Impact of Decarbonization by Employing Ultra Low GWP (<10) for Unitary Products

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ABSTRACT

Refrigerant and HVAC&R design is a complex balance between Safety (flammability and toxicity), Efficiency, Environment and Equity (SEEE). Equity is a balance of cost and complexity of the HVAC&R design. Global regulatory movements as part of the Montreal protocol and beyond have paved the way for the development and implementation of low GWP refrigerants in air conditioning and heat pumps as well as refrigeration applications.

The current lower GWP refrigerant transition has focused on understanding how to safely apply flammable refrigerants. The SEEE balance has resulted in new lower GWP flammable refrigerants being implemented with most having equal to better thermodynamic efficiency with the safety impacting the equity balance of the equipment with safety standards requiring refrigerant sensors, reduced refrigerant charge (increasing circuiting in some equipment) and more complex controls. Regulators continue to focus on reducing the GWP of refrigerant further beyond Kigali goals or have focus on perceived environmental benefits of natural refrigerant (ammonia, carbon dioxide and hydrocarbons). Unfortunately, further HVAC&R compromises to SEEE (specifically safety, efficiency, and equity) are required to achieve these remaining de minimis climate impacts from refrigerants. An understanding of climate investment factors through the development of a cost-effectiveness or equity benchmark is needed to determine whether technology provides good value for the investment to achieve an equitable SEEE balance.

This paper will provide an updated view and general assessment of low to ultra-low GWP refrigerants and their properties and viability for unitary air conditioning and heat pump applications.

Keywords: Efficiency, Glide, Ultra Low GWP, HFO

INTRODUCTION

The unitary marketplace is by far the largest segment of the heating, ventilation, air conditioning and refrigeration (HVACR) marketplace. Products include both ducted and ductless systems self-contained systems from residential homes, small commercial spaces to large institutional buildings like schools and hospitals. Equipment designs commonly refer to these systems as direct expansion (DX) systems where the refrigerant is present in the occupied space to provide the cooling or heating directly in response to the thermal load. Alternatively, a chilled water system (CHW) or indirect system (IDS) uses a refrigeration system to remove heat or add heat to and from a liquid coolant and then the coolant is circulated to the occupied spaces to satisfy the thermal load. Since CWS are indirect in nature from the load, they can employ numerous refrigerant types and technologies since the heat transfer coolant allows for separation of the refrigerant safety, efficiency, environment and equity (SEEE) requirements and occupied space requirements (Figure 1).

Selecting the right refrigerant for the right application at the right time to meet uncertain regulatory policies to restrict and lower the direct GWP of F-gases would seem to be an insurmountable challenge for manufacturers today. When considering refrigerant alternatives for the future, policy makers, the public and manufacturers must select refrigerants with the best balance of:

- **Safety** for consumers (flammability and toxicity)
- **Efficiency** (indirect environmental impacts), including high ambient operations
- **Environmental** performance (direct environmental impact
- **Equity** (Cost and complexity impacts on industry and consumers)

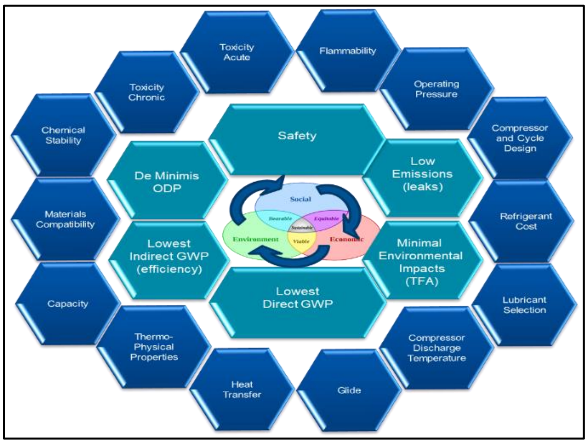

Figure 1. Sustainable refrigerant selection (SEEE) requires best balance of features for the application

The primary refrigerant for unitary products was R-22 prior to the ozone depletion transition and these products were transitioned to R-410A. The transition was not easy for the HVAC industry. While safety (toxicity and flammability) was preserved, energy efficiency and equity were challenges. R-410A is a 50/50 blend of R-32 which is flammable (A2L) per ASHRAE Standard 34 [1] with R-125 which is nonflammable (A1) that results in a low toxicity nonflammable (A1) blend. R-410A is a much higher-pressure refrigerant than R-22 and with the introduction of every increasing energy efficiency standard, resulted in complete redesign of products and the components. New global component supply streams as well as system design knowledge had to be created which required a long time to implement the change to R-410A.

