The Deproliferation of Refrigerant Greenhouse Gases

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ABSTRACT

Greenhouse gas (GHG) emissions from refrigerants are the fastest growing global warming pollutant in the U.S. and the world. Rising temperatures and global electrification efforts will cause an exponential grown of refrigerant use (especially in HVAC systems) in the coming decades. Thanks to the Kigali Amendment of the Montreal Protocol, international refrigerant use is shifting towards more climate friendly options however, the U.S. HVAC market is still dominated by high-Global Warming Potential (GWP) hydrofluorocarbon (HFC) refrigerants. Concerns about flammability layered with bureaucratic and political forces are stalling U.S. efforts to both allow and embrace low-GWP refrigerants.

Refrigerant emission estimates show national policies regulating the intentional venting of refrigerants are both rarely enforced and largely ineffective. Fixing refrigerant leaks and recovering the existing refrigerant in end-of-life appliances are labor intensive and far too often not performed. National and state level policies have begun and will continue to mandate the use of refrigerants with lower GWP levels, but the rollout process is proving to be slow and disjointed.

This paper combines secondary research, in-depth interviews with twenty-one HVAC and refrigerant subject matter experts, a web survey, and theoretical performance analysis of low-GWP refrigerants, to provide recommendations on how to best to incorporate low-GWP refrigerants into carbon reduction incentive programs. For most HVAC appliances, it will be several years before low-GWP refrigerant alternatives are both permitted and readily available. Much can still be done to both track and reduce refrigerant emissions today.

Acknowledgements

The authors of this paper would like to acknowledge the following individuals and organizations who were interviewed between August and December of 2020, as a part of this research effort:

Wes Davis, Director of Technical Services at Air Conditioning Contractors of America

Ken Mozez, Refrigeration Sales Manager at Air Treatment

Steven P. Mella, CEO at ComStar International

Charlie McCrudden, Director of Government Affairs at Daikin US Corporation

Christina Starr, Senior Policy Analyst at Environmental Investigation Agency

Daniel Bresette, Executive Director at Environmental and Energy Study Institute

Amber Todoroff, Policy Associate at Environmental and Energy Study Institute

Tyler Miner, President at Henry Bush Plumbing, Heating & Air Conditioning

Jonathan Stack, Director of Sustainability at Hudson Technologies Company

Bob Wiseman Chairman of the Board at Institute of Heating and Air Conditioning

Kristen Taddonio, Senior Climate and Energy Advisor at Institute for Governance and Sustainable Development

Chris Forth, Executive Director of Regulatory Codes and Environmental Affairs at Johnson Controls

Mark Lessans, Director of Regulatory and Environmental Affairs at Johnson Controls

Mark McLinden, Supervisory Chemical Engineer, National Institute of Standards and Technologies

Danielle Wright, Executive Director at North American Sustainable Refrigeration Council

Ron Yaffe, Vice President of Sales at Norman Wright

Nicole Seiderman, Business Development Manager at Norman Wright

Ahmed Elataf, R&D Associate Staff at Oak Ridge National Laboratory (ORNL)

Bruce Fuhrmann, Commercial Sales and Engineering Manager at US Air Conditioning Distributors

Curtis Harrington, Senior Engineer at UC Davis Western Cooling Efficiency Center

Introduction

Refrigerants are gases that allow for heat to be drawn from one source and transferred to another. They are essential for HVAC systems, freezers in grocery stores, refrigerators, and countless other applications that provide cooling as well as heating. Over the last century refrigerants have evolved to address toxic impacts, ozone depletion, and are currently evolving to mitigate their growing impacts on global warming. The most common refrigerant class used today is hydrofluorocarbons (HFCs). HFCs are refrigerants that are not harmful to the ozone layer. However, their impact on global warming is very large. According to the California Air Resources Board (CARB), HFCs are the fastest growing source of greenhouse gas emissions in California, the nation, and worldwide (Klivans, 2021). Global warming impacts are rapidly increasing the demand for air conditioning (AC) and will continue to do so in the coming decades and beyond. At the same time, global electrification efforts are expected to drive a rapid shift away from fossil fuel heating sources towards heat pumps. All of this means that the global use of refrigerants (especially in HVAC systems) will explode in the coming decades. No less significant is the impact global warming and electrification trends will have on the planet's electrical grids. For all these reasons, future HVAC energy efficiency measures need to simultaneously reduce energy consumption and curtail the greenhouse gas bombs contained within each system.

