

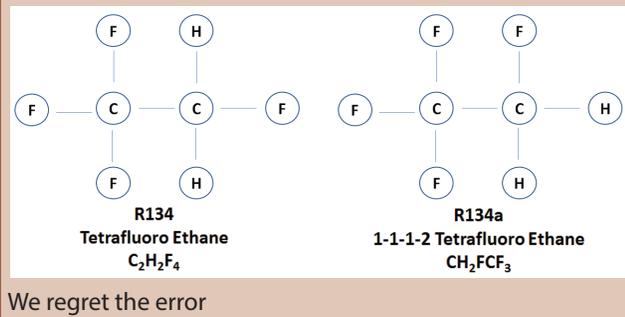
Refrigerant Evolution over a Hundred Years:

Part 3

By K Raghavan

Corrigendum

In Part 2 of this article published in the January-February 2023 issue of the *Journal*, Figure 6 on page 64 was incompletely printed. The complete figure is given below.



HCFC Phase-Out and HFC High-GWP Phase-Down

The next decade for HVACR industry is anticipated to be very challenging with HCFC phase-out and HFC high-GWP fluids' phase-down approaching fast and the difficulty in finding A1-classified, low-GWP alternative refrigerants for different applications. The industry faces many questions: will there be a large proliferation of alternative refrigerants across applications and segments, how do we manage the safety aspects, how efficient and safe are the new Hydro Fluoro Olefins (HFO) alternatives, etc. In this concluding Part 3 of this article series, we will deliberate on the technical aspects of the alternative candidates' safety and performance.

Part 2 of this article published in the January-February issue of the *Journal* described how the Kyoto protocol made it imperative to identify very low-GWP alternatives, even for zero ODP HFC refrigerants. For each of the HFC refrigerants like HFC134a, HFC407C and HFC410A in various applications, there is no like-to-like very low-GWP replacement available with A1 safety classification and equivalent performance. The research work that started in 1990s primarily revolved around working on unsaturated organic compounds, which are HFO fluids, and figuring out the best combination of

About the Author

K Raghavan is a mechanical engineer with 34 years' experience in HVACR field. The views expressed in this article are his own, drawing from his experience. He was a member of ISHRAE Refrigerants Committee, which came out with a Position Paper on Alternate Refrigerants in 2015-16. He was a HIDECOR trainer over 2002-06 to train SMEs on implementing CFC transition in the field. He also contributed to updating the Refrigerant chapter of the text book by Shri P N Ananthanarayanan, revised and published by ISHRAE in 2014.

different mixtures of HFC and HFO. We had earlier discussed about the chemical structure of HFC and HC fluids. Let us now understand the chemical structure of HFO before proceeding further.

What is HFO?

HFO molecular structure consists of hydrogen, fluorine and carbon atoms and has at least one double bond between carbon atoms. Because of the double-bond structure, they are referred as unsaturated. The chemical engineering terminology refers to unsaturated hydrocarbons as Olefin or alkene* and that is how we refer these fluids as HFO to distinguish them from a standard HFC fluid, which has hydrogen, fluorine and carbon atoms connected in a stable, single-bond structure. HFO is also referred as unsaturated HFC. Though in general terms HFC is known as a Greenhouse Gas (GHG), the HFO poses no concern as a GHG due its incredibly low and negligible atmospheric life. This is because of its unstable structure. The disadvantage of its unstable structure is that usually they tend to be flammable.

(*alkane is different from alkene; please refer chemistry handbooks for more details).

Figure 1 illustrates how propene, a HFO, gets fluorinated to derive HFO1234yf (R1234yf). The refrigerant number designation is consistent across all family of refrigerants as per ASHRAE standard 34, including the HFO series. (Please refer Part-1 of this series for more details). The suffix 'yf' written in small letters indicates that this is an isomer. (Refer Part 2 for what is an isomer). Figure 2 illustrates how the HFO isomers 1234yf and 1234ze are structurally different, though having same chemical composition – Tetra Fluoro Propene. With a view to reducing direct emissions from Mobile Air Conditioning (MAC) systems, an EU Directive (2006/40/EC) made it mandatory to use refrigerants with a GWP of <150. Only on complying with this directive, the car manufacturers were to get type approvals for market access to entire EU. (Note: In MAC, with open drive compressors and hose connections, the risk of refrigerant leakages is considerably higher than with stationary systems). Along with CO_2 , HFO-1234yf was one of the prominent low-GWP alternative refrigerants, announced more than 20 years ago for the system performance and safety evaluation and got a wide attention. This fluid is the outcome of one of the rare joint R&D programs undertaken by refrigerant majors DuPont and Honeywell, as a low-GWP

substitute for HFC134a in automobile air conditioning.

