are limited choices available for cold storage owners, so it is more difficult for those to meet the regulations.

7.7.2 Refrigerants under Development

TRC asked the interviewees if the alternative refrigerants they plan to use are currently available. Most interviewees (14) responded yes, eight interviewees said not or that they are waiting on new refrigerants, and four said that they are currently being tested.

Figure 29. Status of Planned Alternative Refrigerants



Some interviewees are considering HFO blends like R-513A with a moderate GWP (in the mid 500's) which can be a replacement for R-134a. However, some say that it does not fit well in all applications and can be used for only medium temperature applications. The refrigerant manufacturers interviewed indicated that one company is developing a micro booster for using products like 513A low and medium temperature to meet CARB guidelines.

There are HFO blends available that are compliant with the 150 GWP limit, but they that are not currently available in the United States because they have an A2L classification and are not allowed for use in facilities due to flammability. For example, a few interviewees reported that manufacturers are testing the following refrigerants, which include low GWP products, but that these are not yet available in the U.S.:

- R-454A
- R-454C
- R-1234yf

There are some options available for chillers such as larger central plant water chillers are using R-1234zd. R-1234zd is currently used in large central plant water chillers.

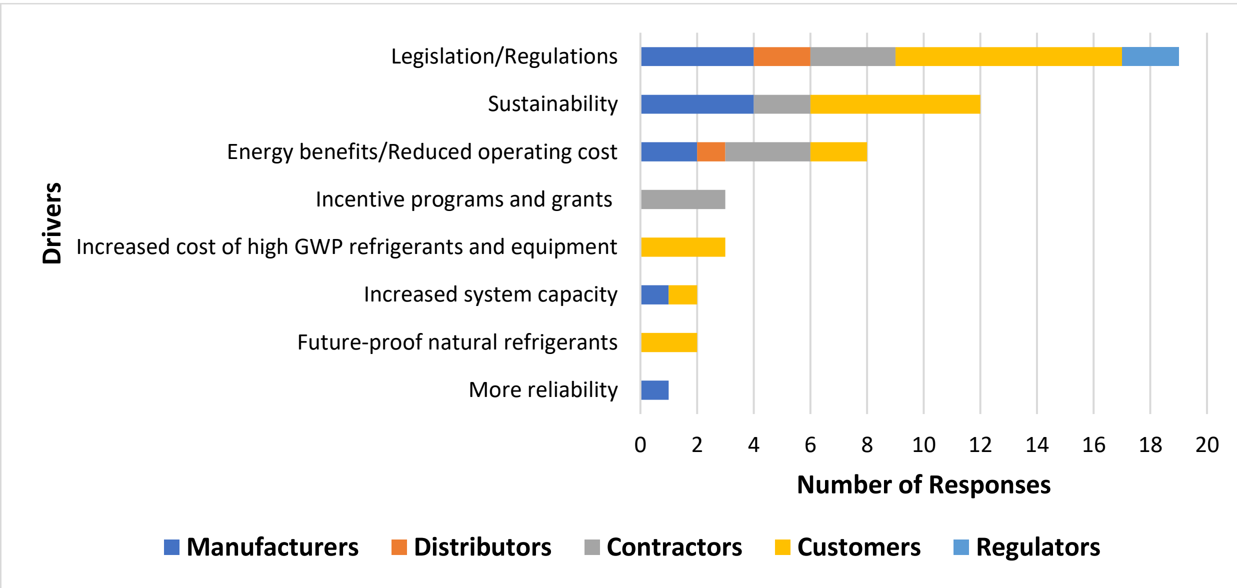
8 Drivers, Barriers, and Opportunities for Low-GWP Systems

This section provides drivers and barriers to low-GWP systems, and interviewees' suggestions for IOU assistance to accelerate adoption of low-GWP systems. TRC also compares results to findings in the HVAC Refrigerant study [16].

8.1 Drivers to Low-GWP Systems

TRC asked all the market actors about the existing drivers that promote low-GWP refrigerant equipment and systems. Responses from the 27 respondents are identified in the chart below (interviewees could identify multiple drivers):

Figure 30. Drivers to Promote Low-GWP Refrigerant Equipment and Systems



As seen from Figure 30, the most commonly cited drivers included the following:

- Legislation and regulations are the biggest driver for the low-GWP refrigerants identified by 19 market actors. Most market actors cited regulations first in their response to this question. (This aligns with the HVAC Refrigerants study, which indicated regulations to be an important driver.)
- The second most common response was sustainability, identified by 12 market actors. Interviewees specifically cited corporate sustainability goals, climate change, people's inclinations towards sustainability, and better public relations for consumer-facing market actors. The sustainability driver was not mentioned in the HVAC study.

Seven interviewees identified energy efficiency and reduced operating costs as another driver for low-GWP refrigerants. As with two interviewees in this study, in the HVAC study, one interviewee indicated the concern for efficiency loss for transcritical CO_2 system in high ambient environments. Some

[16] DNV GL Energy, "HVAC Refrigeration: A Roadmap for Accelerating the Adoption of Low-GWP Refrigerants," May 3, 2021

interviewees noted that CO_2 systems had additional heat recovery capability—40% more than halocarbons or ammonia. The utilization of the recovered heat may depend on the facility type and was noted by four respondents. As indicated by one respondent, "Heat recovery from CO_2 (you don't get it from ammonia) was a huge driver. But grocery stores might not have the same need for waste heat, unless it's needed for space heating. The only need a little sanitation water. Heat recovery is a big thing if you can use it." Less commonly cited drivers included the following:

