

A Bigger Bang for Your Efficiency Program Buck:

How Helping Customers Reduce Refrigerant Emissions Helps the Climate & Boosts Utility Energy Efficiency Program Cost-Effectiveness Too

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ABSTRACT

Refrigerants are ubiquitous in building technologies, from air conditioners and heat pumps to refrigerators and thermal insulation. But with global warming potentials thousands of times more potent than CO₂, they can have a greater climate impact than the energy consumption of the equipment they are in. The California Public Utility Commission has ordered energy efficiency program administrators to start using its new refrigerant Calculator to incorporate refrigerant avoided costs into building efficiency program decision-making, and other states are looking at similar requirements too. What's an efficiency program administrator to do? It is already difficult in many areas to pass cost-effectiveness tests—won't new requirements make it harder? Fear not! This paper describes how incorporating refrigerants into your energy efficiency portfolio can actually help you improve your energy efficiency portfolio's cost-effectiveness. It also provides real-world examples of how helping customers select efficient equipment with climate-friendly refrigerant alternatives improves total resource cost test (TRC) and Total System Benefit (TSB) numbers. HFC refrigerants are being phased down in the United States with the passage of the American Innovation and Manufacturing Act. Globally, the HFC phasedown created by the Kigali Amendment to the Montreal Protocol can avoid up to 0.5 degree C of warming this century and buy time to get to net-zero CO₂. Efficiency professionals are increasingly charged with a dual mandate of improving energy efficiency and lowering greenhouse gas emissions. By understanding refrigerants, building efficiency professionals will be better able to mitigate building GHG emissions while improving energy efficiency.

Introduction: Understanding the Link Between Energy Efficiency, Buildings, and Fluorinated Refrigerant Gases

Refrigerants (also called 'working fluids') are ubiquitous in building technologies, from air conditioners and heat pumps to refrigerators and thermal insulation (EPA 2022). Although often ignored, refrigerants are incredibly important: without them, we would not be able to refrigerate our food or cool our buildings. Refrigerants are also central to building decarbonization: to reduce buildings' reliance on natural gas, the primary component of which is the powerful climate pollutant methane, policymakers and advocates are increasingly advocating the electrification of buildings (Cohn and Esram 2022). This may result in the scale-up of refrigerant-using heat pumps for everything from space and water heating to clothes drying.

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However, most refrigerants contained in today’s existing stock of commercial and residential equipment contain fluorinated gases (F-gases)—hydrofluorocarbons (HFCs). In older equipment, ozone-depleting hydrochlorofluorocarbons (HCFCs) or even chlorofluorocarbons (CFCs) are also prevalent (ICF 2018, EPA 2016).

Fluorinated gases are often extremely powerful greenhouse gases, with thousands or even tens of thousands of times the warming impact of CO₂ (EPA 2016; Zaelke, Borgford-Parnell, and Andersen 2018). HFC refrigerants tend to have high global warming potential (GWP) but short atmospheric lifetimes: for example, HFC-134a, a common refrigerant, has an average atmospheric lifetime of about 14 years (Cross 2013). Practically, this means that when refrigerants are emitted, their warming impacts are concentrated in the decade or two after their release. This has led some policymakers to use the 20-year global warming potentials when evaluating refrigerant emissions instead of the 100-year global warming potentials commonly used in greenhouse gas (GHG) inventories and reporting. For example, the United States Climate Alliance (2021, 30) notes that “New York finalized rules that set limits on economy-wide GHG emissions of 40 percent below 1990 levels by 2030 and at least 85 percent by 2050, measured using a 20-year global warming potential.”

The majority of refrigerant emissions come from air conditioning and refrigeration equipment. In commercial buildings, the quantities of refrigerant used in equipment can be very large (EPA 2016). In locations with relatively clean electricity (<300 lbs of CO₂ per MWh), such as the US west coast (CMU 2022), if the refrigerant contained in an appliance or piece of equipment is emitted, it can have a larger impact on climate change than the electricity consumed by the equipment. For example, according to the EPA’s GreenChill Partnership (2022), “A typical supermarket’s refrigeration system holds a refrigerant charge of about 4,000 pounds and has an average annual leak rate of about 25%.” Energy Star (2022) states that supermarkets can use up to 50 kWh of electricity per square foot per year, with the majority of that consumed by the refrigeration system. For a typical 40,000 square foot grocery store, that amounts to 2 million kWh annually. At 0.3 pounds of CO₂ per kWh—typical of the US west coast (CMU 2022)—that amounts to electricity-related emissions of up to 600,000 pounds, or 272 metric tonnes, of CO₂ per year. This is dwarfed by the 1,443 tonnes of refrigerant CO₂-equivalent leaked annually from an average large retail food refrigeration system using R-404A (see figure 1).

