Refrigerant Guiding Principles

How to navigate the changing chiller refrigerant landscape with confidence

The power behind your mission
"Ozone depletion" and "global warming" are buzzwords in the HVAC industry when it comes to adverse environmental impacts.

Ozone depletion potential (ODP) was addressed in the early 1990s with a successful phase-out of refrigerants with chlorine content. This included CFCs (R-11, R-12) and HCFCs (R-123, R-22). Today, these efforts are widely viewed as being successful, with recent reports indicating the ozone hole is shrinking.

"Global warming" is a heating effect caused by greenhouse gases being trapped in the Earth’s atmosphere. These gases act like a blanket warming the planet, preventing heat from escaping. This results in climate change.

Greenhouse gases (GHG) include carbon dioxide, methane, nitrous oxide, and F-gases (fluorinated gases such as CFC, HCFC, and HFC). Emissions for each type are shown in this graphic.

Carbon dioxide (CO₂) emissions contribute most to the greenhouse effect. CO₂ is released into the atmosphere through the burning of fossil fuels (oil, coal, and natural gas) for electrical generation, to power our vehicles, and to heat our homes. The primary source of methane is from agriculture and is linked to our food supply. Refrigerants used in the HVAC industry represent the smallest portion of total GHG emissions but get the most attention from environmental groups and the media.

Source: www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data
The greenhouse gas effect of refrigerant is measured in terms of CO₂ and is represented by the global warming potential (GWP) of a refrigerant.

Current legislation and regulations tend to focus exclusively on the refrigerant GWP value. However, the dominant contributor to GHG emissions from HVAC equipment is the energy consumption, not the refrigerant itself.

A table providing ODP and GWP values of various types of refrigerants can be seen on the right.

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Designation</th>
<th>ODP</th>
<th>GWP*</th>
<th>ASHRAE Safety Classification</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-22</td>
<td>HCFC</td>
<td>0.055</td>
<td>1760</td>
<td>A1</td>
<td>High</td>
</tr>
<tr>
<td>R-123</td>
<td>HCFC</td>
<td>0.02</td>
<td>79</td>
<td>B1</td>
<td>Low</td>
</tr>
<tr>
<td>R-134a</td>
<td>HFC</td>
<td>0</td>
<td>1300</td>
<td>A1</td>
<td>Medium</td>
</tr>
<tr>
<td>R-410A</td>
<td>HFC</td>
<td>0</td>
<td>1924</td>
<td>A1</td>
<td>High</td>
</tr>
<tr>
<td>R-407C</td>
<td>HFC</td>
<td>0</td>
<td>1624</td>
<td>A1</td>
<td>Medium</td>
</tr>
<tr>
<td>R-32</td>
<td>HFC</td>
<td>0</td>
<td>677</td>
<td>A2L</td>
<td>High</td>
</tr>
<tr>
<td>R-1234zd</td>
<td>HFO</td>
<td>~0</td>
<td>1</td>
<td>A1</td>
<td>Low</td>
</tr>
<tr>
<td>R-1234yf</td>
<td>HFO</td>
<td>0</td>
<td>1</td>
<td>A2L</td>
<td>Medium</td>
</tr>
<tr>
<td>R-1234ze</td>
<td>HFO</td>
<td>0</td>
<td>1</td>
<td>A2L</td>
<td>Medium</td>
</tr>
<tr>
<td>R-514A</td>
<td>HFO</td>
<td>0</td>
<td>2</td>
<td>B1</td>
<td>Low</td>
</tr>
<tr>
<td>R-513A</td>
<td>HFO Blend</td>
<td>0</td>
<td>573</td>
<td>A1</td>
<td>Medium</td>
</tr>
<tr>
<td>R-454B</td>
<td>HFO Blend</td>
<td>0</td>
<td>466</td>
<td>A2L</td>
<td>High</td>
</tr>
<tr>
<td>R-290 (Propane)</td>
<td>Natural</td>
<td>0</td>
<td>3</td>
<td>A3</td>
<td>High</td>
</tr>
<tr>
<td>R-717 (Ammonia)</td>
<td>Natural</td>
<td>0</td>
<td>0</td>
<td>B2L</td>
<td>High</td>
</tr>
<tr>
<td>R-718 (Water)</td>
<td>Natural</td>
<td>0</td>
<td>0</td>
<td>A1</td>
<td>Very Low</td>
</tr>
<tr>
<td>R-744 (Carbon Dioxide)</td>
<td>Natural</td>
<td>0</td>
<td>1</td>
<td>A1</td>
<td>Very High</td>
</tr>
</tbody>
</table>