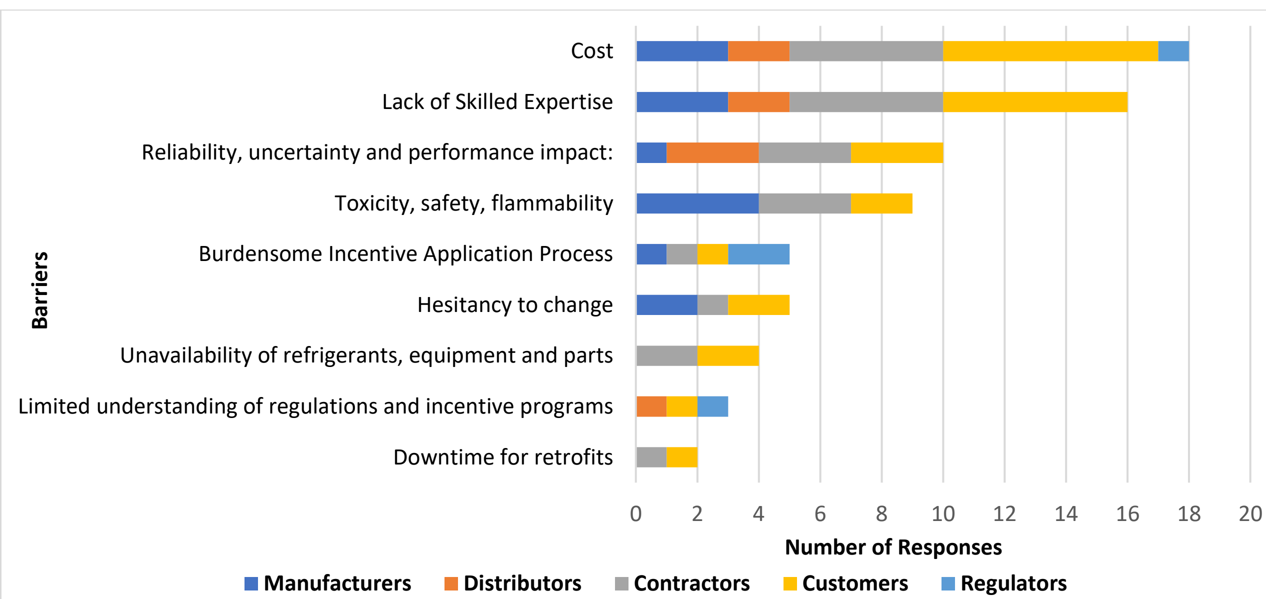
- A few interviewees identified incentives and grants as the drivers for end users to upgrade to low-GWP refrigerants. A few discussed the CEC FPIP, which helped some customers with low-GWP refrigerant equipment installations.
- Another driver is the increase in costs of high-GWP refrigerants and equipment parts. Some interviewees anticipated a three-fold increase in high-GWP refrigerants cost in the coming years.
- Some interviewees identified that CO_2 and ammonia systems have more capacity than standard high-GWP refrigerants. One food processing (industrial) customer reported CO_2 was "future-proof" since it was unlikely to be phased out soon and does not have the same safety concerns as ammonia.
- One responded reported that new low-GWP refrigerants systems can be more reliable with fewer failures.

One of the contractors could not list any drivers and spoke only about barriers.

8.2 Barriers to Low-GWP Systems

TRC asked all interviewees about barriers for low-GWP refrigerant equipment and systems. Responses from the 25 respondents are identified in Figure 31 (interviewees could identify multiple barriers):

Figure 31. Barriers to Low-GWP Refrigerant Equipment and Systems



As seen from Figure 31, cost and lack of skilled expertise were the most common barriers, while some interviewees also cited reliability and toxicity.

First cost is the biggest barrier to low-GWP refrigerant equipment and system retrofits. As reported in Section 7.5, most interviewees estimated an order of magnitude increase in cost for retrofitting a high-GWP grocery store system to a low-GWP system such as CO_2. Other comments included that some interviewees believe contractors are charging more to install low-GWP refrigerants systems because they are not familiar with the new systems. In the HVAC Refrigerants study, the cost to replace larger HVAC equipment relative to refrigerant change-out was also cited as a significant barrier to refrigerant only retrofits. The HVAC Refrigerants study also listed the need for the change to be cost effective.

The second most cited barrier is **lack of skilled local expertise**. As indicated by most interviewees, there are few contractors, technicians, or energy engineers in the industry who can work with natural refrigeration systems. If contractors cannot retrofit or install the systems optimally, there may be a negative impact on the system performance. Service companies will dissuade customers from switching to low-GWP refrigerants if they are not familiar with the new systems. Contractors and vendors will need training to familiarize with the new systems and low-GWP refrigerants on site. However, there are no standardized procedures or best practices available for the new low-GWP systems. While training was mentioned in the HVAC Refrigerants study, it did not appear to be as significant of a barrier as was found in this study.

The third most cited barrier is **reliability, uncertainty, or the performance impact** of low-GWP refrigerant systems. Some interviewees suggested that there might be a negative impact on the equipment energy use with low-GWP refrigerants. Some interviewees indicated that the synthetic blends are not tested by manufactures and ready for use. Toxicity, flammability, and safety is another barrier, although the severity of this barrier depends on the type of low-GWP refrigerant. Ammonia is highly regulated and has safety concerns for use in populated regions. As a result, it cannot be used in the interiors of supermarkets. CO_2 operates at a higher pressure than high-GWP refrigerants (which is why an entire system must be replaced moving from high-GWP to CO_2). Hydrocarbons (A3) and other low-GWP synthetic blends (A2L) are flammable and there are existing building codes that restrict the use of these refrigerants. One of the interviewees note that "CO_2, ammonia and propane are safe for the environment but not safe for occupants working in the facility." In the HVAC Refrigerants study, similar concerns were raised for flammability and the impacts that future building codes will have on allowing more flexibility in the use of mildly flammable refrigerants. The HVAC Refrigerants study discussed similar market barriers relative to lower GWP refrigerants having higher toxicity and flammability. Some of these concerns are mitigated somewhat for industrial and to a lesser extent for commercial refrigeration applications because the refrigerant can be located remotely from areas of concern.