Central to this paper is the global warming potential (GWP) of refrigerants. GWP is a widely recognized method for measuring the harmful impact that gases can have on our planet's health. The GWP of a gas is measured by the heat trapping impacts (referred to as the greenhouse effect) on the atmosphere of one metric ton of the gas relative to the heat trapping impacts of one metric ton of carbon dioxide (CO2). A gas's GWP is commonly quantified by using the 100-year CO2 equivalent impact, but the 20-year GWP impact is also widely used and relevant (Forster, et al. 2007).

Unfortunately, many refrigerant-containing systems and appliances (especially HVAC systems) leak or are intentionally emitted into the atmosphere. Almost all refrigerants found in HVAC equipment today have high-GWP levels. The two most common refrigerants installed in new HVAC equipment today are R-410a and R-134a. For example, R-410a has a 100-year GWP of 2,088, meaning over a 100-year period, these R-410a will trap over 2,000 times more heat than the same mass of CO2. Emissions occur at three distinct stages of an appliance's lifetime. A small percentage of emissions occurs during equipment delivery and installation. A sizeable portion of leaks occurs during the lifetime operation, both from the equipment itself leaking and through de minimis leaks stemming from refrigerant charge adjustments (RCAs). Finally, a significant portion of emissions occur at the end-of-life (EOL), either through direct venting, improper disposal, and/or de minimis leaks that occur during recovery and reclamation.

Fixing refrigerant leaks in existing appliances and recovering the remaining refrigerant in appliances at the end-of-life (EOL) are labor intensive tasks that are often not performed. Subject matter experts we spoke with cited both cost savings and lack of enforcement as reasons why these emissions persist. Global, national, and state level policies are working to phasedown the use of high-GWP HFCs, but the process will inevitably be slow and disjointed. All the while, stockpiles of high-GWP HFCs found in our appliances will continue to build. With all the factors contributing to global warming, it is critical that all stakeholders with some capacity to minimize high-GWP refrigerant emissions make every effort to do so.

This paper will provide an update on shifting national and state-level policies mandating the phasedown of high-GWP HFC refrigerants. By leveraging secondary research, in-depth interviews with twenty refrigerant and HVAC subject matter experts (SMEs), a web survey with fifty-five similar SMEs, and theoretical performance analysis of low-GWP refrigerants, this paper also provides recommendations for how to best to incorporate low-GWP refrigerants into carbon reduction or total system benefit utility sponsored incentive programs.

Policies Impacting the High-GWP Refrigerant Phasedown

This section will provide a summary of past and present global, U.S., and state-level policies impacting the use of refrigerants.

The Montreal Protocol

Seen as one of the world's most successful environmental treaties, the Montreal Protocol (MP) began as a global pact to protect the earth's stratospheric ozone through regulation and the prescribed phase-out of substances that harm the ozone layer (UNEP 2022). Now over 30 years since the original MP was ratified, there are signs that the ozone layer is recovering. This result is directly attributed to the MP, which many consider to be the most? successful global environmental treaty to date. Following the original signing of the MP in 1987, parties have met annually to monitor the success of the agreement and to periodically adjust or draft amendments. In October 2016, parties of the MP met in Kigali, Rwanda, and drafted an amendment to reduce the use of HFCs by 80-85 per cent by the late 1940s, now known as the Kigali Amendment. The

United States contributed to the research and proposals that lead to the agreement, which was adopted by 197 countries at the time of signing. It became an official amendment in 2017 and entered into force in 2019. The prescribed phasedown of HFCs and other impacts of the Kigali Amendment are estimated to reduce potential global warming impacts between 0.2-0.4ºC by 2100 (Szopa et al. 2021). As of June 2022, over 130 countries have ratified the Kigali Amendment, including Canada, Mexico, China, India, and all of Western Europe (UN 2022). For countries classified as developed in the Montreal, the initial HFC reduction process began in 2019. Notably, as of June 2022, the United States has not formally ratified the agreement although the Biden administration submitted advice and consent to the US Senate for ratification in November of 2021 (Biden 2021).