One key to moving forward quickly with a HVACR refrigerant change is to find near design compatible solutions in pressure and capacity while preserving safety. Both R-32 and R-454B are near design compatible for R-410A, unfortunately, they are both flammable (A2L). The industry invested heavily to understand 2L flammability behavior in all HVAC&R applications to move forward with this transition. The good news was although safety was a potential roadblock, the efficiency and equity requirements were preserved while reducing environmental (GWP – global warming potential) impacts of the refrigerant with primary industry adoption of R-32 and R-454B. Even though R-32 and R-454B can provide more than 70% reduction in GWP over R-410A, refrigerant GWP regulation requires a greater than 85% reduction of GWP over R-410A with regional GWP refrigerant regulation that have developed which require greater than 99% reduction in GWP.

NEED FOR <10 GWP UNITARY REFRIGERANTS

Figure 2 summarizes the Kigali Montreal phasedown schedules as well as the newly updated European Union (EU) F-gas and New York State (NYS) phasedown down schedules. Essentially both the EU and NYS phasedown require refrigerants for all applications to be <10 GWP. Additionally, the EU and NYS use different GWP value endpoints as required by Kigali. Kigali's GWP rules require the use of UNEP climate assessment report 4 (AR4) $GWP_{100\ year}$ values while the EU is using $GWP_{100\ year}$ with various climate assessment reports. NYS regulations require the use of $GWP_{20\text{-}year}$ using AR6. All these various GWP endpoints do not allow for HVACR OEMs to understand how to select a refrigerant, components and systems that provides the best balance of SEEE since energy efficiency and equity are big drivers in refrigerant selection. In the end, these regulations point to a range of refrigerant GWPs and HVACR technologies options that would be required by the region of use. Fragmentation in refrigerant regulations has led to large uncertainty in developing countries phase down programs as well which look to developed countries actions and technology adoptions. This paper will try to summarize the various SEEE tradeoffs with available and near-term available refrigerant technologies.

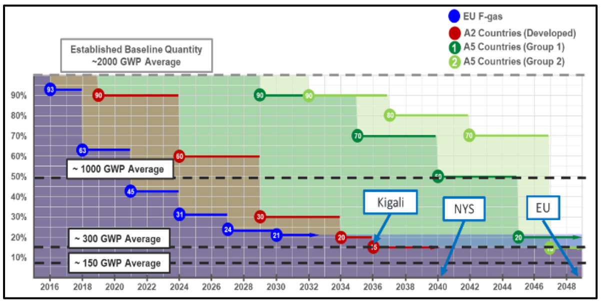

Figure 2. Fluorinated Refrigerant Phasedown Summary

Application	EPA HFC deadline for manufacture/import of equipment for replacement or new installation		NY DEC new HFC regulation for manufacture/import of equipment for replacement or new installation	
	GWP limit	Date (Jan 1)	GWP limit	Date (Jan 1)
Centrifugal chillers *	700	2025	20	2030
Positive displacement chillers *	700	2025	20	2030
Heat pump chillers *	700	2025	20	2034
Residential and light commercial air conditioning and heat pumps	700	2025	10	2034
VRF Systems	700	2026	10	2030
Other residential (not on EPA, defined by NY DEC)	NA	NA	10	2027
Other commercial (not on EPA, defined by NY DEC)	NA	NA	10	2034
Data centers	2690	2026	10	2030

* DEC EPA SNAP rule adoption date on 1-Jan-2024

Figure 3. Fluorinated Refrigerant Phasedown Summary for USEPA and New York State (NYS)

IMPACT OF REFRIGERANTS GWP ON CLIMATE

It is interesting to note that refrigerant GWP is a relative comparison to carbon dioxide (R-744) being equal to 1 but it does not necessarily communicate the impact to heating of the atmosphere. The authors wrote an ASHRAE paper to provide a practical guide to understanding how GWP is calculated, interpreted and impacts climate warming of the atmosphere.[3] Ozone depletion potential (ODP) measures were simpler to understand since all refrigerant ODPs were compared to a high ODP refrigerant (R-11 equal to 1.0 rather than a low GWP gas like R-744. In addition, many chlorinated gases were not included in the Montreal Protocol regulations because their ODPs were considered too low to have a significant impact on the ozone layer. The missing understanding with ODP was that some chlorinated gases had so short of atmospheric life that they could not reach the stratosphere to destroy ozone. Unfortunately, GWP gases are not compared in this manner with being relative to high GWP gas but rather a lower GWP gas like CO_2 which has low infrared absorption potential but has an extremely long atmospheric life (500 to 1000 years). Thus, atmospheric concentration effects over time are not understood easily and thus the use of the GWP is practical when implementing controls. For example, methane (R-50) has a $GWP_{100year}$ per AR4 of 28. First glance would indicate that it is 28 times at heating the atmosphere and it is extremely high, but the atmospheric life of methane is about 12 years vs CO_2 of hundreds of years. If one were to stop methane emissions today, the concentration in the atmosphere would be gone within 20 years versus hundreds of years for CO_2.