Less frequently cited barriers to low-GWP systems include the following:

- Five interviewees reported that the **IOU incentive application process is burdensome,** which acts as a barrier to current efficiency incentives and would act as a barrier to an incentive program for low-GWP retrofits. They reported that the current incentive application is fatiguing and complicated for the customers. The custom incentive applications require energy modeling, and not many engineering firms are skilled with refrigerant modelling. Also, the incentive amount is minimal compared to the project costs. As one customer noted, "The juice isn't worth the squeeze" in terms of incentive provided compared to their time spent. One interviewee indicated that, outside of the food processing industry, there are limited incentive funding options available. Utilities only incentivize the energy efficiency aspect of the project and not reduction in GHG emissions. Some interviewees reported hesitancy to moving to low-GWP systems because regulations keep changing. Customers are looking for something that will last long term and want to avoid risks with the new systems. Some interviewees identified unavailability of refrigerants, equipment, and parts as a barrier. One customer reported that the market is waiting for drop-in retrofits, which can be a more economical solution, and they have stopped CO_2 conversions. Only a few customers cited limited understanding of the regulations. Those that did reported there is confusion with end users on the regulations, and that company leadership may not be fully aware of the business impact of these regulations. Two interviewees identified the downtime needed for retrofits as a barrier.

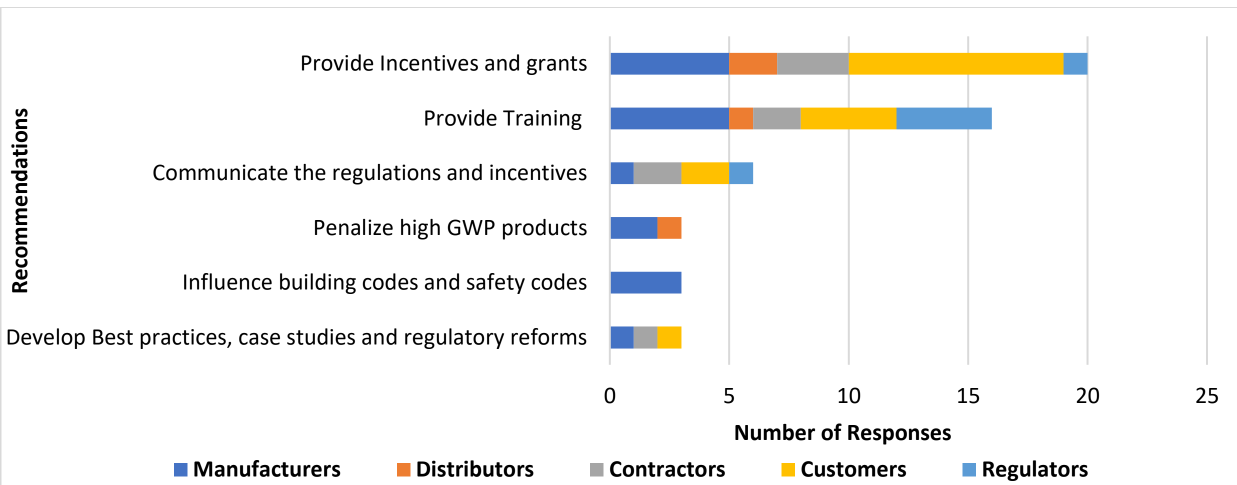
- One reported the need for separate control systems for microdistributed systems as they cannot be integrated with existing energy management systems.

These high-level findings align with the findings of the Klemick (2017) "Potential Barriers to Improving Energy Efficiency in Commercial Buildings: The Case of Supermarket Refrigeration"[17] study, which found that cost, reliability, uncertainty, and lack of information on the new technologies were the most commonly cited barriers to low-GWP systems.

8.3 Market Actor's Suggestions for IOU Assistance

TRC asked all interviewees for their suggestions on what utilities such as SCE, or state agencies, could do to promote the drivers and overcome the barriers. The main recommendations from the 28 respondents are identified in the chart below:

Figure 32. Interviewees' Recommendations for IOU Assistance



The most popular recommendation was to make incentives and grants available to customers. Comments included:

- Customers will benefit from more financial backing until the volume drives the project costs down. In addition to incentives for energy efficiency, utilities should consider providing incentives for reduction in GHG emission as well. (TRC notes this is a decision of the CPUC, not

[17] Klemick, Heather & Kopits, Elizabeth & Wolverton, Ann (2017). "Potential Barriers to Improving Energy Efficiency in Commercial Buildings: The Case of Supermarket Refrigeration 1," Journal of Benefit-Cost Analysis, Cambridge University Press, vol. 8(1), pages 115-145, April.

the IOUs, and that the total systems benefit procedure will allow GHG emissions to be included in cost effectiveness calculations.)

- Some interviewees suggested the incentive application process to be made less burdensome and more consistent and streamlined. Customers get hung up in the review process early on and many get fatigued with the program and decide to move on without the program.
- One customer indicated that the utilities should support more incentives for manufacturers to design smaller packaged CO_2 or ammonia systems, so more products will be available to customer. The customer suggested that to promote use of low-GWP refrigerants systems, 10%-30% of the project cost should be covered by incentives or grants.

The next most popular response was to provide training to manufacturers, contractors, operators, or customers. Comments included:

- Some interviewees recommended that the IOUs provide training on return on investment and highlighting pros and cons of each low-GWP refrigerant to help the market decide the best refrigerant for specific applications. Most recommended this be aimed at contractors, operators, and customers on options for new equipment, as well as on incentives and grant opportunities, to help customers make the switch.
- Two market actors: one manufacturer who did not have any low-GWP products planned and a contractor (who reported the manufacturer his company works with does not have any low-GWP products) requested training to manufacturers on CARB regulations and upcoming regulations.
- One interviewee recommended the IOUs hold local conferences with organizations and industry leaders. In a separate communication, SCE staff reported they developed and hosted (with NASRC) one such conference in 2019.