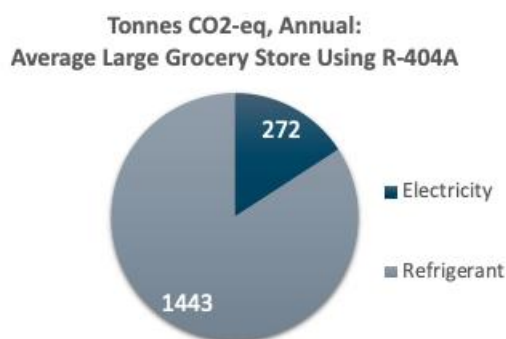


Figure 1: Supermarket refrigerant GHG emissions can greatly exceed electricity-related GHG emissions in regions where electricity is relatively low-carbon. The chart assumes electricity emissions intensity of 300 pounds per megawatt-hour (0.3 pounds per kWh) and uses 100-year GWPs for refrigerant.²

² This calculation was completed using the refrigerant calculator developed by E3 for the CA Public Utilities Commission, with input from CARB (RACC, 2021). According to the calculator, an average large retail food refrigeration system uses 3,352 pounds of refrigerant and leaks 24.2% annually, or 811.184 pounds/yr.

As the aforementioned supermarket example shows, in commercial buildings with equipment that uses lots of high-GWP refrigerant, reducing refrigerant emissions can be a GHG reduction opportunity comparable to—and sometimes larger than—improving energy efficiency, especially in regions with relatively clean electricity. Indeed, in some states with low-carbon electricity, such as California, fluorinated gas emissions exceed electricity emissions when measured using 20-year global warming potentials (see figure 2) (CARB 2020; G. Gallagher, Air Pollution Specialist, CARB, pers. comm., September 11, 2020).

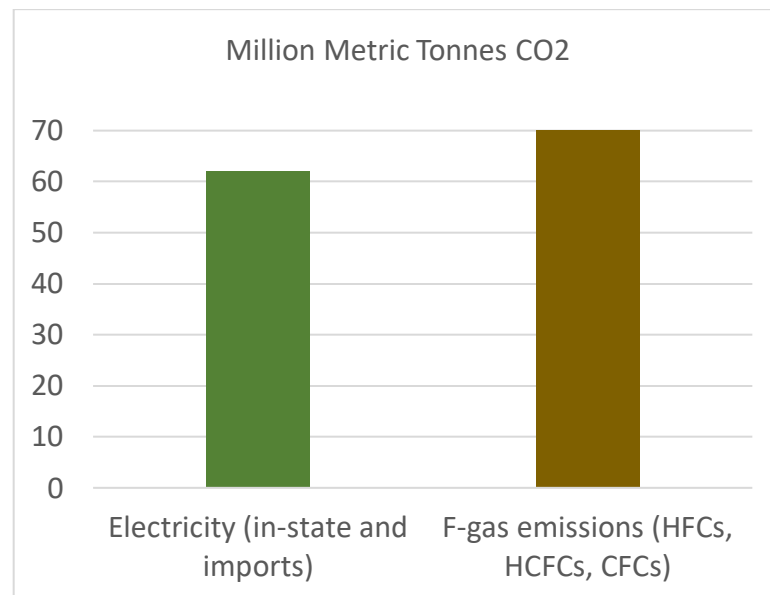


Figure 2: California Electricity vs. F-Gas Emissions, 2018, using 20-year GWPs. Data Source: CARB, 2020. F-gas emission 20-year global warming impact confirmed by Glenn Gallagher, California Air Resources Board

Regulatory Action and Implications for Building Efficiency Professionals

Scientists evaluated the growing use of HFC refrigerants and found that vastly reducing HFC use in new products and equipment by controlling production of HFCs can mitigate 70-100 billion tons of CO₂-equivalent by 2050 and avoid up to 0.5°C of warming by 2100 (Velders et. al. 2009; EPA 2017). Furthermore, reducing emissions of refrigerant from existing equipment globally has the potential to avoid up to an additional 100 billion tonnes of CO₂-eq this century (EIA, 2019). This large greenhouse gas emission reduction opportunity has prompted global, national and state action.