The United States Clean Air Act and Significant New Alternatives Policy Program (SNAP)

In 1990, the United States significantly revised the Clean Air Act (CAA) to curb four major threats to the environment and to the health of Americans: acid rain, urban air pollution, toxic air emissions, and stratospheric ozone depletion (EPA CAA 1990). Title VI of the Clean Air Act charges the EPA to implement policy and regulation designed to protect the ozone layer and to ensure that the United States adheres to the Montreal Protocol. The EPA created a series of programs to facilitate this effort, one program in particular, is the SNAP Program (EPA SNAP 2022). The definition found on the SNAP homepage of the EPA Website states:

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

In July 2015, SNAP finalized Rule 20, prohibiting "… the use of certain high-GWP HFCs as alternatives." In December 2016, SNAP finalized Rule 21 and provided "new listings of safer substitutes and prohibition on the use of certain high-GWP alternatives."

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

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

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

California Senate Bill 1383, and 1013

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

American Innovation and Manufacturing Act, 2021

On December 27, 2020, the US Congress enacted the Consolidated Appropriations Act, 2021.

"The AIM Act, which was included in the Consolidated Appropriations Act, 2021, directs EPA to phase down production and consumption of HFCs in the United States by 85 percent over the next 15 years."

The impact of the AIM Act is that the rest of the country will join California in transitioning away from high-GWP HFC refrigerants.

Quantifying the Impacts of Refrigerant Emissions

This section will discuss the various entities that track and quantify refrigerant emissions in California and the U.S. It will discuss the laws and regulations designed to minimize emissions as well as the emission sources. Quantifying emission rates and understanding the laws designed to prevent emissions are critical when exploring strategies that can both minimize future emissions and the GWP impact of emissions in the future.

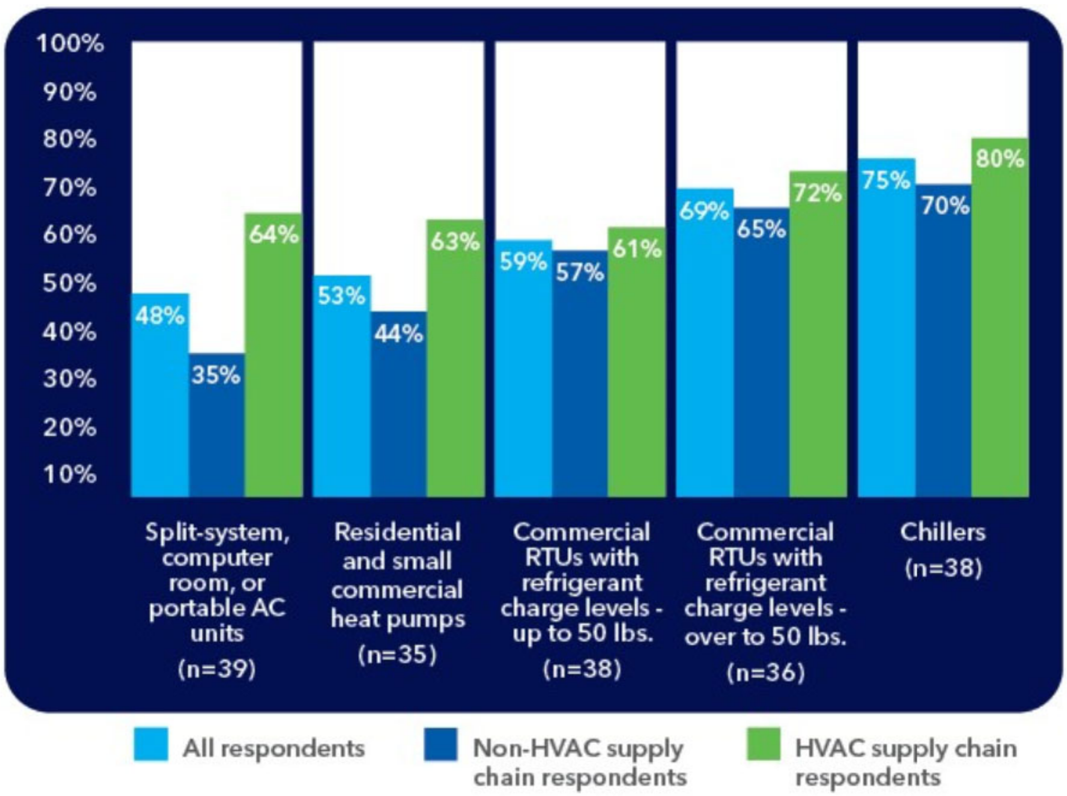
The single most effective way to reduce the global warming impacts of refrigerants is to eliminate emissions. In the 1990s the EPA established Section 608 of the CAA to regulate the testing and certification requirements of technicians who maintain, service, repair, or dispose of equipment that could release refrigerants into the atmosphere (EPA CAA 2022). According to many of the HVAC contractors or refrigerant SME's we spoke with about the release of EPA Section 608, the proposed fines and penalties included in this regulation initially gave the HVAC industry quite a scare when first announced in the 1990s. However, all SMEs we spoke with about EPA Section 608 said that after a while it became clear there was little to no enforcement of the regulation. Some of the SMEs reported knowing of instances or even being witness to HVAC contractors reported to the EPA for egregious violations, only to never face any fines or penalties.