The authors also explain that the HFCs GWP phasedown actions are a proactive climate action instead of reactive to immediate climate need. Figure 4 and Figure 5 provide a summary of climate warming by various atmospheric gases as well provide a summary of various HFC phasedown scenarios on climate heating.

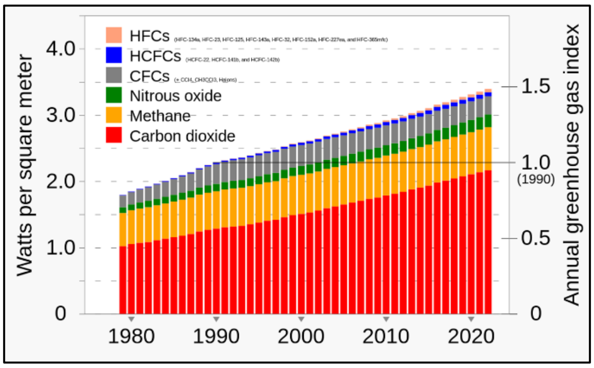

Figure 4. Atmospheric heating by various gases from NOAA [2]

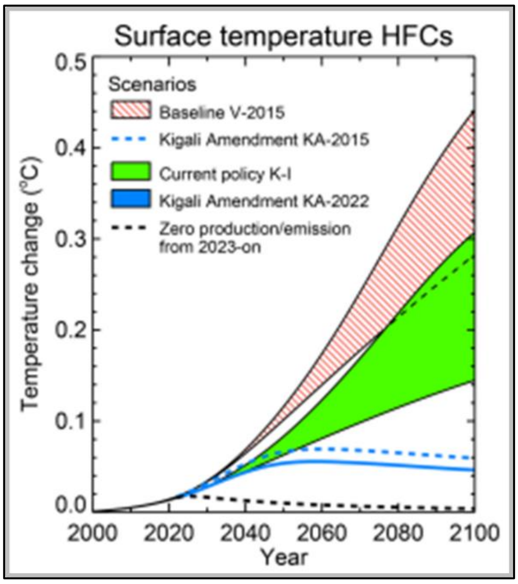

Figure 5. Impact of climate heating by various HFC phasedown programs [4]

Figure 4 shows that HFCs currently only account for less than 2% of the radiative heating while CO_2 accounts for more than 50%. It is well known that indirect emissions due to energy consumption to power HVAC&R systems and thus emissions of CO_2 account for more than 90% of climate heating impacts today. Thus, energy efficiency plays the most critical role in reducing the climate impacts from the use of HVACR equipment. Figure 5 shows that if no HFC phasedown actions were taken, HFC would account for about 0.45°C in the late 21st century. Today, HFCs currently account for less than 0.02°C of atmospheric heating. Kigali HFC phasedown actions keep refrigerants contributions essentially equal to current levels of atmospheric heating. This study also questions whether further actions are needed to reduce the GWP beyond 85% phasedown goal. Energy efficiency is the primary measure that should be leveraged to continue to reduce the climate impact.

Understanding energy efficiency impacts from refrigerant choices can be difficult to understand but what is more complicated is the impact and importance of these refrigerant choices on equity for consumers which impact the equipment cost but more importantly the electric grid.

LESS THAN 10 GWP UNITARY REFRIGERANTS

Table 1 summarizes less than 10 GWP fluorinated and hydrocarbon refrigerant options with appropriate pressures, capacities (about >35% of R-454B) and critical temperatures for use with unitary DX systems regardless of safety or system design restrictions, like capacity, chemical stability or materials compatibility. Each refrigerant is compared back to R-454B as a baseline refrigerant for capacity based on displacement per unit of capacity. Also included are some A2L blends with <10 GWPs which are appropriate for use in DX systems. A simple thermodynamic model was developed to obtain the below summary at conditions of 4.4°C evaporator/46.1° condenser with 5.6K suction superheat, 8.3 subcooling at 0.7 isentropic compressor efficiency with midpoint conditions considered in the evaporator and condenser.
Comparison of efficiency is not evaluated here as well since many of the refrigerants require use in a CWS versus a DX application, e.g. all hydrocarbons and R-717. Some refrigerants, like R-717, require materials changes, e.g. no copper or refrigerants like R-1132(E) require blending to chemically stabilize the refrigerant, e.g. R-474A or R-474B.