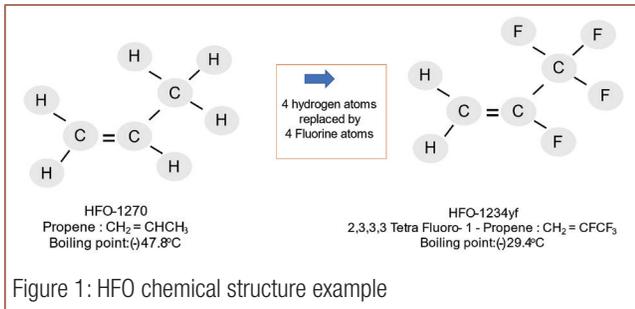


Figure 1: HFO chemical structure example

Table 1: Hot cell ventilation system details

	HFC134a	HFO-1234yf
Chemical formula	CH_2FCF_3	$\text{CH}_2 = \text{CFCF}_3$
Chemical name	1,1,1,2 – Tetrafluoroethane	2,3,3,3 Tetra Fluoro - 1 - Propene
Molecular mass	102	114
Atmospheric boiling point	(-)26.1°C	(-)29.4°C
Safety group	A1	A2L
Atmospheric lifetime	14 years	0.029 years (11 days)
ODP	0.00	0.00
GWP ₁₀₀	1430	<1
Evaporator pressure	54.7 Psia (3.77 bar)	58.1 Psia (4.00 bar)
Condenser pressure	114.7 Psia (7.91 bar)	113.6 Psia (7.83 bar)
Net Refrigerating effect	69.2 Btu/lb (160.96 KJ/Kg)	55.5 Btu/lb (129.09 KJ/Kg)
Mass flow rate	2.89 lb/min (1.31 Kg/min)	3.61 lb/min (1.64 Kg/min)
Compressor displacement	2.51 ft ³ /min (4.27 m ³ /hr)	2.62 ft ³ /min (4.45 m ³ /hr)
Power consumption	0.433 HP (323 W)	0.444 HP (331 W)
COP	10.903 Btu/W (3.2 W/W)	10.623 Btu/W (3.11 W/W)
Discharge temperature	90.6°F (32.6°C)	86°F (30°C)

Conditions: Evp temp: 45F, Cond temp: 86F, Superheat and subcooling are zero, no line losses, 100% efficiencies.

Source: ASHRAE 2021 Fundamentals, Chapter 29.9, Table-8

For about seven to eight years now, many non-A5 countries car AC systems have been using HFO1234yf in place of HFC134a. *Table 1* gives a comparison of theoretical cycle performance between HFC134a and HFO1234yf in AC application. Except for the marginal increase in compressor displacement, all other system performance parameters are very close to HFC134a parameters. This makes the design switch over from HFC134a lot easier, compared to re-designing the system for adopting high pressure CO₂

system. The key benefits offered by HFO1234yf are the <1* GWP and atmospheric life of just 11 days. The safety classification for this fluid is A2L mildly flammable.

(*As per AR5 report GWP₁₀₀, some prior dated documents do refer HFO1234yf GWP as 4).