Less frequently cited recommendations included the following:

- Utilities should communicate the current regulations and incentive opportunities to manufacturers, distributors, contractors, and customers. Utilities can start penalizing high-GWP refrigerants (this interviewee did not describe how), to dissuade customers from continuing to use high-GWP refrigerant equipment. They can start tracking and reporting requirement for high-GWP refrigerants (like R-22). Several interviewees reported there are no building codes available for the use of CO_2 or A2L refrigerants. However, TRC notes there are requirements for CO_2 systems in the proposed 2022-Title 24, Part 6 code language changes, with final adoption to be finalized in 2021. Additionally, CO_2 safety requirements are listed in ASHRAE 15, which is referenced by California mechanical code. Interviewees reported that utilities can influence these codes to allow the use of these refrigerants in facilities. Ammonia has several regulatory and reporting requirements due to toxicity. Interviewees recommended that utilities can help influence the safety code to allow use of ammonia without the added regulatory burden. Similar regulation change is happening in the industrial section with IIAR for the use of ammonia. Utilities should develop standards for best practices for low-GWP refrigerants through partnerships with industry organizations on the new low-GWP refrigerant technologies.

A few respondents raised concerns relative to end-of-life emissions and refrigerant charge activities. In the HVAC Refrigerants study, one of the key findings was that refrigerant charge practices and incentive programs may lead to increased lifetime GWP releases, because a higher charge and the related charging activities leads to more leaks. The HVAC Refrigerant study included suggestions for providing incentives for proper refrigerant recovery. Their proposed approach would be to incentivize proper reclaiming and disposal of legacy refrigerants so there would be a driver to follow the regulations, which otherwise, may not be carefully enforced. While leaks were discussed by interviewees in this study, the programmatic “refrigerant charge” element was not. This is possibly because the HVAC refrigerant charge programs are common, whereas refrigeration refrigerant charge programs are not. Other recommendations, not listed in the figure included:

- Focus on smaller/medium size customers
- Develop roadmaps for new technologies and how people can use them
- Help customers to design systems with demand flexibility
- Have more facilitators for programs
- Conduct a market survey for what would hit the mark for decision makers
- Reduce sales tax on low-GWP refrigerant equipment
- Attract more technicians in the industry

9 Conclusions and Recommendations

9.1 Conclusions

The C&I Refrigeration industry is rapidly evolving. As with many technologies, standard practice appears to be very different for new facilities vs. retrofits.

For new facilities, the market is primarily installing low-GWP systems—typically CO_2 with some microdistributed for commercial (including grocery stores), and primarily ammonia in industrial with some CO_2 systems.

For existing commercial and cold storage facilities, the market has various options for retrofitting systems. This includes moderate-GWP systems—defined by this study as 733 to 1,429 GWP; and low-GWP systems—defined by this study as <150 GWP. Because the CARB regulations impose a weighted-facility-average GWP for existing facilities, many customers are exploring different options. Most commercial refrigeration customers reported they plan to retrofit systems to moderate-GWP systems (R448A and R449A). In addition, no interviewees reported they have retrofitted a grocery store (or other commercial facility) to a low-GWP system such as CO_2 or microdistributed. A few market actors reported they are “waiting and seeing”, either what synthetic HFO blends (which would require a less extensive retrofit) manufacturers might release, or for codes and standards to allow HFO systems (which have a lower GWP, but flammability concerns) to be allowed for use in U.S. facilities. For industrial facilities, interviewees reported they are either not retrofitting facilities (since they are already ammonia), or they are retrofitting to CO_2 – i.e., replacing with a CO2 system. One cold storage interviewee reported replacing their existing system with a new CO_2 system. While ammonia dominates industrial facilities in non-populated areas, split systems that use high-GWP (halocarbon) refrigerants are common in smaller facilities and those in more populated areas.

Most market actors reported they are moving to moderate- or low-GWP systems because of regulations, although they frequently cited sustainability reasons as well.

Multiple market actors indicated they (or other market actors) had unanswered questions regarding low-GWP systems. For example, many raised questions regarding the energy performance, and operational or maintenance needs of CO_2 or microdistributed systems, or they raised concerns about the lack of qualified technicians to maintain these systems. There was also interest, but flammability concerns and many unknowns (in terms of cost,energy performance, and future building codes), regarding HFO blends (e.g., 454A/454C) that are yet to be released, which have led some to adopt a “wait and see” attitude when developing a plan for meeting the upcoming CARB regulations. .

Figure 33 summarizes the prominent moderate and low-GWP refrigeration systems that the study team heard frequently discussed by interviewees, common applications of those systems, advantages, and disadvantages of such systems, and TRC’s determination (based on results of this study) of whether the IOUs should encourage the use of these refrigerants through incentives, training, or other initiatives.

Figure 33. Overview of Moderate and Low-GWP Refrigeration Systems

Low-GWP System Type	Applications	Advantages	Disadvantages	Energy Considerations (Compared to high-GWP systems)	Should be encouraged by IOUs?
Ammonia- Central Plant	-Industrial	-Low GWP -High efficiency -Well developed market with high amount of construction and service support	-Not practical for locations near residential areas -High environmental/safety compliance burden -Cost. Approximately an order of magnitude higher for change-out	More efficient	Yes, for non-residential areas
Transcritical CO_2 Rack Systems	-Commercial (grocery store) -Occasionally Industrial (food production, cold storage)	-Low GWP - Should comply with any upcoming environmental regulations - Low toxicity -Low reporting effort	- Cost. Approximately an order of magnitude higher than change-out, but less than cascade CO_2 Systems - Complex system design and limited operational knowledge from market actors. - May have lower performance in warmer climates than a cascade CO_2 Systems	Higher energy usage when the system in transcritical range, lower usage in subcritical range, releases heat which could be used for processes, heat recovery, or hot water	Yes
CO_2 or Hybrid CO_2 Design (R-744)[18]	- Rare. A few industry and grocery stores	-Low GWP - Should comply with any upcoming environmental regulations - Low toxicity -Low reporting effort	- Cost. Approximately an order of magnitude higher than change-out, but less than cascade CO_2 Systems - Complex system design and limited operational knowledge from market actors.	Typically, lower energy usage, can add heat recovery for process and/or hot water loads	Yes