*GWP values as per the Fifth Assessment Report (AR5) of the IPCC

Total Equivalent Warming Impact

Total Equivalent Warming Impact (TEWI) is a method used to estimate the total emissions of a HVAC system over the lifetime of the equipment. It is the sum of both direct and indirect emissions generated over the lifetime of a system and includes factors such as CO₂ emissions from energy consumption, GWP and refrigerant leakage. It also accounts for the reclaim of refrigerant at the end of the equipment’s life (as per the chart right). This type of lifecycle evaluation is critical for the HVAC industry to understand the potential climate impact of both the refrigerant fluid as well as the system operating performance.
TEWI calculation method

The methodology for calculating TEWI for new stationary refrigeration and air conditioning systems that operate on vapor compression principles and are powered by mains electricity is:

\[
\text{TEWI} = (GWP \times m \times L_{\text{annual}} \times n) + (GWP \times m \times (1 - \alpha_{\text{recovery}})) + (E_{\text{annual}} \times \beta \times n)
\]

where:
- GWP = Global Warming Potential Relative to CO₂ equivalence
- m = Refrigerant Charge (kg)
- n = System Operating Life (years)
- L_{\text{annual}} = Leakage Rate p.a. (kg)
- \alpha_{\text{recovery}} = Recovery/Recycling Factor (0 to 1)
- E_{\text{annual}} = Energy Consumption per year (kWh p.a.)
- \beta = Indirect Emissions Factor (kg CO₂/kWh)


Recovery efficiency (\(\alpha_{\text{recovery}}\))
Proportion of refrigerant charge that is recovered from a system when it is decommissioned at the end of its useful working life. The Recovery/recycling factor has a value from 0 to 1.

Indirect emission factor (\(\beta\))
The indirect or CO₂ emission factor is the mass of CO₂ emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking into account efficiency losses in generation and distribution (Units: kg CO₂/kWh).

It is important to understand that HVAC equipment’s impact on global warming is more indirect (95–99%), due to the electric power it consumes, rather than direct emissions (1–5%) from any refrigerant via inadvertent leaks.

Low-GWP refrigerant does not directly result in a smaller carbon footprint for HVAC equipment. Power consumption contributes 95% or more of net CO₂ emissions. As such, it is a priority to focus on the total energy consumption of the HVAC system at all operating points throughout the year and not just the design conditions.

To simplify the above equation: a 1.5% annual saving in power approximately offsets the direct global warming potential of a refrigerant having 1500 GWP.
The Montreal Protocol and Kigali Amendment

The Montreal Protocol is widely hailed as the most successful environmental agreement to date, phasing out 98% of ozone-depleting substances (ODS) and putting the ozone layer on the path to full recovery by the middle of this century. This globally ratified treaty banned the use of CFCs in 2010 and defined a complete phase-out schedule of HCFC refrigerants in new equipment by 2020 for developed (Non-Article 5 countries) and by 2030 for developing countries (Article 5 countries), eliminating the choice of HCFCs R-22 and R-123.

The Kigali Amendment to the Montreal Protocol is a global regulation that provides a phase-down (reduction) schedule for the use of HFC refrigerants in multiple sectors, including the HVAC industry. Adopted in October 2016 and entering into force on January 1, 2019, the Kigali Amendment will significantly contribute to the goals contained in Article 2 of the Paris Agreement to "...pursue efforts to limit the [average global] temperature increase to 1.5° Celsius". Many countries have ratified this agreement and committed to targets to mandate gradual reductions in HFC consumption and production.

It’s important to note this agreement is for scheduled phase-down and not phase-out of HFCs. HFC production will remain, this allows for the continued operation of equipment installed and commissioned over the next decade. This allows for the continued operation of equipment installed and commissioned over the next decade.