Globally, the 2016 Kigali Amendment to the Montreal Protocol established a phasedown schedule that will limit the production and consumption of new, high-GWP HFC refrigerant gases. Thus far, nearly 130 countries have ratified that Amendment, including India and China—but not yet the United States as of March 2022 (UNEP, 2022). Domestically, the USA passed the American Innovation and Manufacturing Act (AIM Act) in December 2020, which is set to reduce the climate impact of newly produced HFCs 85% by 2036 (IGSD 2020). It is notable that the national law does not mandate cuts in HFC emissions from existing equipment (rather, it focuses upstream, constraining supply), in contrast to some state laws. In the State of California, for instance, emissions reductions are required. A 2016 law on short lived climate pollutants,

SB1383, requires the State to reduce HFC emissions 40% below 2013 levels by 2030 (see figure 3) (CARB 2020 B; SB1383 2016).

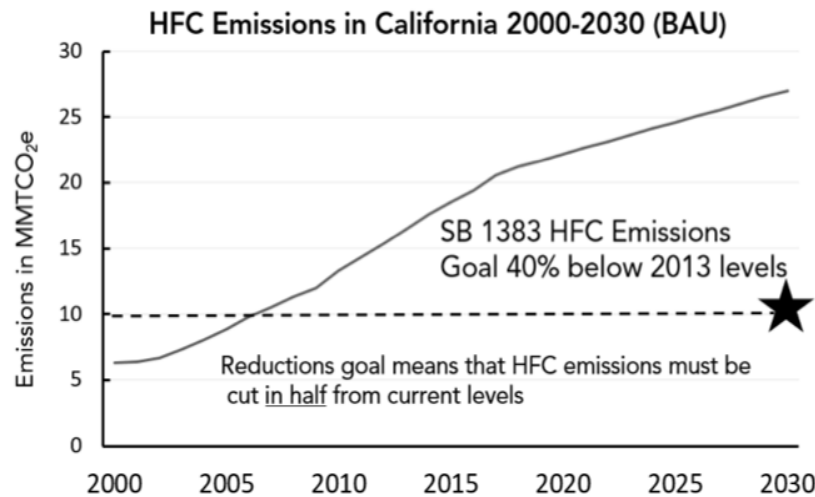


Figure 3: HFC emission reduction requirements in California (CARB 2020 B).

Practically, achieving a 40% reduction in HFC *emissions* by 2030 requires addressing refrigerant contained in both new and existing equipment (CARB 2020 B). California and a dozen other states have enacted limits on refrigerant GWP in a number of end-use applications, including most large commercial building equipment such as grocery store refrigeration systems and chillers, and have also petitioned the US EPA to establish national restrictions (Federal Register 2021; HFCbans.com 2022). Utilities have been looped into the effort to reduce HFC and other fluorinated refrigerant emissions as well. The 2018 California Cooling Act (SB1013 2018) encouraged the California Public Utilities Commission (CPUC) to develop a strategy to include low-GWP refrigerants in equipment funded by energy efficiency programs it oversees. The State of Washington recently passed a bill encouraging utilities to address refrigerants as well (HB 1050, 2021). In California, the CPUC responded in kind by:

1. developing a refrigerant calculator that program administrators can use to evaluate refrigerant GHG impacts and the avoided costs from reducing refrigerant GHG emissions (RACC 2021);
2. updating their tools, such as the Cost Effectiveness Tool (CET) to include refrigerant, and
3. ordering utilities and energy efficiency program administrators to:
 - a. use the refrigerant avoided cost calculator and incorporate that into portfolio cost-effectiveness evaluations³; and
 - b. Seek out every opportunity to mitigate refrigerant emissions (CPUC 2021 B).

³ California Public Utilities Commission Decision 20-04-010 stated “we find that because methane and refrigerant leakage are included in the carbon inventory maintained by [the California Air Resources Board], any reduction in these greenhouse gas emissions contributes to California’s greenhouse gas reduction efforts. Because ratepayers incur costs related to these efforts, we find that the avoided costs of methane and refrigerant leakage, similar to the existing greenhouse gas avoided cost, is a real and quantifiable benefit of distributed energy resources. Accordingly, we adopt the proposed avoided cost of high global warming potential gases into the Avoided Cost Calculator.”