[18] includes cascaded system, distributed systems, compact chillers, and secondary loop systems

Low-GWP System Type	Applications	Advantages	Disadvantages	Energy Considerations (Compared to high-GWP systems)	Should be encouraged by IOUs?
			- May have lower performance in warmer climates than a cascade CO_2 Systems		
Microdistributed (self-contained) propane (R-290) systems	- Rare but used in some grocery stores. Has potential for other small commercial or industrial facilities	-Low GWP and uses less refrigerant - Should comply with any upcoming environmental regulations - Low toxicity - Could allow for less downtime for retrofit if replaced incrementally, but GWP losses not fully alleviated until legacy system de-commissioned.	- Cost. Approximately an order of magnitude higher than change-out - Controls and leak detection system more distributed and may not integrate well with legacy control systems. - Added heat load on store HVAC system if air cooled, resulting in potential higher energy consumption -Added system complexity and cost if water cooled (extra fluid cooler, leak potential) -Flammability concerns -Even less market knowledge than CO_2 systems -Noise -Reliability	Unknown by the few interviewees that discussed this system, although one noted less efficient	Yes
Low-GWP HFO Systems (new or retrofit): R-454C	-Commercial -Industrial	-Low GWP - Should comply with any upcoming GWP regulations for retrofits	-Flammable, high reporting requirements -Lack of building codes and standards to allow for widespread use -Not commercially available	Unknown	No, due to restricted availability and flammability concerns

Low-GWP System Type	Applications	Advantages	Disadvantages	Energy Considerations (Compared to high-GWP systems)	Should be encouraged by IOUs?
		-Low(er) cost. Similar pressures to existing HFC systems, leading to potential costs of conversion being similar to R-448A retrofits.			
Moderate-GWP: R-513A	Commercial refrigeration (but not freezers)	- Should comply with any upcoming GWP regulations for retrofits -Low(er) cost. Similar pressures to existing HFC systems, leading to potential costs of conversion being similar to R-448A retrofits	-Environmental concerns over toxicity in water supply	Unknown	No, due to restricted availability and unresolved environmental concerns
Moderate-GWP: R-448A (new or retrofit Rack Systems)	-Commercial -Industrial	- Lower cost. Estimated to be approximately 10% the cost of an entire system replacement. - Low toxicity	- Complies with current regulations but federal or future state regulations could reduce allowable GWP so they no longer comply -Higher ongoing operational costs due to legacy components -Ongoing reporting requirements	Depends on how well retrofit was done	No, because of GWP

As shown, this study identified more than one low-GWP system for each application (commercial, cold storage, and industrial). This is beneficial since it provides the market with multiple options to best meet the needs of each facility.

The next section summarizes barriers identified to low-GWP systems and potential IOU program offerings to address those.

9.2 Recommendations for IOU Future Program Offerings

TRC developed recommendations to address specific barriers that we identified during interviews with market actors and market research. Particularly for the GHG incentives and non-resource offerings, SCE should discuss their planned initiatives with CARB, to ensure these support CARB goals but do not duplicate their initiatives. These recommendations are organized into three main categories:

1. **Energy Savings Incentives:** which the IOUs could start implementing in the near future (Figure 34),
2. **GHG Incentives:** which the IOUs could start implementing once the total systems benefit (which accounts for GHG reductions) takes effect in 2024 (Figure 35.)
3. **Non-Resource Offerings**: which the IOUs could start implementing in the near future, but for which they cannot claim savings (Figure 36.). Similar to the energy savings incentives, the non-resource offerings should be implemented in the near future. Besides providing much-needed support to the current market to transition to low-GWP refrigerants, the non-resource offerings will also provide a ready pipeline of projects when the GHG-based incentives are available.

Figure 34. Energy Savings Incentive Recommendations

	Energy Savings Incentives		
	Barrier	**Recommendation**	**Rationale**
1	High incremental cost/inability to incentivize direct GHG emissions reductions until 2024	Develop higher energy efficiency incentive rates for low-GWP refrigeration system energy savings retrofit projects[19], for accelerated replacement measure for equipment not requiring retirement during the current RUL. Also provide more comprehensive offerings (e.g., include advanced commissioning and performance monitoring)	♦ Higher incentive rates will be needed to support the high incremental cost of accelerated replacement until GHG can be incentivized directly ♦ Eligible systems may include CO_2/ammonia cascade systems, transcritical CO_2 systems, low charge ammonia systems (packaged and secondary glycol/chilled water systems) ♦ Comprehensive offerings will "sweeten the deal' for low-GWP systems, and new systems require more commissioning and performance monitoring to realize the potential energy savings
2	Customers that recently retrofitted to moderate-GWP	Eliminate energy efficiency incentives for high-GWP (>1,300) refrigeration systems, but	♦ Allows funding to focus on low-GWP programs

[19]While it was beyond the scope of this project to review measure offerings, the TRC team notes that anti-sweat heaters (one of the most commonly used refrigeration measures in the SCE database) have become industry standard practice, and should be considered for phasing out of program offerings.

	systems (e.g., R448) are unlikely to replace them soon	provide efficiency incentives for moderate-GWP systems (at lower levels than for low-GWP). The same efficiency measures for refrigeration that are currently popular (see Section 6.1) would also be applicable to low or moderate-GWP systems.	♦ Does not incentivize investment in non-compliant assets ♦ Allows recently renovated moderate-GWP to participate and reduce their energy consumption