HFC phase-down schedule under the Kigali Amendment

![HFC phase-down schedule](http://www.unep.fr/ozonaction/information/mmcfiles/7880-e-Kigali_FS05_Baselines_&_Timetable.pdf)

Our refrigerant Stewardship Model

The HVAC industry is attempting to navigate the complex and ever-changing refrigerant landscape with a commitment to continuous improvement and a dedication to delivering on its promises to customers.

Many questions arise for building owners and operators:

- Where will the currently evolving codes and regulations lead?
- What refrigerants will eventually be adopted as the new global standard?
- Until those questions are answered, how will designers, facility managers and owners make well-informed decisions when buying or maintaining HVAC equipment?

Amid the uncertainty, current and future refrigerant choices will be driven by safe, sustainable, efficient and cost-effective solutions that meet the following criteria:

- Safe & Reliable
- Efficient & Sustainable
- Available & Affordable

Our Refrigerant Stewardship Model

- Safe & Reliable
- Efficient & Sustainable
- Available & Affordable
Safe & Reliable

New refrigerants must be tested for safety and reliability in order to ensure long-term stability and compatibility with HVAC system components and to safeguard chiller equipment lifespans. Uncertainty around the safety of a refrigerant can lead to additional costs or increased risk of hazards. For these reasons, new technologies must be properly vetted before being introduced to the market.

Some of the commercial refrigerants being advertised today - in particular R-410A alternatives for scroll compressor products like rooftops, scroll chillers and VRF - are flammable. In response, standards and codes are being developed to establish rules for how equipment and building design must accommodate these fluids and how flammable refrigerants can be used safely. Unfortunately, these new codes are very complex. In order to mitigate risk and address uncertainty, equipment safety standards should be developed, implemented and adopted by the jurisdiction where the equipment will be installed before flammable refrigerants are considered.

New refrigerants must also be tested for reliability to ensure compatibility with HVAC system gaskets, elastomers, and materials of construction. They must also provide long-term stability. If a refrigerant begins to break down over time, it can impact system performance and operation, resulting in expensive, time-consuming repairs.

Efficient & Sustainable

Refrigerants are a key factor in HVAC equipment and a critical component in chiller performance. For a refrigerant alternative to be considered, its use should result in overall chiller performance similar to or better than conventional or existing refrigerants.

Over the product lifespan, new HVAC products should enable proactive maintenance, optimize efficiency and lower costs. Efficient and safe refrigerant solutions can provide cost-effective comfort to building occupants while also decreasing energy consumption, greenhouse gas emissions, and maintenance costs.

Our Stewardship Model calls for consideration of new refrigerants only if they help to reduce the lifetime carbon footprint of our company’s products. Energy efficiency cannot be sacrificed to meet this goal. In selecting the right refrigerant, low-GWP options do not always guarantee a better carbon footprint. Most alternative fluids coming on to the market have different chemical properties than existing refrigerants and sometimes do not match the current thermal and efficiency performance standards. This means while it may be possible to replace existing fluid by substituting a newer lower-GWP alternative, the switch may result in a change in performance with a potential negative impact on efficiency or capacity. If efficiency is lowered, more energy will be needed to provide the same level of cooling. A new refrigerant that results in lower capacity poses a different challenge: customers will see higher initial costs since additional or larger equipment will be required to meet existing capacity.

For these reasons, new refrigerants should result in overall chiller performance that is equal to or better than the fluids they replace.
Available & Affordable

As the final criteria of our Stewardship Model, new and existing refrigerants must be both available and affordable. Due to the proprietary nature of some of these new refrigerants, many alternatives can cost several times more than existing options. For flammable refrigerants, there are additional costs and considerations for safety equipment or modifications with potentially higher insurance premiums to consider. It is essential for building owners and operators to address these ownership costs with the critical safety, performance and efficiency factors of each application.

Availability is also crucial in selecting refrigerants. Some of the recently introduced alternatives are released with limited production and distribution, putting some customers at risk with limited or no local supply in the event of emergency repairs. The challenge is understandable, as it takes time for production to ramp up and for supply chains to be established. There is also a significant risk in adopting a new refrigerant that is limited to one or very few applications — the fact these boutique refrigerants will likely never come down in cost and availability may be a longer-term concern. Lack of availability can create incalculable risk. By committing too early to a refrigerant that is not widely available or in use, technicians cannot undergo the proper training in the correct use of the refrigerant. Then building owners may end up with prohibitive long-term ownership costs if supply remains limited.