As building energy efficiency professionals who often have a dual mandate of saving energy and reducing GHG emissions, the implications are clear: we can no longer ignore refrigerants in the efficiency programs and products we promote.

Can Reducing Refrigerant Emissions Make it Easier to Pass Cost-Effectiveness Tests for Commercial Building Energy Efficiency Portfolios?

It is increasingly difficult in many areas to pass cost-effectiveness tests for utility-sponsored energy efficiency programs—won't new requirements make it harder? Fortunately, the opposite may be true. Instead of making it harder to pass cost-effectiveness tests, incorporating refrigerants could make it easier to pass cost effectiveness tests when greenhouse gas savings are incorporated in metrics such as the Total Resource Cost Test or Total System Benefit (CPUC, 2021 A and B). This is because efficiency program administrators can now claim credit for refrigerant emissions reductions that they help achieve through efficiency programs. The CPUC and their contractor, E3, articulated a formula for calculating the benefits of “changes in refrigerant or usage or type” (see figure 4) (Morgenstern and Mantegna 2020). In the section that follows, we illustrate how commercial building efficiency program administrators could improve their efficiency portfolio cost-effectiveness by including refrigerant retrofits in commercial building efficiency upgrades involving chillers and supermarket refrigeration systems.

Use Case #3: Changes in Refrigerant Usage or Type

- + This use case will apply to all DERs that change the amount or type of refrigerant being used in a building
- + Refrigerant leakage is calculated for both the new and replaced appliances, using leakage rates and GWPs from CARB included in the ACC spreadsheet
- + Refrigerant leakage emissions valued at GHG adder \$/tonne

Change in refrigerant leakage emissions = **New appliance refrigerant leakage** - **Replaced appliance refrigerant leakage**

(CO2-equivalent)
(CO2-equivalent)
(CO2-equivalent)

Figure 4. Formula for calculating avoided costs from a change in refrigerant usage or type. Source: E3. (Morgenstern and Mantegna 2020)

Supermarket Refrigeration Example

According to the California Air Resources Board and the Refrigerant Calculator developed by E3 for the CPUC, a single large retail food refrigeration system averages 3,352 pounds of refrigerant (RACC, 2021). The average annual leak rate for these systems is 24% (see Appendix A: refrigerant use and emissions from common types of commercial building equipment.) The most common supermarket HFC refrigerant is R-404A, although many existing systems still use ozone-depleting substances like HCFC-22. R-404A has a 100-year global warming potential of

3,922, and a 20-year global warming potential of 6,010 per the Intergovernmental Panel on Climate Change’s 4th Assessment report, which is used in the calculator (RACC, 2021). However, low-global warming potential refrigerant alternatives, such as R-744, are available for new systems that have negligible impact on climate change. Imagine that as part of an energy efficiency portfolio, a utility is sponsoring the retrofit of an existing supermarket refrigeration system to make it more energy efficient. In doing so, they provide additional funding to change to R-744 refrigerant instead of staying with R-404A. Using the refrigerant calculator, we see that net present value (NPV) of the R-404A refrigerant emissions from a system installed in 2022 is \$739,220 (see figure 5).

Inputs		Result
		NPV Avoided Costs (\$2020)
Device type	ge retail food refrigeration 2,000 lb	\$ 739,220.48
Use ARB average device lifetime or user-specified?	ARB average	
Active device lifetime (yr)	15	
Device installation year	2022	
Use ARB average refrigerant charge or user-specified?	ARB average	
Active device refrigerant charge (lb)	3352	
Device refrigerant used	R-404A	
WACC selection	PG&E	
Active WACC (%)	7.81%	
GWP time horizon (100-yr is default)	100-yr	

Figure 5: Net present value avoided costs of switching from R-404A to CO₂ in supermarket refrigeration. Source: RACC 2021.

Using the formula articulated by CPUC and E3 (figure 4), we can determine the change in refrigerant leakage emissions and NPV avoided costs:

$$\begin{aligned}
 & \text{New supermarket refrigerant (CO}_2\text{, aka R744) @ 0.368 tonnes per year, NPV of \$188.50} \\
 - & \text{Replaced supermarket refrigerant (R404A) @ 1,442.94 tonnes per year, NPV of} \\
 & \text{\$739,220.48} \\
 \hline
 = & \text{Reduction in refrigerant leakage emissions of 1,442.57 tonnes of CO}_2\text{-equivalent per year} \\
 & \text{and NPV avoided costs of \$739,031.98}
 \end{aligned}$$

If it can be demonstrated that the change in refrigerant would not have occurred absent the energy efficiency program’s investment, this \$739,032 could potentially be included in the “benefit” column of the cost effectiveness test (as greenhouse gas avoided costs), increasing the cost-effectiveness of the overall investment portfolio.