A review of the EPA's enforcement history database for criminal prosecutions under the CAA finds only 26 records when using the search term "venting" or "refrigerant." These 26 records span 2022 to 1997 and include all states and territories of the US. Only four of those records involved defendants being charged with intentional venting of hazardous refrigerant into the atmosphere and only one occurred in the last ten years. The remaining records include 11 instances of illegal refrigerant sale or smuggling, six instances of AC theft for copper parts that resulted in hazardous venting, and five other non-venting related cases (EPA Enforcement 2022). The lack of enforcement coupled with the additional labor and cost associated with the proper recovery, reclamation, and/or disposal is a key reason refrigerant emissions occur so readily.

All of this is widely known by the EPA and CARB. The EPA began performing annual inventories of US greenhouse gas (GHG) emissions and sinks in the early 1990s (EPA GHG 2022). CARB performs a similar emissions inventory but uses a modified methodology more specific to California as a region (CARB 2022). EPA categorizes HVAC refrigerant emissions into three distinct stages: emissions that occur prior to and during installation, emissions that occur during operation from leaks or servicing (reported on an annual rate), and emissions that occur at the EOL from venting, improper disposal, or leaks after recovery. CARB's emissions report does not include a separate category for emissions that occur during installations, and it also varies the way the end-of life emissions estimates considers operational leakage impacts on the end-of-life remaining charge. CARB's emissions factors table includes a column that defines the estimated, "Number of years prior to EOL with no "top-off" refrigerant added to replace full charge." (CARB 2022)

In early 2021, refrigerant SMEs that included HVAC supply chain respondents as well as non-HVAC supply chain respondents, were surveyed. One question asked respondents to estimate the successful reclamation rate of remaining refrigerant at end-of-life across five different HVAC equipment size category bins. The results of each group of respondents as well as the overall average is presented in Figure 1.

Figure 1. HVAC refrigerant reclamation rates at EOL



Respondents of this question were asked: What percent of the following HVAC equipment types have the remaining refrigerant reclaimed at the end-of-life?

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

- The HVAC supply chain respondents have significantly more optimistic estimates for reclamation success rates for the smaller equipment types than the non-HVAC supply chain respondents with that disparity narrowing considerably for the commercial RTUs and chiller categories.

- While there are many conflicting estimates, everyone agrees the smaller the equipment the less likely it is to have the remaining refrigerant properly recovered.

Low-GWP HVAC Refrigerant Options

This section discusses the current and future low-GWP refrigerants identified through secondary research and in-depth interviews with refrigerant subject matter experts. Based on these findings, the consensus for a viable low-GWP candidate must possess the following attributes (McLinden et al. 2017):

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

Existing safety codes require nonflammable refrigerants for typical applications, but that requirement is being reconsidered. The commonly accepted flammability and toxicity ratings based on ASHRAE Standards 34 is A1, but A2L and in some cases A3 is also being considered (ASHRAE 2020). Table 1 provides the safety group classifications.

Table 1. ASHRAE Standards 34 refrigerant ratings

INCREASING FLAMMABILITY	SAFETY GROUP	
Higher Flammability	A3	B3
Flammable	A2	B2
Lower Flammability	A2L	B2L
No Flame Propagation	A1	B1
	Lower Toxicity	Higher Toxicity
	INCREASING TOXICITY	

Table 2 summarizes the common current and future refrigerants identified by this study and their typical applications. The major hurdle for the short-term low-GWP refrigerants is flammability.