Under the Johnson Controls Stewardship Model, risk of long-term availability must be considered when evaluating new refrigerants. This holds true for existing refrigerants too. If a product currently in use is slated for phase-out, or is otherwise expected to become limited in quantity, the projected risk of availability could result in the need for Johnson Controls to make a refrigerant change.

The way forward

Many alternatives are being proposed to replace HFCs in the face of regulatory pressure to eliminate higher-GWP refrigerants. To date, the focus has been on new unsaturated fluoro-chemicals, also known as hydrofluoroolefins (HFOs), especially R1234yf, R1234ze, and R1233zd. They have very low GWP levels and are classified as low toxicity. R-1234yf and R-1234ze are both mildly flammable (ASHRAE 32 classification A2L) and R-1233zd is non-flammable (A1). To lower the GWP of higher density HFCs, HFOs are mixed with HFCs. However, there is a trade-off between a lower GWP and flammability. Also, few of the alternatives proposed are toxic in nature, as can be seen below.
The perspectives from Asia-Pacific

Various refrigerant alternatives offered by manufacturers internationally may not be the best choice for a consumer considering the concerns previously explained. It is imperative to make an informed decision considering all aspects rather than just the GWP of the refrigerant. The following table illustrates various practical aspects that should be considered when selecting refrigerant for a chiller.

(a) Centrifugal and Screw Chillers: While there are many alternatives available, safety, availability, cost and efficiency remain key concerns. R-134a with local production and an availability of 70% of baseline (2024-26 consumption) remains the best choice despite a slightly higher GWP due to the high energy efficiency of R-134a chillers, its availability and cost. This refrigerant is protected against future regulation changes by R-513A refrigerant, which is already tested on chiller platforms. R-1233zd A1 category (HFO) is the best bet for the future but availability and cost remain a concern.

(b) Scroll Chillers: R410A remains the best option available at this time. R-452B is an alternative but safety codes and standards need to be revised before the mildly flammable (A2L) refrigerants such as R-452B can be used.