It should be noted that changing refrigeration equipment in existing facilities can be a difficult endeavor, and not all facilities may be ready to change to an ultra-low global warming

potential alternative like R744 in the near-term. Alternatives with lower global warming potentials are available as retrofit options, such as R448A or R449. An example of an efficiency retrofit that includes a change from R-404A to R448A is provided below. In this example, it is assumed that the facility has 15 years of useful life remaining after the retrofit—that is, 15 years of R404A emissions are avoided and replaced with an equivalent quantity of R448A emissions. As you can see, the avoided costs are lower, but still substantial:

New supermarket refrigerant (R448A) @ 510 tonnes per year, NPV of \$261,273.80
- Replaced supermarket refrigerant (R404A) @ 1,443 tonnes per year, NPV of \$739,220.48
= Reduction in refrigerant leakage emissions of 933 tonnes of CO ₂ -equivalent per year and NPV avoided costs of \$477,946.68

Chiller Example

According to the California Air Resources Board and the Refrigerant Calculator developed by E3 for the CPUC, a single large chiller averages 3,978 pounds of refrigerant and leaks about 2.3% of this each year (RACC 2021). Large industrial process chillers can use even more, averaging over 5,873 pounds of refrigerant. Industrial process chillers are estimated to be more leak-prone, averaging about 12% per year (see Appendix A: refrigerant use and emissions from common types of commercial building equipment) (RACC 2021). Common HFC chiller refrigerants include HFC-134a (R-134a; 100-year GWP of 1,430 and 20-year GWP of 3,830) and R-410A (100-year GWP of 2,088 and 20-year GWP of 4,340). Ultra-low-global warming potential refrigerant alternatives are available such as R-717 for new systems, and medium-GWP refrigerants such as R-513A or R-450A could be used for retrofits.

As an example, say that as part of an energy efficiency portfolio, a utility is sponsoring the upgrade of an industrial process chiller to make the facility more energy efficient. In so doing, they provide additional funding to switch to a new system that uses low-GWP refrigerant. Using the refrigerant calculator, we see that net present value benefits of the switch:

New chiller refrigerant (R-717, ammonia) @ 0 tonnes per year, NPV of \$0
- Replaced refrigerant (R-134A) @ 468.56 tonnes per year, NPV of \$325,723
= Reduction in refrigerant leakage emissions of 468.56 tonnes of CO ₂ -equivalent per year and NPV avoided costs of \$325,723

In areas where R-717 (ammonia) cannot be used, retrofitting to a medium-GWP refrigerant such as R-513A may be feasible. In this case, the calculation would be adjusted as follows. The savings assume 15 years of useful life on the retrofitted system:

New chiller refrigerant (R-513A) @ 206.35 tonnes per year, NPV of \$143,445
- Replaced refrigerant (R-134A) @ 468.56 tonnes per year, NPV of \$325,723
= Reduction in refrigerant leakage emissions of 262.21 tonnes of CO ₂ -equivalent per year and NPV avoided costs of \$182,278

Quantifying Cost-Effectiveness: Analysis of Impact on Total Resource Cost Test (TRC) and Implications for Total System Benefit (TSB)

From the examples above, one can see that there is potential to boost commercial building energy efficiency portfolio cost-effectiveness while mitigating greenhouse gas emissions from refrigerant, if the reductions in refrigerant can be proven to be additional. However, few utilities or efficiency program administrators are familiar with the refrigerant avoided cost calculator to date, despite the fact that they are supposed to use it. Lack of awareness is an issue. Fortunately, familiarity challenges can be overcome. Since few energy efficiency program administrators were familiar with the refrigerant calculator, and since few refrigerant experts were familiar with utility cost-effectiveness calculations, the Institute for Governance & Sustainable Development (IGSD) contracted Quantum Energy Analytics to use the refrigerant calculator and incorporate its outputs into some example energy efficiency programs (Merkt and Harcharik 2021).