Figure 35. GHG Incentive Recommendations

	GHG Incentives		
	Barrier	**Recommendation**	**Rationale**
1	High incremental cost for accelerated replacement of entire systems	Develop incentives based on $/MTCO$_2$e reduced, focused on accelerated replacement of existing systems, with a target of offsetting 25-40% of incremental project costs. Incentivize systems with GWP below 150.	♦ Accelerated replacement measures incur the highest incremental cost and require higher incentives to influence change ♦ Accelerated replacement measures provide the biggest opportunity for program influence. New construction must already meet GWP ≤ 150 due to regulations, and market actor interviews indicated that low-GWP systems are becoming standard practice for new construction – but not for retrofits. ♦ $/MTCO$_2$e will scale with system size and system cost ♦ $/MTCO$_2$e is relatively easy to calculate utilizing industry standard leak rates or reported refrigerant purchasing data
2	High incremental cost for accelerated replacement of entire systems	Explore program offerings for grocery stores replacing existing high-GWP display cases with self-contained low-GWP cases (microdistributed propane) utilizing a $/TR of capacity replaced metric	♦ Allows for incremental progress instead of large capital investments that not all customers can afford ♦ The IOUs will need to investigate how and when savings should be claimed, since GHG reduction cannot be guaranteed until the entire rack system (which serves multiple display cases) is replaced.
3	Customers report the challenge for participating in custom program offerings is often not worth the incentive	Allow customers to participate in a GHG reduction program without requiring associated energy savings calculations and engage CPUC on appropriate baseline assumptions (the “do nothing” option).	♦ GHG impacts are very easy to calculate with the ACC, but energy modeling is costly for customers ♦ Market actors reported limited availability and knowledge of accurate transcritical CO_2 modeling (which is a primary low-GWP option) ♦ GHG impact of eliminating high-GWP refrigerants is orders of magnitude higher than possible energy differences (i.e., energy increases would not offset direct emission reduction) ♦ Would streamline application process and increase participation and GHG reduction
4	Uncertainty around HFO refrigerants due to flammability issues and environmental issues, inhibiting an	Develop lower incentive rates (based on $/MTCO$_2$e) for HFO refrigerant systems, or incentivize only natural refrigerants in future programs	♦ Water toxicity issues are a serious concern and has caused other utilities (SMUD) to avoid directly incentivizing HFO systems ♦ Provides time for building codes and standards to be updated and additional scientific research to be performed

	entire category of possible low-GWP solutions		before making conclusions on market viability and environmental impact
5	Uncertainty of GHG savings due to improper disposal of refrigerants occurring at end of system life	Make proper refrigerant disposal a requirement for program participation (documentational requirement)	♦ Ensures GHG reductions are maximally realized

Figure 36. Non-Resource Offerings Recommendations

	Non-Resource Offerings		
	Barrier	**Recommendation**	**Rationale**
1	Lack of education and understanding by end users of regulatory impacts and compliance options.	Develop a *Refrigerant Audit* program analogous to energy audits, where SCE or affiliated third parties survey refrigeration systems. Audit reports would offer tailored recommendations on low-GWP options, leak detection systems, and potential GHG incentive amounts as a free service to customers. It would also provide information regarding other available programs such as the CEC FPIP, CARB F-Gas, and EPA GreenChill.	♦ Provides actionable next steps for customers that might not have the engineering competency in-house to develop a solution towards compliance ♦ Educates customers on the GHG options, leading to increased influence ♦ Educates customers on future potential GHG incentive programs once allowed by the CPUC, leading to increased influence and participation
2	Uncertainty of energy performance, particularly for CO_2.	Develop an "early adopter" program for customers that replace existing refrigeration systems with low-GWP systems. This program could provide design assistance, advanced commissioning; and measurement and verification (M&V) services and performance monitoring services. M&V services would include benchmarking low-GWP system performance with other customers. This could be part of GHG reduction programs or *Refrigerant Audit* programs. The magnitude of direct cash incentives may be adjusted to allow program funds to cover cost of service.	♦ Active performance monitoring can provide ongoing corrective actions to maximize system performance and energy efficiency, which may ease initial doubt of increases to customers' energy costs ♦ M&V data taken from early adopters can be used for case studies that increase market confidence and knowledge

	Non-Resource Offerings		
	Barrier	**Recommendation**	**Rationale**
3	Lack of education and training for refrigeration technicians and operators (CO_2).	Become a sponsorship partner for industry organization events that promote technical learning (conferences, dedicated training sessions, etc.)	♦ Promotes knowledge sharing by the most experienced market actors, accelerating overall industry support and low-GWP system adoption
4	Lack of low-GWP solutions for small condensing unit applications (walk-ins, etc.), so incremental costs are particularly high for these system types	Explore Emerging Technologies projects associated with product development and site demonstrations of CO_2 condensing units, or develop upstream program incentives directed at condensing unit manufacturers	♦ Promotes scalable product solutions that reduce the future per unit cost. ♦ Provides low-GWP options for smaller end users that are accustomed to selecting equipment from catalogs as opposed to engineered solutions, resulting in increased compliance. ♦
5	Uncertainty of energy performance, particularly for CO_2.	Invest in the next generation of commercial refrigeration whole building modeling simulation software, either DOE2.2R or Energy Plus, in coordination with the California Technical Forum (CalTF) and CPUC, to include low-GWP systems that could be utilized by SCE staff engineers to develop program, industry trade allies associated with the refrigerant audits, and ultimately customers to use for proper modeling and program participation. Leverage the Emerging Technologies program to provide an updated review on needed Energy Plus functionality and data needs that would be required to model the majority of the low GWP systems and functions that cannot currently be modeled. Update work papers to include commercial and industrial refrigeration GHG impacts.	♦ Empowers end users with resources to accurately predict future energy consumption ♦ Can be utilized for future code improvement efforts and energy efficiency program development ♦ Existing modeling software for refrigeration not compatible with current CEC standard software (DOE2.2R vs. CBECC-Com Nonresidential) ♦ Energy Plus does not include basic functionality for refrigeration modeling (like floating head pressure)
6	Lack of education and understanding by end users of regulatory impacts and compliance options.	Provide a recognition-based program where SCE can provide awards to customers that adopt best practices for reducing their GHG emissions via leak reduction or low-GWP conversion.	♦ Program guidelines and criteria for recognition would help educate customers on what is considered best practice ♦ Enables a mechanism for influencing compliance before direct GHG incentives can be provided 2024 (customers benefit from positive public