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### REFRIGERANT TABLE

<table>
<thead>
<tr>
<th>Refrigerant Name</th>
<th>Chemical Type</th>
<th>ASHRAE Safety Classification</th>
<th>Compressor Type</th>
<th>Pressure Type</th>
<th>Current Use</th>
<th>Concern(s)</th>
<th>Customer Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-123</td>
<td>HCFC</td>
<td>B1</td>
<td>Centrifugal</td>
<td>Low</td>
<td>Limited and declining use in centrifugal chillers due to scheduled phase-out under Montreal Protocol, only by one manufacturer. Availability and cost escalation, phase-out, costly conversions to R514a alternative. High risk carried by customer considering alternative available in market.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-514A Blend</td>
<td>B1</td>
<td>Centrifugal</td>
<td>Low</td>
<td>One manufacturer announced as a R-123 drop-in Toxicity (B1 class), availability and cost, transition refrigerant developed for R123 replacement, manufactured in low quantities by one manufacturer and used by only one chiller manufacturer. Not a popular choice among manufacturers; may get stopped due to low volume and shift to other better alternatives.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-1233zd</td>
<td>HFO</td>
<td>A1</td>
<td>Screw &amp; Centrifugal</td>
<td>Low</td>
<td>Low-pressure refrigerant introduced in select markets, but limited to a small subset of their offerings Availability and cost Gaining popularity among manufacturers but still expensive to customers in India. Possible future refrigerant.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-1336mzz</td>
<td>HFO</td>
<td>A1</td>
<td>Screw &amp; Centrifugal</td>
<td>Low</td>
<td>Used in foam blowing and to produce R-514A Availability, cost, and capacity Transferring to a low-pressure refrigerant chiller platform would be a significant investment to retool and optimize.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-1234yl</td>
<td>HFO</td>
<td>A2L</td>
<td>Screw &amp; Centrifugal</td>
<td>Medium</td>
<td>Low-GWP refrigerant alternative of choice for a majority of automotive air conditioners and a component of R-513A Flammability, efficiency, availability, and cost Safety codes and standards need to be revised prior to the wide use of mildly flammable refrigerants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-1234ze</td>
<td>HFO</td>
<td>A2L</td>
<td>Screw &amp; Centrifugal</td>
<td>Medium</td>
<td>Low-GWP refrigerant alternative to R-134a used in select applications despite flammability Flammability, efficiency and loss in capacity, availability, and cost Safety codes and standards need to be revised prior to the wide use of mildly flammable refrigerants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-134a</td>
<td>HFC</td>
<td>A1</td>
<td>Screw &amp; Centrifugal</td>
<td>Medium</td>
<td>Wide use across global screw and centrifugal chillers Higher global warming potential Best option for screw and centrifugal chillers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-450A Blend</td>
<td>A1</td>
<td>Screw &amp; Centrifugal</td>
<td>Medium</td>
<td>Potential drop-in alternative to R-134a Availability, cost, and capacity Good low-GWP alternative for R-134a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-513A Blend</td>
<td>A1</td>
<td>Screw &amp; Centrifugal</td>
<td>Medium</td>
<td>Compatible with screw and centrifugal chillers R-134a chillers Availability and cost Best low-GWP alternative for R-134a. Confirmed compatibility with global chiller platforms. Available with select products from the factory.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-717 Natural</td>
<td>B2</td>
<td>Screw</td>
<td>Medium</td>
<td>Used in many industrial applications Flammability and toxicity Very effective in highly-designed industrial applications including industrial refrigeration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-32</td>
<td>HFC</td>
<td>A2</td>
<td>Scroll</td>
<td>High</td>
<td>Proposed alternative to R-410A. Produced and promoted by Daikin Flammability, availability, and cost Safety codes and standards need to be revised prior to the wide use of mildly flammable refrigerants.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-410A</td>
<td>HFC</td>
<td>A1</td>
<td>Scroll</td>
<td>High</td>
<td>Wide use across global scroll chillers Higher global warming potential Best option for scroll chillers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-452B Blend</td>
<td>A2L</td>
<td>Scroll</td>
<td>High</td>
<td>Proposed alternative to R-410A Flammability, availability, and cost Safety codes and standards need to be revised prior to the wide use of mildly flammable refrigerants.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

The HVAC industry is in the middle of another major refrigerant transition. This will be an orderly transition with an emphasis on what is needed for the future of HVAC products and how to protect the investments that building owners have made in their operations. Manufacturers are working to find solutions that minimize negative impacts on safety, first cost, and energy efficiency, among other considerations.

- HFC refrigerants R-134a and R-410A are not banned, and are still globally used. They are the best options for chiller equipment today. All proposed legislation focuses on future equipment installations, not serviceability. Unlike CFC and HCFC refrigerants with ozone-depleting potential having defined phase-out periods, HFC phase-down is focused on responsible use allowing for continued operation of existing equipment with a gradual ramping down of refrigerant demand. The reduction by 2047 will be 15% in India, allowing for the continued use of HFCs that are used responsibly, such as those used in stationary equipment like chillers.

- R-1233zd is a non-ozone depleting, ultra-low-GWP, non-flammable alternative that is commercially viable for low-pressure centrifugal chillers and is more efficient and less toxic than R-123 and R-514A. Multiple manufacturers currently offer chiller platforms with R-1233zd.

- R-514A is an approved substitute for existing R-123 chillers but has higher replacement costs and a similar high toxicity classification. Global production is extremely limited to just one producer with a lack of market price control, and R-514a, at the time of writing, is only used by one manufacturer in a limited section of the chiller platform.

- R123 is already at the end of its operating life. There are few other uses for the R-123, so its phase-out is inevitable.

References

Source: www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data
About Johnson Controls

Johnson Controls is a global leader creating a safe, comfortable and sustainable world. Our 105,000 employees create intelligent buildings, efficient energy solutions and integrated infrastructure that work seamlessly together to deliver on the promise of smart cities and communities in 150 countries. Our commitment to sustainability dates back to our roots in 1885, with the invention of the first electric room thermostat. We are committed to helping our customers win everywhere, every day and creating greater value for all of our stakeholders through our strategic focus on buildings.

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