Three programs were modeled to see what reducing high-GWP refrigerant emissions “avoided costs” does to cost-effectiveness. The first program was a midstream/upstream program for commercial and residential air conditioning. Commercial air conditioning measures came from SCE-13-SW-002F (PY 2021) and residential measures came from PGE21002 (PY2020). The second program was midstream and upstream stand-alone refrigerator measures. Commercial refrigerator measures came from SCE-13-SW-002H (PY 2021) and residential measures came from PGE21002 (PY 2020). The third program Quantum Energy Analytics evaluated was a downstream grocery refrigeration program. This measure came from SDGE3223 (PY 2020). The methodology that Quantum Energy Analytics used was to run the Cost Effectiveness Tool (CET) two times: first with the measure as-is, and second with costs adjusted to reflect incentives paid to mitigate refrigerant emissions during measure replacement at equipment end-of-life. Notably, this approach included end-of-life emissions but did not include the benefit of mitigating annual refrigerant leakage; if it did, the benefits would be even greater, especially for the grocery example. Program administration costs were kept the same, but gross measure costs were increased by \$10 per pound of refrigerant emissions avoided. The results are summarized in tables 1 and 2.

Table 1: Results of Total Resource Cost Test Analysis with Refrigerant Avoided Costs. (Merkt and Harcharik 2021).

Program	Original TRC	TRC with refrigerant	Budget	Gross kWh	Gross kW	Gross Therm	Net kWh	Net kW	Net Therm
Midstream A/C	0.99	2.39	\$585,115.00	1,098,619	607	(3,905)	629,588	292	(2,929)
Downstream Grocery Refrigeration	2.18	2.39	\$12,667.00	167,250	(2)	65	100,350	(1)	39
Midstream Refrigeration	0.27	0.51	\$621,116.00	1,350,317	293	(35,971)	264,986	57	(6,834)
Measure	Original TRC	TRC with refrigerant	Budget	Gross kWh	Gross kW	Gross Therm	Net kWh	Net kW	Net Therm
Midstream AC-residential	0.57	2.38	\$287,350.00	498,400	417	-	179,424	150	-
Midstream AC-Commercial	1.26	2.42	\$297,765.00	600,219	189	(3,905)	450,164	142	(2,929)

Downstream Grocery Refrigeration	2.18	2.39	\$12,667.00	167,250	(2)	65	100,350	(1)	39
Midstream Refrig-Commercial	0.99	2.86	\$5,382.46	20,550	2	-	12,330	1	-
Midstream Refrig-Residential	0.26	0.47	\$615,733.74	1,329,767	291	(35,971)	252,656	55	(6,834)

Table 2: Percent improvement in Total Resource Cost Test by Reducing Refrigerant Emissions (Merkt and Harcharik 2021).

Measure	Original TRC	TRC with refrigerant	Percent Increase
Midstream AC-Residential	0.57	2.38	318%
Midstream AC-Commercial	1.26	2.42	92%
Downstream Grocery Refrigeration	2.18	2.39	10%
Midstream Refrigeration-Commercial	0.99	2.86	187%
Midstream Refrigeration - Residential	0.26	0.47	77%

For each measure, the total resource cost test scores were improved. Increases ranged from 10% to 318%. For the grocery measure, inclusion of annual leakage reductions (instead of only end-of-life refrigerant leakage) would have further improved the TRC (Merkt and Harcharik 2021). These findings suggest that similar improvements can be expected as California and other states consider more holistic metrics such as Total System Benefit (TSB) which also incorporates refrigerant-related avoided costs.

Conclusion

Refrigerants are ubiquitous in building technologies, but with global warming potentials thousands of times more potent than CO₂, they can result in more greenhouse gas emissions than the energy consumption of equipment they are contained in. Regulators such as the California Public Utilities Commission have deemed it no longer acceptable to only measure the GHG impacts of avoided energy consumption. Energy efficiency program administrators must start incorporating refrigerant avoided costs into building efficiency program decision-making, and other states are looking at similar requirements too. Fortunately, incorporating refrigerants need not make it harder to pass cost-effectiveness tests—and indeed, may even help commercial building energy efficiency program administrators design more cost-effective portfolios. In supermarkets, switching from high-GWP refrigerants like R404A to ultra-low refrigerant like R744 (CO₂) can slash refrigerant leakage emissions by an average of 1,442 tonnes of CO₂-equivalent per year. Over 15 years of emissions reductions, that can yield NPV avoided costs of over \$739,000. Retrofitting supermarkets to use lower-GWP refrigerant options like R448A could reduce refrigerant leakage emissions by an average of 933 tonnes of CO₂-equivalent per year and provide NPV avoided costs of \$477,946 over 15 years. In large chillers used for