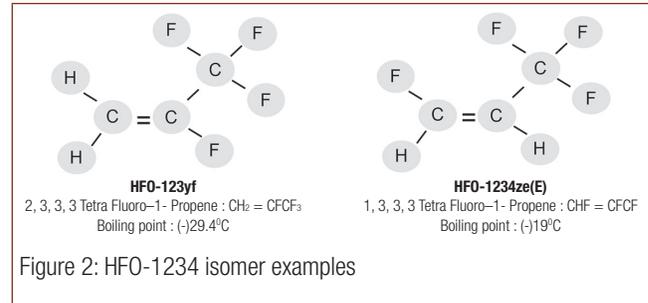


Figure 2: HFO-1234 isomer examples

Table 2: Popular HFO refrigerant properties

	HFO-1234yf	HFO-1234ze(E)	HCFO-1233zd(E)
Chemical formula	$\text{CH}_2 = \text{CFCF}_3$	$\text{CHF} = \text{CHCF}_3$	$\text{CHCl} = \text{CHCF}_3$
Chemical name	2,3,3,3 Tetra Fluoro - 1 - Propene	1,3,3,3 - Tetra Fluoro - 1 - Propene	1 chloro- 3,3,3 - Trifluoro - 1 - Propene
Molecular mass	114	114	130.5
Atmospheric boiling point	(-)29.4°C	(-)19°C	17.8°C
Safety group	A2L	A2L	A1
Atmospheric lifetime	0.029 years (11 days)	0.045 years (17 days)	0.071 years (26 days)
ODP	0.00	0.00	0.00034
GWP100	<1	<1	1

Other well-known refrigerants, which have been recently adopted in ACR systems are HFO1234ze(E) and HCFO1233zd(E). Refer *Table 2*. HFO1234ze(E) has been used predominantly as a blowing agent for polyurethane foam and as a propellant. Its favourable thermodynamic properties and very low GWP value provided an opportunity to try it as a refrigerant. A word of caution is about its flammability rating. In *Material Safety Data Sheet (MSDS)*, HFO1234ze(E) is declared as non-flammable. However, this only applies to transport and storage while being used as a blowing agent. If it is used as a refrigerant, a higher reference temperature of 60°C for flammability tests becomes valid and hence, it is classified in the moderately flammable group A2L similar to HFO1234yf.

HFO1234ze(E) boiling point (-18°C) considerably limits its use in lower evaporating temperature application. Its volumetric refrigerating capacity is about 20% below that of HFC134a or HFO1234yf. It is being evaluated in high temperature applications as a low-GWP solution.

Table 3: A few examples of HFO blends

	Fluid designation	Components of blend	Normal Bubble point	GWP	Safety group
1.	R445A	R744 / 134a / 1234ze(E) 6% : 9% : 85%	(-)50.3°C	146	A2L
2.	R447A	R125 / R1234ze(E) / 32 3.5% : 28.5% : 68%	(-)49.3°C	572	A2L
3.	R449A	R32 / 125 / 1234yf / 134 24.3% : 24.7% : 25.3% : 25.7%	(-)46°C	1397	A1
4.	R449B	R32 / 125 / 1234yf / 134 25.2% : 24.3% : 23.2% : 27.3%	(-)46.1°C	1410	A1
5.	R453A	R32/125/134a/227ea/600/601a 20%:20%:53.8%:5%:0.6%:0.6%	(-)42.2°C	1765	A1

HFOs also find prominent use as one of the components of HFC-HFO blends being tried out in different HVACR applications. *Table 3* gives few examples of HFO being used as one of the components in low-GWP HFO-HFC blends. Please pay attention to the presence of components HFC134a, HFO1234yf and HFO1234ze(E), HFC32, HFC125 and HFC152a, their respective ratios and how the proportion of individual components help to achieve either A1 safety classification or low-GWP with A2L rating for the resultant blend refrigerant.

In *Table 1*, we observed that HFO1234yf requires slightly higher displacement than HFC134a to produce equivalent capacity. This is referred as lower volumetric capacity. Use of HFC32 helps to increase the volumetric capacity. Presence of HFO and further adding HFC32 in higher proportion increases the flammability of the blend. To neutralize this effect, refrigerants like R125 with high fluorine content is added. Depending on which fluid is added in what proportion, most of the times, we end up getting low-GWP blends like 445A and 447A (refer *Table 3*) but they end up with A2L rating. When lowering the proportions of HFO and HFC32, the resultant blends like 449A, 449B, 453A etc. (*Table 3*) become safe and get A1 rating but their GWP increases to moderate or higher range.

One more interesting technical characteristics of the resultant blend is the final glide it ends up having due to the different components having different boiling temperatures. Usually blends having very low-GWP with more components end up having a noticeable glide. Blends with <1K glide are referred as near-azeotrope or semi-azeotrope.