Table 2. Study identified HVAC refrigerants by appliance type

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

Research and discussions with HVAC manufacturers present mounting evidence that the transition from high-GWP HFCs like R-410a and R-134a to low-GWP A2L HFCs will not be the last. In other parts of the world, the shift towards natural refrigerants[1]like hydrocarbons, ammonia, and CO2 is well underway. Widespread adoption of natural refrigerants is a key

[1] In 2009, The American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. Board of Directors approved a position document that classifies the following organic and inorganic compounds as natural refrigerants: ammonia, carbon dioxide, hydrocarbons, and water. (Ayub 2011)

milestone needed to meet the full phasedown schedule of the Kigali Amendment HFOs will also be in the mix long-term, but both their cost, high production energy intensity, and lower stability make them slightly less appealing long-term solutions. Undoubtably, the immediate options for California will be A2Ls.

Refrigerant Performance Analysis

This section discusses the results of the performance analysis simulated using the National Institute of Standards and Technology (NIST) CYCLE_D-HX for common high (GWP>750), low (GWP<750) and ultra-low GWP (GWP < 10) refrigerants. Depending on their thermodynamic properties, the COP and unit capacity vary greatly. The charge level is then calculated from the unit capacity of refrigerants.

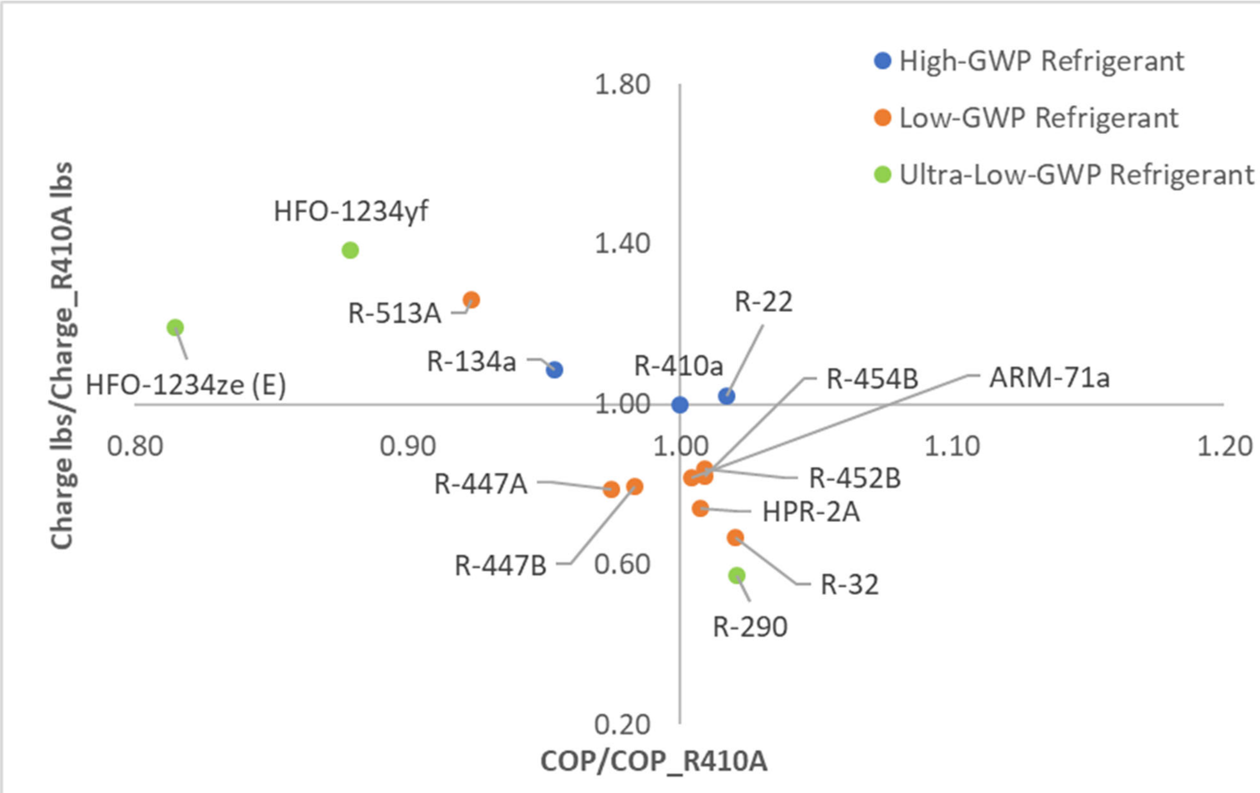
Equation 5. Relative charge-level calculation

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

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

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

Figure 2. Refrigerant performance for Unitary Air Conditioning



It should be noted that in June of 2021, the EPA's SNAP program updated the list of acceptable substances for both retail food refrigeration and light commercial air conditioning and heat pump (new) use. For air conditioners and heat pumps that update included: "R-452B, R-454A, R-454B, R-454C, and R-457A as Acceptable, Subject to Use Conditions…; and R-32 as Acceptable, Subject to Use Conditions, for Use in Residential and Light Commercial Air Conditioning and Heat Pumps—Equipment Other Than Self-Contained Room Air Conditioners, for New Equipment." (EPA SNAP 2022)

Conclusions and Recommendations

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

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

Flammability is the biggest barrier.