industrial and other processes, switching from R-134A refrigerant to a non-greenhouse gas like R-717 (ammonia) could reduce refrigerant GHG emissions by 468 tonnes of CO₂-equivalent per year, and provide NPV avoided costs over \$325,000. Retrofitting from R-134a to lower-GWP alternative R-513A could reduce refrigerant leakage emissions by 262 tonnes of CO₂-equivalent per year and provide NPV avoided costs up to \$182,278. An analysis by Quantum Energy Analytics showed improvements of 10-318% in the TRC by including measures to mitigate refrigerant emissions. Refrigerant mitigation avoided costs could improve the cost-effectiveness scores of efficiency portfolios, possibly enabling deeper energy retrofits that would not otherwise have proven cost-effective. These promising results suggest that utilities, energy efficiency program administrators, and the consultants that advise them should consider seeking out additional cost-effective measures to help commercial buildings switch to lower-GWP refrigerants. Doing so can help mitigate emissions of HFCs—among the world’s most potent greenhouse gases—while also potentially increasing cost-effectiveness of efficiency portfolios.

Appendix A: Refrigerant use and emissions from common types of commercial building equipment.

Source: RACC 2021.

Sector	Equipment / Appliance	Average lifetime (years)	Average amount of refrigerant (pounds)	Average annual leak rate	Average end-of-life refrigerant loss	Lifetime refrigerant loss (pounds)
Stationary Refrigeration	Large commercial & retail food refrigeration 2000 lbs. +	15	3,352	24.2%	20.0%	12838
	Medium commercial & retail food refrigeration 200-2,000 lbs.	15	684	22.9%	20.0%	2486
	Small commercial & retail food refrigeration 50-200 lbs.	20	103	15.6%	20.0%	342
	Sub-small retail food refrigeration < 50 lbs.	14	23	15.0%	34.0%	56
	Large cold storage 2,000 lbs. +	20	7,252	14.8%	20.0%	22916
	Medium cold storage 200-2,000 lbs.	20	552	10.3%	20.0%	1248
	Small cold storage 50-200 lbs.	20	113	4.0%	20.0%	113
	Large industrial process cooling 2,000 lbs. +	20	5,873	12.3%	20.0%	15622
	Medium industrial process cooling 200-2,000 lbs.	20	660	12.5%	20.0%	1782
	Small industrial process cooling 50-200 lbs.	20	104	9.1%	20.0%	210
	Stand alone (self-contained) refrigeration units	20	1.023	1.0%	98.5%	1.11
	Refrigerated Food Processing and Dispensing Equipment	12	3.0	1.0%	98.5%	3.14
	Commercial Ice Machines	5	3.3	0.5%	98.5%	3.26
	Water Coolers & Fountains	14	0.25	1.0%	98.5%	0.25
	Refrigerated vending machines	15	0.63	1.0%	98.5%	0.62
	Office refrigerator freezer	14	0.34	1.0%	77.0%	0.27
Water Heating & Laundry	Heat Pump Water Heaters	14	2.4	1.0%	100.0%	2.40
	Heat Pump Clothes Dryers	14	0.88	1.0%	100.0%	0.88
Stationary Air-conditioning	Large Chiller 2,000 lbs. +	20	3,978	2.3%	20.0%	2625
	Medium Chiller 200-2,000 lbs.	20	526	3.0%	20.0%	421
	Commercial Unitary AC 50-200 lbs., > 135,000 BTUh	20	70	7.0%	20.0%	112
	Commercial Unitary AC, < 50-lbs., < 135,000 BTUh size (includes smaller "residential-type" central AC and heat pumps)	15	18.2	4.7%	56.0%	23
	Window/Room AC and PTAC Units, commercial	12	1.5	2.0%	98.5%	1.52
	Portable AC	10	1.5	1.0%	98.5%	1.52
	Dehumidifiers	5	1.0	1.0%	98.5%	0.99

Appendix B: CO₂-equivalent GHG emissions of common refrigerants used in commercial building equipment, and climate-friendly refrigerant alternatives