These very low-GWP fluid developmental experiments by refrigerant manufacturers have been going on for a long time now. Some of them have been submitted to ASHRAE committee for refrigerant number designation and have got the numbers designated, but many fluids are still being tried out at manufacturers' level.

Europe's F-gas Regulation

When it comes to environment protection, Europe has always been at the forefront, leading the transformation. Europe pursues policies to be ahead of the globally binding HCFC phase-out and HFC phase-down schedules applicable

for non-A5 countries. Its Fluorinated Greenhouse Gases regulation, popularly known as F-Gas Regulations are more stringent on the HCFC and HFC phase-out and phase-down schedules and require the industry to find alternative solutions quickly to meet timelines. Refer *Table 4* for the new ban on HVACR units to push the industry to low-GWP fluids. F-gas Regulations are quite comprehensive and include measures like rules on containment, use, recovery and destruction of fluorinated greenhouse gases.

Table 4: F-gas 517/2014 GWP limits for new appliance and service

Placing on the market (New Equipment) Ban	GWP Limit	Effective Date
Refrigeration and freezers for commercial use (hermetic system)	2,500	Jan 2020
Refrigeration and freezers for Residential use (hermetic system)	150	Jan 2022
Centralized commercial refrigeration systems of > 40KW ⁽¹⁾	150	Jan 2022
Movable Room Air conditioners	150	Jan 2020
Single Split AC system containing < 3 Kg	750	Jan 2025
Service & Maintenance ban for all HFC systems	2,500	Jan 2020

(1) In Cascade system, Fluorinated GHG of <1500 GWP may be used on the High side.

We discussed about the development of HFO1234yf for MAC due to the stringent EU Directive (2006/40/EC). The current F-gas Regulations in force are 517/2014. In April 2022, the EU commission has made a legislative proposal to update 517/2014 and this is currently being negotiated by the EU Parliament and the commission.

Low GWP Alternatives Timeline

Table 5: Kigali Amendment: Phase-down schedule for HFCs in Article 5 and non-Article 5 parties

Baseline and phase-down as CO ₂ e	A5 parties (developing countries) – Group 1	A5 parties (developing countries) – Group 2	Non-A5 parties (developed countries)
Baseline formula	Average HFC consumption for 2020-2022 + 65% of HCFC baseline	Average HFC consumption for 2024-2026 + 65% of HCFC baseline	Average HFC consumption for 2011-2013 + 15% of HCFC baseline*
Freeze	2024	2028	–
1 st step	2029 – 10%	2032 – 10%	2019 – 10%
2 nd step	2035 – 30%	2037 – 20%	2024 – 40%
3 rd step	2040 – 50%	2042 – 30%	2029 – 70%
4 th step	–	–	2034 – 80%
Plateau	2045 – 80%	2047 – 85%	2036 – 85%

Notes:

* For Belarus, Russian Federation, Kazakhstan, Tajikistan, Uzbekistan, 25% HCFC component of baseline and different initial two steps (1) 5% reduction in 2020 and (2) 35% reduction in 2025

1. Group 1: Article 5 parties not part of Group
2. Group 2: Countries with High Ambient Temperatures (HAT): Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates
3. Technology review in 2022 and every five years
4. Technology review four to five years before 2028 to consider the compliance deferral of two years from the freeze of 2028 of Article 5 Group 2 to address growth in relevant sectors above certain threshold.

Table 5 illustrates the HFC phase-down schedule as per the Kigali amendment. We regularly come across information regarding negotiations among global leaders and emission targets agreed by different countries in global conferences. Some of these global forums of interest and relevance (to HVACR industry) are briefly described below.

COP Conferences

United Nations Framework Convention on Climate Change (UNFCCC) conducts an annual conference of countries that signed the original UN climate agreement in 1992. In subsequent years, many other countries also have been invited to these conferences as observers. Refer Figure 3. The key objectives of these annual events referred as Conference of Parties (COP) are to review the progress in dealing with climate change and to negotiate the Kyoto protocol to establish legally binding obligations for countries to reduce their greenhouse gas emissions. The first UN Climate Change Conference was held in 1995 in Berlin (COP-1) and the latest COP-27 in November 2022 in Egypt.

the Paris Agreement recognized that climate change is a shared problem and called on all countries to set emissions targets.