Virtually all low-GWP alternative refrigerants with cooling capacity and energy-efficiency performance characteristics similar to refrigerants currently in use are mild to highly flammable. All the HVAC experts we spoke with emphasized the fact that they are not currently permitted to install mildly flammable refrigerants in most common HVAC equipment today. Lab testing performed by one of the experts we interviewed shows that mildly-flammable refrigerants being considered for near-term adoption are only flammable in conditions where high rates of leakage occur in a confined space (Elatar et al. 2018). Mechanical, fire, and building codes are currently being modified to allow for mildly flammable refrigerants given appropriate measures to minimize risk are in place.

Refrigerant transitions take time.

Our secondary research and interviews with HVAC-refrigerant experts revealed an extensive list of national organizations, state and local codes, and other authorities required to approve the use of new refrigerants in the United States. Any increase in flammability or change in toxicity for a refrigerant extends the length of time for its approval. The United States is a safety-focused society relative to some other industrialized countries. For instance, Europe and Asia are already moving quickly ahead in using mildly flammable refrigerants and natural refrigerants (to some degree) in HVAC equipment. The proposed HFC reduction timeline and the recent passing of the American Innovation and Manufacturing Act of 2020 ensures the transition will happen in California and the rest of the United States eventually (EPA HFC 2021).

Figure 3. Web survey: Minimum lead time needed to transition to <750 GWP refrigerants following code finalization

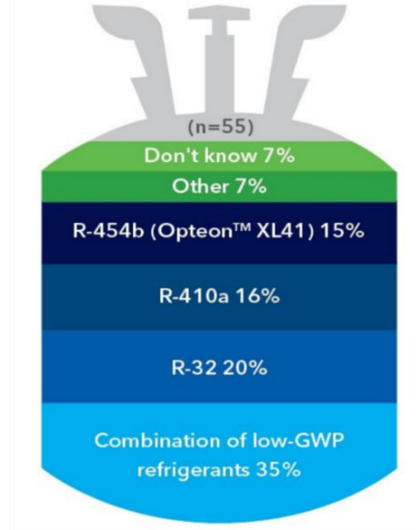
*The distribution presented above does not include the 19% of "don't know" respondents.

The refrigerant evolution continues.

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

Mildly flammable HFCs are the near-term solution.

Figure 4. Web survey: Anticipated most common HVAC refrigerant installed in 2025



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

Promote mildly flammable HFCs in the near-term.

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

Natural refrigerants are the long-term solution.