Table 1. Investigated fluids with GWP<10 in order of increasing normal boiling point temperature (Capacity R-454B = 1.0)

Refrigerant [-]	**Capacity *Rel to R-454B**	**Safety**	**T_{crit} [°C]**	**NBP [°C]**
R-1132(E)	1.03	B2	75.7	-52.6
R-1270	0.73	A3	91.1	-47.6
R-474B	0.67	A2L	85.4	-45.8
R-474A	0.61	A2L	87.9	-43.5
R-290	0.60	A3	96.7	-42.1
R-717	0.79	B2L	132.4	-33.3
R-1234yf	0.43	A2L	94.7	-29.5
R-1234ze(E)	0.34	A2L	109.4	-19.0

IMPACT ON ENERGY EFFICIENCY

Trane Technologies undertook a study with the Western Cooling Efficiency Center (WCEC) at University California Davis to understand the impact on the electrical grid of choosing a DX versus CWS in all United States climate zones by electric grid service areas. The paper will provide a high-level look at the results of this work since the work is still underway and unpublished and the limits of this publication.
Many <10 GWP refrigerants flammability or toxicity safety requires them to be in a CWS versus a DX system configuration. For example, R-290 has well qualified indoor refrigerant charge limits for use in a DX system which requires use in a CWS above a few hundred grams. A few hundred grams of R-290 can provide a few kilowatts of cooling capacity per circuit. Larger R-290 refrigerant charges are allowed in CWS in some places in

the world by standards. In the EU, up to 10 kilograms of R-290 is allowed which enables the delivery of 10's to 100's kilowatts of thermal capacity.

The baseline refrigerants and system selected were an R-454B DX system meeting the minimum efficiency requirements compared to an R-454C DX and R-290 CWS configurations. R-454C was chosen as a surrogate to R-474B to understand the impact of glide. Figure 6 below shows a comparison of the impact of glide on efficiency. A detailed efficiency versus ambient model was developed for each refrigerant at the required application capacities. A system model was developed using a detailed system model across various ambients. These models were calibrated using internal and external testing data to ensure their relative accuracy and precision. These models also included heating as well as cooling use.

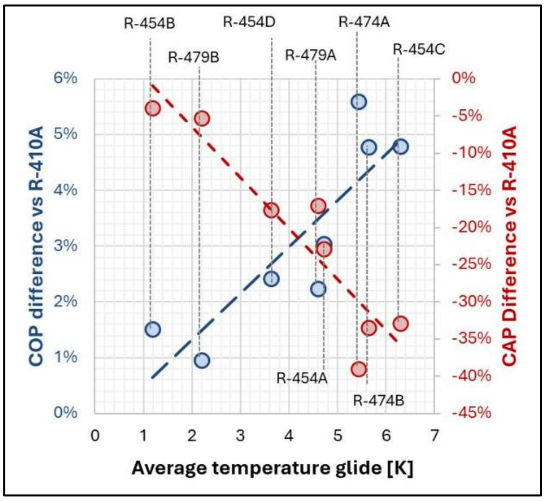

Figure 6. Impact of temperature glide on COP and Capacity for various refrigerant options

	R290 30% PG	R290 40% PG
R454B	12%	13%
R454C	6%	7%

Figure 7. Summary of Western Cooling Efficiency Center energy use findings comparing R-454B DX, R-454C DX to R-290 CWS [5]

Not surprisingly, a R-290 CWS heat pump uses more than10% more energy than a traditional R-454B DX system. Most of this increased energy use is the result of deploying a secondary heat exchanger and losses associated with freeze protection requirements during heating season, e.g. polyethylene glycol (PG) /water for secondary heat transfer fluid. The heat transfer fluid pump also accounts for some additional impacts.

CONCLUSIONS

Recently updated HFC phasedown schedules by the European Union and New York State have challenged the conventional environmental wisdom of the Kigali amendment and the impacts of direct refrigerant emissions to atmospheric heating and climate change. The Kigali amendments goals were to restrict HFC GWP emissions by 85% through limiting refrigerant GWP which results in bringing HFCs impacts to de minimis levels that are measurable of less than 0.05°C temperature increase. EU and NYS goals are to further reduce HFCs emissions impacts without consideration of balancing other climate impacts like efficiency and equitable cost of equipment and those environmental impacts.

This paper provides a SEEE investigation of deploying various less than 10 GWP refrigerants in appropriate applications, DX vs CWS, to allow for meeting safety requirements while understanding the energy efficiency impacts. Equity was not discussed by it can be inferred with the complexity of CWS vs DX systems.

The investigation revealed that a R-290 CWS will use 12-13% more energy compared to a DX system using R-454B. R-454C was used as a surrogate for R-474B performance since they both have similar efficiency, capacity and glide. Higher glide blends will result in more energy use on the order of 6-7% and R-474B would have similar performance to R-454C. Regulators should consider refrigerant technology options and their impacts on efficiency before considering global warming targets.

NOMENCLATURE

COP : *Coefficient of Performance*
CAP : *Capacity*
GWP : Global Warming Potential
SEEE : Safety Efficiency Environment Equity

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