Each of the COP conferences attempts to evolve a consensus among participating countries and comes out with a final draft of a forward-looking nature. A lot of information and reports are available on <https://unfccc.int/>. The COP conferences dwell on various aspects like funding, technology transfer, research on renewable energy, commitment to emission reduction, review of timeline etc. Though the goal is to limit the global warming to <1.5°C above pre-industrial level by 2030, the plans and emission cut commitments of developed and developing countries are still above 2°C level as of now. From the HVACR industry perspective, we could anticipate the potential likelihood of the timeline for the phase-out or phase-down of some of the chemicals being brought forward.

Kigali Amendment to Montreal Protocol: Phase down of HFCs

The Montreal Protocol (refer Part-2 article for details) underwent a revision and amendment at Kigali (capital city of Rwanda, an African country) in 2016 and came into force in 2019. This focuses on phase-down schedule of HFCs and is projected to reduce future global average warming in 2100 due to HFCs from a baseline of 0.3-0.5°C to less than 0.1°C. Though the contribution of HFC as a percentage to overall global warming may be very low just now, two key factors go against HFC gases:

1. HFC has inherent characteristic of filtering infrared waves and hence, can trap heat to the extent of hundreds or thousands time more than CO₂. Refer Table 6.
2. Many developing countries are economically growing very fast and are expected to consume very high levels of the incumbent HFC in ACR systems, over the next one or two decades.

Table 6: CO₂ equivalent weight of HFC (on emission)

Refrigerant	5 ton CO ₂ -eq.	10 ton CO ₂ -eq.	50 ton CO ₂ -eq.	500 ton CO ₂ -eq.
HFC32	7.41 Kg	14.82 Kg	74.07 Kg	740.74 Kg
HFC134a	3.50 Kg	7.00 Kg	34.97 Kg	349.65 Kg
HFC404A	1.27 Kg	2.54 Kg	12.75 Kg	127.49 Kg
HFC407C	2.82 Kg	5.64 Kg	28.18 Kg	281.85 Kg
HFC410A	2.39 Kg	4.78 Kg	23.95 Kg	239.46 Kg

Credit: AREA Guidelines

HFC emissions are projected to peak before 2040 and decline to less than 1 Gt CO₂-eq/year by 2100 similar to the emissions in 2016 (0.88 GtCO₂-eq/year). HFOs and HCFOs are not included in the Kigali Amendment.

One of the key features of the Kigali Amendment is that countries are expected to work towards ensuring global industry standards to enable the safe introduction of low-GWP alternatives to HFCs and to maximize energy efficiency in the