	Non-Resource Offerings		
	Barrier	**Recommendation**	**Rationale**
			outreach and recognition as a sustainable business)
7	No supermarket retrofit identified that used a low GWP refrigerant system	Explore Emerging Technologies project that targets a supermarket retrofit, to investigate feasibility of retrofitting to CO_2, micro-distributed propane, or another low GWP system.	♦ While CO2 systems have become the norm for new supermarkets, most market actors reported they are moving to a moderate GWP system (such as R448A) for retrofits. ♦ An Emerging Technologies study could explore if and how a customer could retrofit to CO2 or micro-distributed, with as short a period of non-operation as possible.

9.3 Concluding Statement

As market actors navigate the CARB regulations, many are still undecided on what type of system they will choose, particularly for retrofitting existing facilities. In addition, customers can choose to do nothing (i.e., maintain their existing high-GWP system) for a number of their facilities, because of the facility-weighted average structure of the CARB regulations. This represents an opportunity for the IOUs to educate and incentivize customers to choose low-GWP systems. The IOUs cannot directly incentivize low-GWP systems until the CPUC allows them to claim credit for GHG reductions (to take effect in 2024 under the revised Total System Benefits policy). However, they can encourage such systems by restricting their encourage energy efficiency measures to low-GWP or moderate-GWP systems only, and by providing higher incentives for low-GWP systems than moderate-GWP. In addition, there is considerable opportunity now for educating the market, providing free M&V, and providing other industry support through non-resource programs such as through the refrigerant audit program and early adopter program recommended here. Once the IOUs can claim credit for GHG reductions, they should develop incentive programs and other offerings to encourage the market to make the more costly, but much more environmentally beneficial choice of a low-GWP retrofit.

10 Appendix: Data Sources for Regulations and Refrigerant Characteristics

10.1 Sources for Regulations

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   California Energy Commission
   2019
2. Public Utilities and Energy, Appliance Efficiency Regulations (Title 20)
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4. Clean Air Act Title VI – Stratospheric Ozone Protection
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   Environmental Protection Agency
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6. Overview of SNAP
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7. SNAP Substitutes in Refrigeration and Air Conditioning
   Environmental Protection Agency
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https://www.epa.gov/sites/production/files/2020-10/documents/notice_36_prepublication_version_10-22-20.pdf
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Air Conditioning, Heating, & Refrigeration Institute (AHRI)
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    Karim Amrane, Ph.D. Sr. VP, Regulatory & Research and Francis Dietz VP, Public Affairs
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10.2 Refrigerants Requirements and Characteristics Sources

TRC assembled the refrigerant system requirements and refrigerant characteristics from the following online sources.

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11 Appendix: Prohibited Refrigerants

Figure 37 below provides a detailed list of currently prohibited refrigerants.

Figure 37. Prohibited Refrigerants: Standard Practice and Less Commonly Used

CARB & EPA (SNAP)

Title 17, Division 3, § 95371-95377 List of Prohibited Substances (CARB) & Title 40, § 82 Subpart G, Rules 20 and 21 (US EPA SNAP)

Refrigerant	Supermarket Systems		Remote Condensing Units		*Stand-alone medium temperature units	Stand-alone low temperature units	Stand-alone units	Cold Storage Warehouse		Industrial Process Refrigeration		Ice Skating Rink Refrigeration		Food Processing Refrigeration	Standard Practice Refrigerants
	New	Retrofits	New	Retrofits	New	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	
FOR12A					P										
FOR12B					P										
HCFC-22/HFC-142b/CFC-12	P	P	P	P	P	P	P	P	P	P	P	P	P		
HFC-134A					P										Yes
HFC-227ea	P		P		P	P		1/1/2023						1/1/2021	
Hydrocarbon blend A								P	P			P	P		
Hydrocarbon Blend B	P	P	P	P	P	P	P	P				P	P		
KDD6					P	P								1/1/2021	
R-125/290/134a/600a (55.0/1.0/42.5/1.5)					P	P		1/1/2023						1/1/2021	
R-403B	P	P	P	P	P	P	P	P		P	P				
R-404A	P	P	P	P	P	P	P	1/1/2023						1/1/2021	Yes
R-405A	P	P	P	P	P	P	P	P		P	P	P	P		
R-407A					P	P		1/1/2023						1/1/2021	Yes
R-407B	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-407C					P	P								1/1/2021	Yes
R-407F					P	P								1/1/2021	Yes