Equipment / Appliance	Common refrigerants in existing equip & 100-yr GWP	Lifetime refrigerant loss (pounds)	CO ₂ -eq. (tonnes)	Social cost*	Less harmful alternative	CO ₂ -eq. savings, alternative refrigerant (tonnes)
Large retail food refrigeration 2,000 lbs. +	R-404A (3922) R-407A (2107)	12,838.2	22,835	\$1,139,886	R-744 (new) R-448A/449A (retrofit)	22,829
Medium retail food refrigeration 200-2,000 lbs.	R-404A (3922) R-407A (2107)	2,486.3	4,422	\$220,740	R-744 (new) R-448A/449A (retrofit)	4,421
Small retail food refrigeration 50-200 lbs.	R-404A (3922) R-134A (1430) HCFC-22 (1810)	342.0	608	\$30,083	R-744 (new) R-448A/449A (retrofit)	608
Sub-small retail food refrigeration < 50 lbs.	R-404A (3922) HCFC-22 (1810)	56.1	100	\$4,983	R-744 (new) R-448A/449A (retrofit)	100
Large cold storage 2,000 lbs. +	R-404A (3922) HCFC-22 (1810)	22,916.3	40,761	\$2,015,800	R-717 (new) R-448A/449A (retrofit)	40,761
Medium cold storage 200-2,000 lbs.	R-404A (3922) HCFC-22 (1810)	1,247.5	2,219	\$109,661	R-717 (new) R-448A/449A (retrofit)	2,219
Small cold storage 50-200 lbs.	R-404A (3922) HCFC-22 (1810)	113.0	201	\$9,903	R-717 (new) R-448A/449A (retrofit)	201
Large industrial process cooling 2,000 lbs. +	R-134a (1430) HCFC-123 (77)	15,622.2	10,131	\$875,442	R-717 or R-1233zd(E) (new) R-513A (retrofit)	10,131
Medium industrial process cooling 200-2,000 lbs.	R-134a (1430) HCFC-123 (77)	1,782.0	1,156	\$99,864	R-717 or R-1233zd(E) (new) R-513A (retrofit)	1,156
Small industrial process cooling 50-200 lbs.	R-134a (1430) HCFC-123 (77)	210.1	136	\$11,765	R-717 or R-1233zd(E) (new) R-513A (retrofit)	136
Stand alone (self-contained) refrigeration	R-134a (1430) HCFC-22 (1810)	1.1	0.72	\$61	R-290 (new)	0.72
Refrigerated Food Processing and Dispensing	R-134a (1430) R-404A (3922)	3.1	2.03	\$177	R-513A (new/retrofit)	1.14
Commercial Ice Machines	R-404A (3922)	3.3	5.80	\$293	R-290 (new)	5.80
Refrigerated vending machines	R-134a (1430)	0.6	0.40	\$34	R-290 (new)	0.40
Office refrigerator freezer	R-134a (1430)	0.3	0.18	\$15	R-600A (new)	0.18

Heat Pump Water Heaters	R-134a (1430)	2.4	1.56	\$133	R-744 (new)	1.56
Water Coolers & Drinking Fountains	R-134a (1430)	0.2	0.16	\$14	R-290 (new)	0.16
Heat Pump Clothes Dryers	R-134a (1430)	0.9	0.57	\$49	R-290 (new)	0.57
Large Chiller 2,000 lbs. +	R-134a (1430) HCFC-123 (77)	2,625.0	1,702	\$146,213	R-717 or R-1233zd(E) (new) R-513A or R-450A (retrofit)	1,702
Medium Chiller 200-2,000 lbs.	R-410A (2088) HCFC-22 (1810)	421	421	\$26,593	R-717 or R-1233zd(E) (new) R-513A or R-450A (retrofit)	421
Commercial Unitary AC 50-200 lbs., > 135,000 BTUh size	HCFC-22 (1810) R-410A (2088)	112	92	\$8,444	R-454B or R32 (new)	68
Commercial Unitary AC, < 50-lbs., < 135,000 BTUh size	R-410A (2088) HCFC-22 (1810)	23	23	\$1,458	R-454B or R32 (new)	18
Window/Room AC and PTAC Units, commercial	R-410A (2088) HCFC-22 (1810)	1.5	1.52	\$97	R-32 (new)	1.06
Portable AC	R-410A (2088)	1.5	1.52	\$97	R-32 (new)	1.06
Dehumidifiers	R-410A (2088)	1.0	0.99	\$64	R-32 (new)	0.69

*As calculated by the Refrigerant Avoided Cost Calculator (2021) using 100-year GWPs.

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