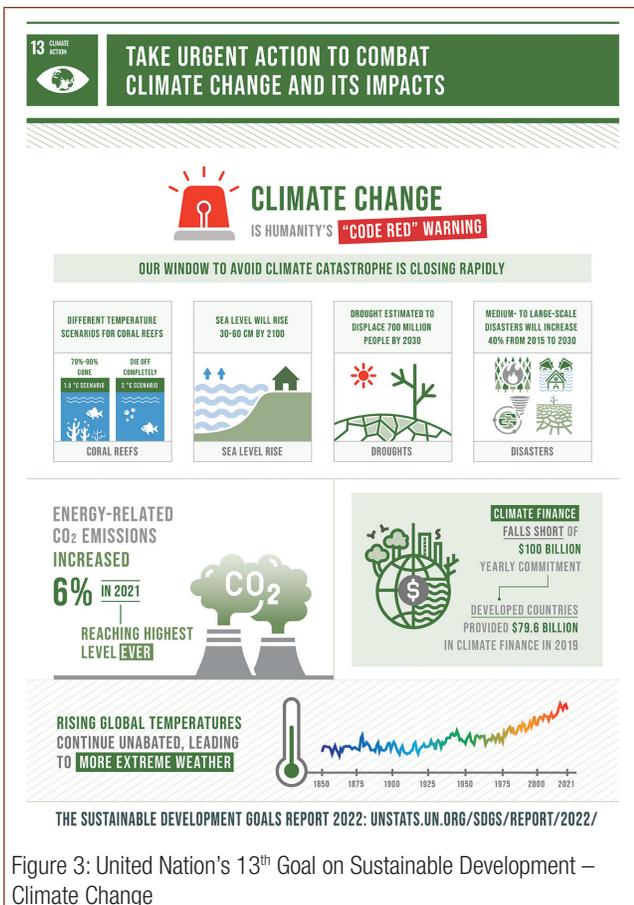


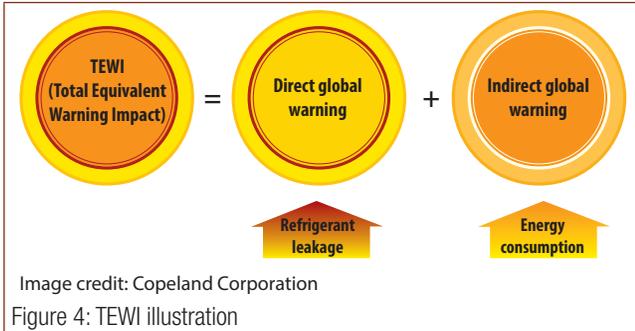
Figure 3: United Nation’s 13th Goal on Sustainable Development – Climate Change

It is of interest to note that the Kyoto protocol was adopted in COP-3 at Kyoto, Japan in 1997. The 2015 COP-21 Paris agreement with legally binding treaty on countries, has effectively replaced the Kyoto Protocol. The Kyoto Protocol required only developed countries to reduce emissions while

transition out of HFCs. Improvements in energy efficiency in ACR equipment can potentially double the climate benefits of the HFC phase-down during the transition to low-GWP alternative refrigerants. At this stage, let us review the two terms regularly used by the industry on this point.

TEWI and LCCP

Total Equivalent Warming Impact (TEWI) is the sum of direct refrigerant emissions expressed in terms of CO₂ equivalents and indirect emissions of CO₂ from the system's energy use over its service life. Refer Figure 4. For every 1W of energy consumed by the equipment, the total energy produced at the power generation station is 2-3W by considering all the inefficiencies in generation, transmission and distribution. Globally, a large proportion of power generation is happening by burning fossil fuel (coal), which is one of the major sources of CO₂ emission into atmosphere. Hence, every 1W of energy saved in equipment helps to save 2-3W power generation related CO₂ emissions at power plant level. The term TEWI focuses on this concept. Another often-cited terminology is Life Cycle Climate Performance (LCCP), which includes TEWI and adds direct and indirect emissions effects associated with manufacturing the refrigerant and end-of-life disposal.



Whenever these terms were used as a justification to delay introducing low-GWP fluid, no governments or any organization like UNEP, UNFCCC etc. have recognized and accepted this concept as there is a clear-cut mandate to phase-out or phase-down certain chemicals, which is non-negotiable. Energy efficiency improvement technologies and further research and cooperation on these measures are targeted by Kigali amendment as an add-on to further enhance and keep in check the <1.5°C temperature rise target.

AREP and SNAP Programs

Research work coordination on finding suitable refrigerant alternatives with the involvement of refrigerant manufacturers, compressor manufacturers, OEMs, safety agencies and safety standard committees, etc. are being spearheaded by AHRI and EPA through dedicated program teams. These program details are very briefly narrated below. A lot of useful information is available on their websites.

The AHRI low-GWP Alternative Refrigerants Evaluation Program (AREP) includes compressor calorimeter testing, system drop-in testing, soft-optimized system testing, and heat transfer testing. All tests other than heat transfer coefficient measurements are expected to be performed at participating companies' laboratories using their own resources at their own expense. The low-GWP AREP program is managed by a technical committee reporting to the AHRI Executive Committee. The AHRI Research Department administers the low-GWP AREP program and coordinates and disseminates information and reports among the participating companies and the observers.

The US Environmental Protection Agency's (EPA) Significant New Alternatives Policy (SNAP) program implements section 612 of the amended Clean Air Act of 1990 of the USA, which requires EPA to evaluate substitutes for the ozone-depleting substances to reduce overall risk to human health and the environment. Through these evaluations, SNAP generates lists of acceptable and unacceptable substitutes for each of the major industrial use sectors. The intended effect of the SNAP program is to promote a smooth transition to safer alternatives.

Emerging Alternative Refrigerant Trends

The AREP and SNAP program reports available to public give a lot of information on the status of emerging alternative refrigerant trends. As the F-gas Regulation on HFC phase-down has already kicked-in, many MNC brands have started offering solutions to meet the F-gas timeline. Let us briefly review these solutions.