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

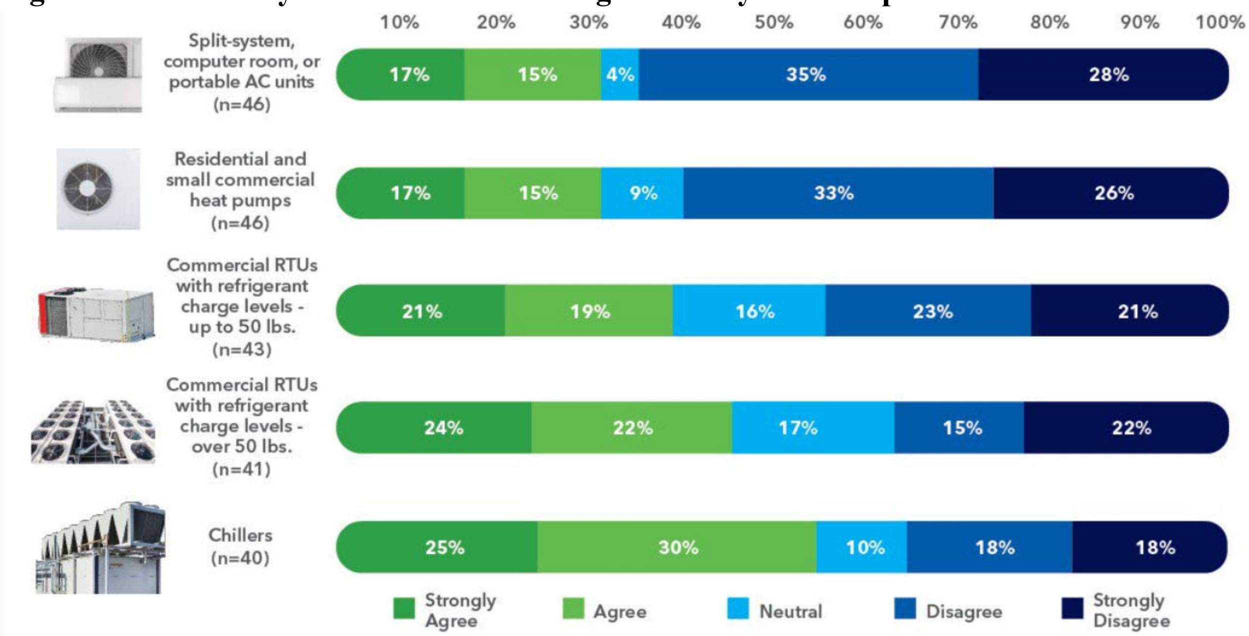
Promote natural refrigerants.

Utility PAs should promote the use of natural refrigerants wherever code permits. Incentives should be directed towards accelerating the use of natural HVAC refrigerants over HFCs and HFOs. We recommend PAs promote natural refrigerants either through emerging technology programs, under custom programs, or in pilot programs. The Sacramento Municipal Utility District (SMUD) and the North American Sustainable Refrigeration Council have both offered incentives to promote the use of natural refrigerants.

Significant barriers limit refrigerant-only retrofits.

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

Figure 5. Web survey: Are <750-GWP refrigerant-only retrofits practical?



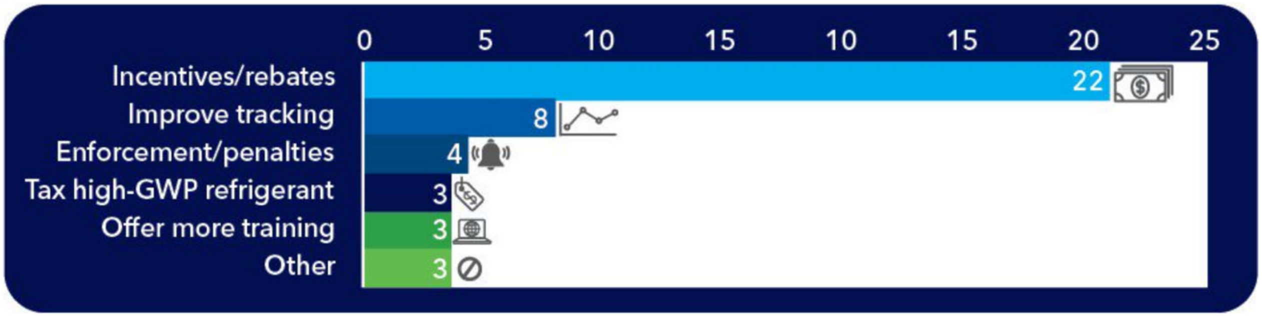
Direct drop-in of the refrigerants only viable for larger HVAC equipment.

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

End-of-life emissions are alarming, yet prohibitions are not enforced.

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

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



Compensate PA program participants that provide documentation of responsible EOL refrigerant recovery.

PAs should consider requiring documentation of responsible end-of-life refrigerant recovery as a prerequisite for any replacement system PA program participant. Providing adequate compensation for program participants who submit documentation proving responsible end-of-life refrigerant recovery would not only reduce emissions, but it will help track end-of-life emission rates and improve future emission estimates.

Refrigerant charge adjustments cause emissions to increase.

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

Stop funding refrigerant charge adjustments.

Utility commissions and energy efficiency regulators should consider discontinuing any HVAC maintenance programs that promote refrigerant charge adjustments. PAs should educate HVAC contractors about the problems associated with pro-active refrigerant charge adjustments and promote best practices for assessing charge levels without tapping refrigerant lines. These methods include checking for dirt buildup, oil spots, abnormal sounds, and temperature measurements to calculate superheat or subcooling.

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