CARB & EPA (SNAP) Title 17, Division 3, § 95371-95377 List of Prohibited Substances (CARB) & Title 40, § 82 Subpart G, Rules 20 and 21 (US EPA SNAP)															
Refrigerant	**Supermarket Systems**		**Remote Condensing Units**		***Stand-alone medium temperature units**	**Stand-alone low temperature units**	**Stand-alone units**	**Cold Storage Warehouse**		**Industrial Process Refrigeration**		**Ice Skating Rink Refrigeration**		**Food Processing Refrigeration**	**Standard Practice Refrigerants**
	New	**Retrofits**	**New**	**Retrofits**	**New**	**New**	**Retrofit**	**New**	**Retrofit**	**New**	**Retrofit**	**New**	**Retrofit**	**New**	
R-410A					P	P		1/1/2023						1/1/2021	Yes
R-410B					P	P		1/1/2023						1/1/2021	
R-417A					P	P		1/1/2023						1/1/2021	
R-421A					P	P		1/1/2023						1/1/2021	
R-421B	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-422A	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-422B					P	P		1/1/2023						1/1/2021	
R-422C	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-422D	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-423A								1/1/2023							
R-424A					P	P		1/1/2023						1/1/2021	
R-426A					P										
R-428A	P	P	P	P	P	P		1/1/2023							
R-434A	P	P	P	P	P	P		1/1/2023						1/1/2021	
R-437A					P	P								1/1/2021	
R-438A					P	P		1/1/2023						1/1/2021	
R-507A	P	P	P	P	P	P	P	1/1/2023						1/1/2021	Yes
RS-24 (2002 formulation)					P										
RS-44 (2003 formulation)					P	P		1/1/2023						1/1/2021	
SP34E					P										
THR-03					P										

12 Appendix: Refrigerant Characteristics

To inform Phase 2, TRC identified some of the major refrigerant manufacturers and refrigerant trade names. This information was used in Phase 2 to identify organizations for interviews for collecting cost information. Figure 38 below lists some of the large and mid-sized refrigerant manufacturing companies identified by RefrigerantsHQ.com.

Figure 38. Refrigerants Manufacturers

Manufacturers	Size
Chemours (Formerly: DuPont)	Large Manufacturers
Honeywell	Large Manufacturers
Mexichem	Large Manufacturers
Arkema	Large Manufacturers
Bluon Energy	Mid-Sized Manufacturers
ICOR International	Mid-Sized Manufacturers

Figure 39 and Figure 40 below list the low-GWP refrigerants offered by the two largest refrigerant manufacturers in the United States, Chemours and Honeywell. The figure includes the product name, its chemical name, and substituted refrigerants.

Figure 39. Chemours Refrigerants

Product Name	Chemical Name	Substitute for -
Opteon™ XL10	R-1234yf	R-134a
Opteon™ XP10	R-513A	R-134a
Opteon™ XL40	R-454A	R-404A, R-507A, R-407A, R-407F
Opteon™ XL20	R-454C	R-22, R-407C, R-404A
Opteon™ XP40	R-449A	R-404A, R-507, R-22, R-407
Opteon™ XP41	R-463A	R-410A
Opteon™ XP44	R-452A	R-404A, R-507

Figure 40. Honeywell Refrigerants

Product Name	Chemical Name	Substitute for -
Solstice N40	R-448A	R-404A, R-22, R-402A, R-480, R-5007A
Solstice N13	R-450A	R-134a
Solstice N15	R-515B	R-134a
Solstice ze	R-1234ze	R-134a
Solstice L40X	R-455A	R-404A
Solstice L41	R-447A	R-410A

13 Appendix: Other Jurisdictions' Environmental Requirements

The following provides a summary of relevant environmental regulations from a sample of other states as well as Canada.

Washington state legislature passed House Bill 1112, which authorizes a ban on HFC refrigerants starting January 1, 2020. The bill is similar to the regulations adopted by the EPA's SNAP Rules 20 and 21, which prohibit high-GWP HFCs for use in certain applications. It bans the sale or lease of equipment using those HFCs and promotes the use of less damaging HFCs or suitable substitutes. Also, all manufacturers, importers, and distributors must notify the Washington Department of Ecology of the status of their products and equipment that contain HFCs and label them accordingly. The bill also calls for the Department of Ecology to complete a report by December 2020[20] that recommends how to increase the use of refrigerants with a low-GWP in mobile sources, utility equipment, and consumer appliances and incentivize the elimination of legacy equipment using HFCs. The state is committed to reducing HFC emissions by 20 percent by 2030.

New York also finalized new regulations in September 2020 to significantly reduce the use of HFCs. The state's Department of Environmental Conservation regulations adopted Rules 20 and 21 from the EPA's SNAP program to drive manufacturers to produce cleaner products and reduce greenhouse gases. The regulations ban the sale, installation, and commercial use of certain HFC refrigerants in new or retrofitted food refrigeration equipment, large air-conditioning equipment, or chillers. The state expects HFC emissions to be reduced by more than 20 percent of projected levels by 2030.

Massachusetts is on track to enact new regulations to reduce HFC refrigerants in the coming years. The Massachusetts Department of Environmental Protection regulations would prohibit the selling, leasing, renting, and manufacturing of HFC-containing products and equipment. The prohibitions will phase in over four years from January 1, 2021 to January 1, 2024; these dates are based on the EPA analysis of available alternative refrigerants[21]. The state is also part of the U.S. Climate Alliance, which is a bipartisan coalition of states and Puerto Rico committed to upholding the objectives of the Paris Climate Accord for GHG reductions.

Canada has adopted several refrigerant regulations beyond those of the Montreal Protocol, which was signed in 1987 by 197 countries including the U.S. The Canadian government has enacted the Kigali Amendment to the Montreal Protocol, which sets targets for phaseout of HFCs for all countries through the year 2047; the goal is to reduce the HFC consumption levels by 85 percent by that date. Canada's commitment to reduce HFC includes the following GWP limits:

- 1,400 for stand-alone medium temperature refrigeration equipment by 2020
- 1,500 for stand-alone low temperature refrigeration equipment by 2020
- 2,200 for centralized refrigeration systems by 2020
- 2,200 for a condensing unit used in refrigeration systems by 2020
- 750 for a chiller used in refrigeration or air conditioning systems by 2025
- 2,200 for mobile refrigeration system by 2025

[20] TRC will attempt to obtain a copy of this report in Phase 2.

[21] TRC did not review the EPA analysis as part of Phase 1 but will review it as part of Phase 2.