Refrigeration

Table 7: Commercial refrigeration alternates – Global use status – EPA SNAP report

Refrigerant	GWP ^b	Stand-alone Systems ^{c,d}	Remote Condensing Units ^{c,d}	Multiplex Rack Systems ^{c,d}
R-449A	1,400	◆+ ^a	◆+	◆+
R-449B	1,412	◆+ ^a	◆+	◆+
R-448A	1,387	◆+ ^a	◆+	◆+
HFC-32	675		□	□
R-513A	630	□+	◆+	◆+
R-450A	601	□+	◆+	◆+
R-447A	583		□	
R-446A	461		□	
R-451B	164	□	□	□
R-451A	149	□	□	□
HFO-1234ze(E)	6	□	□	
R-441A	<5	◆+ ^a	□	□
HFO-1234yf	4	□	□	
R-600a (isobutane)	3	◆+ ^a	◆	
R-290 (propane)	3	◆+ ^a	◆	□
R-744 (CO ₂)	1	◆+	◆+	◆+
R-717 (ammonia)	0			◆+

^a ◆ = Available now; □ = Under Development; + = U.S. EPA SNAP-approved

^b GWP values are from IPCC Fourth Assessment Report (2007) and U.S. EPA (2015c).

Residential refrigerators and freezers have comfortably shifted to hydrocarbons like HC600a. Small capacity commercial refrigeration units like beverage vending units and freezers use HC290, CO₂ etc. For a long time, safety

standards like UL had limited the HC refrigerant charge quantity to not more than 150 grams. In 2021, UL approved the second edition of its UL 60335-2-89 standard, allowing up to 300 grams of HC charge in appliances with closed door and 500 grams in display refrigeration cases without doors. A2L rated HFC blends have different LFL limits. Applying the amended 60335-2-89 standard, the gas charge limits for A2L refrigerants have gone up in closed door, open-door and remote condensing unit refrigeration units.

Table 8: Commercial Refrigeration characteristics – EPA SNAP report

Equipment	Capacity (kW)	Refrigerant Charge (kg)	Annual Operational Leak Rate (%)
Stand-Alone or Self-Contained Systems	0.1 to 1	0.1 to 2	< 1%
Remote Condensing Unit Systems	0.1 to 20	1 to 20	5 to 20%
Multiplex Rack Systems	40 to > 200	20 to 3,000	10 to 35%

Sources: IPCC (2005); TEAP (2013); TEAP (2014); UNEP (2015a); UNEP (2015b)

HFC404A can no longer be used under F-gas regulation in EU in commercial and supermarket refrigeration units including for service. Only alternatives with <2500 GWP are allowed. Table 7, an extract from EPA SNAP report, gives the alternatives that are already in use (HFC/HFO blends 448A, 449A, etc.) and new fluids that are being considered (HFC/HFO blends 450A, 451A, etc.). A few manufacturers are testing HFC32, HFO1234yf etc. also in commercial refrigeration. Over next few years, the choice may get narrowed down to a selected few rather than the whole proliferation that we see currently. Selection of UNEP SNAP report also gives information on the gas charge quantity range for different capacity equipment and the annual leakage rate from industry experience. Referring to Table 8, readers may get an idea of CO₂ equivalent emissions that could be avoided by switching from HFC404A with a GWP of 3,920 to alternatives having much lower GWP.

Air-Conditioning and Chiller Systems

Table 9: Air conditioning and chiller system alternates – EPA SNAP report

Refrigerant	GWP ^b	Small Self-Contained AC ^c	Small Split AC ^c	Single & Multi-Split AC (Large) ^c	VRF (Large) ^c	Ducted Systems (Large) ^c	Chillers ^d
HFC-32	675	◆+	◆	◆	◆	◆	□
R-513A	630						◆+
R-450A	601						◆+
HFO-1336mzz(Z)	9						□+
HFO-1234ze(E)	6					□	◆+
R-441A	<5	◆+					
Solstice™ 1233zd(E)	4.7 - 7						◆+ ^d
HFO-1234yf	4					□	
R-290	3	◆+	◆				◆
R-744 (CO ₂)	1					◆	◆
R-717 (ammonia)	0						◆+

Note: R-448B, R-448A, R-447A, and R-718 are currently under development for use in various residential and commercial AC applications.
 ◆ = Available now; □ = Under Development; + = U.S. EPA SNAP-approved
^a GWP values are from IPCC Fourth Assessment Report (2007) and U.S. EPA (2015c).
^b UNEP (2015a - e).
^d U.S. EPA SNAP-approved for centrifugal chillers only.

In window and split air conditioners, HFC32 has emerged as a strong candidate. This helps A5 countries to phase-out HCFC22 a little ahead of the schedule and non-A5 countries to substitute the incumbent HFC410A with HFC32. All the

major rotary compressor manufacturers in Asia have adopted HFC32 in inverter and non-inverter room AC compressor models, helping the appliance manufacturers to comply with timelines. HC290 is also present in window AC and smaller capacity split AC of some brands.

In ducted, packaged and data center AC segment, appliances using HFC410A could comfortably switch over to HFC32 where the system pressures are in similar range and the slightly higher discharge temperatures of HFC32 are suitably managed by appropriate design measures by compressor and system manufacturers. This segment uses only scroll compressors. Major American and European scroll manufacturers have HFC32 range of scrolls; but continue to explore performance of further lower GWP fluid designs. Very few AC manufacturers, who persisted with HFC407C, without switching to HFC410A two decades ago, do not have equivalent pressure low-GWP fluid yet. This small group also may move to HFC32 or further lower GWP HFC-blends. USA and EU compressor and appliance manufacturers, though they have HFC32 range of products, are also evaluating various moderate and low-GWP fluids like HFO and HFC/HFO blends. Table 9 gives an extract of UNEP SNAP report on these alternatives being tried out.

VRF, an Asian innovative AC technology, has made very successful inroads over the last two decades in USA, EU and other developed regions. This system design based on inverter rotary and scroll compressors from the Asian majors has already adopted HFC32 as the low-GWP solution. Unless a very low-GWP HFC/HFO blend emerges with A1 safety classification and equivalent or better performance than HFC32 with a compelling reason, this segment may stay with HFC32 in the foreseeable future.

Chillers with HFO1234ze(E) and HFO1233zd(E) centrifugal chillers are already available globally and HFO1336mzz(Z) is being tried in low-pressure centrifugal chillers. These HFO and HFC/HFO blends are also being tried in scroll or screw chillers.

Table 10: Air conditioner and chiller system characteristics – EPA SNAP report

Equipment Type	Capacity (kW)	Refrigerant Charge (kg)	Annual Operational Leak Rate ^a (%)
Small Self-Contained AC	2-7	0.2-2	<1
Small Split AC	2-12	0.5-3	1-4
Single Split and Multi-Split (Large)	10-40	3-10	1-4
VRF Systems (Large)	12-150	5-100	1-5
Ducted Systems (Large)	12-750	5-200	2-6
Small/Medium Chillers ^b	50-750	40-500	2-4
Large Chillers ^c	750-21,000	500-36,000	2-4

Sources: UNEP (2015a - e) and Johnson Controls (2014).

^a Typical annual operational leak rate does not include additional refrigerant leaks that can occur during equipment installation, maintenance, servicing, and disposal.

^b Typically use positive displacement compressors (i.e., reciprocating, rotary, scroll, or screw).

^c Typically use screw or centrifugal compressors.

Table 10 gives an extract of UNEP SNAP information on the approximate gas charge quantity of AC and chiller systems including the annual leakage rates, which helps to get a perspective of CO₂ equivalent emission reduction possibilities by switching out of existing HFC134a, 410A refrigerants.

Conclusion

The next ten years could see many alternative solutions for each of the market segments and products with a wide proliferation of refrigerant models. Safety standards on A2L and A3 refrigerants could undergo further amendments with the emergence of stringent safety design measures incorporated in HVACR systems by OEMs. With the global commitment on limiting the planet's temperature rise to <1.5°C, some of the phase-down timelines may be brought ahead by many countries, including India.

While the very wide variety of alternative solutions may get narrowed down to a select few over next 20 years, the HVACR industry needs to keep up with the pace of new refrigerant introduction in the industry, share the information and knowledge on the new chemicals and train our field staff in safe handling of these new fluids.

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