SELECTING THE RIGHT REFRIGERANT FOR COMMERCIAL REFRIGERATION

Achieving High Performance While Reducing Environmental Impact

globalFACT

TABLE OF CONTENTS

Figures & Tables

About globalFACT

The Global Forum for Advanced Climate Technologies (globalFACT) promotes education, awareness, and policies that support the important role of new generation, low- and reduced-global warming potential (GWP) advanced climate technologies in protecting the environment while meeting the increasing demands for safe alternatives.

Advanced climate technologies include new generation HFOs and blends, and select HFCs with lower GWP compared to previous products. These solutions for refrigerants, propellants, and blowing agents significantly reduce total climate impact, and maintain or improve energy efficiency, affordability, and flexibility to enable use for a wide variety of applications and climates.

Our Purpose

globalFACT is a resource for information on the latest news, research and improvements in advanced climate technologies. We support the informed selection and use of these products through:

- Fostering discussion of the considerations, benefits, and usage of a broad range of new generation, low- and reduced-GWP products
- Developing and disseminating data and information to help users and stakeholders make more informed decisions regarding advanced climate technologies
- Compiling and promoting best practices for deploying advanced climate technologies that are cost effective, energy efficient, environmentally sustainable, and safe

Our Members

globalFACT is a non-profit, membership organization comprised of the world's leaders in advanced climate technologies.

Learn More

For more information about globalFACT and advanced climate technologies:

www.globalFACT.org
facebook.com/gblFACT
@globalFACT
info@globalfact.org

EXECUTIVE SUMMARY

Keeping food fresh is critical to world health. Refrigerants used in supermarket cooling equipment play a key role. But concerns over certain refrigerants' global warming potential (GWP)—a refrigerant's potential contribution to climate change—are rising.

There are several low-GWP options for supermarket owners and managers, refrigeration engineers, and contractors to consider that support compliance with climate regulations, safety, energy efficiency, and profitability.

This paper outlines options to aid in the decision-making process when choosing alternative refrigerants in commercial refrigeration equipment.

Regulations are being discussed and introduced globally that mandate leak reduction and reduced use of high-GWP refrigerants to mitigate the direct effect of refrigerant emissions. In some cases, there is a phase down of HFC supply, which offers the flexibility to choose which end-uses to transition first. In other cases, complete bans of very-high-GWP refrigerants have been proposed or implemented. And in other jurisdictions, a combination of regulatory structures is used. In short, the journey to a more environmentally preferable commercial refrigeration industry has proved to be an ambitious one, involving many policies and regulations in place across the globe that are driving the transition to alternatives. However, reducing the GWP of the refrigerant alone is not sufficient to address the climate impact of refrigeration systems; it also is important to consider the indirect impact related to the electricity consumption of the refrigeration system. Several lower-GWP refrigerant solutions that also maintain or improve existing energy efficiency performance are available.

CONTACT US

info@globalfact.org

globalFACT.org

/gblFACT

@globalFACT

INTRODUCTION

The commercial refrigeration industry is evolving to meet the challenges presented by new regulations. The industry is witnessing an unprecedented era of technology development to meet regulatory and customer demands with more climate-friendly alternatives that strike an even better balance between energy efficiency, environmental impact and economic considerations. Refrigerant and equipment manufacturers are introducing innovative, new generation alternatives and equipment that deliver improved cooling performance and energy efficiency while driving down GWP. Multiple refrigerant solutions will be critical to serve the diversity of needs and variables among equipment users. As regulatory obligations in countries around the globe necessitate conversions, many in the commercial refrigeration industry are taking an objective, informed and pragmatic approach to ensure an orderly transition. There are many factors to consider in selecting a new generation refrigerant, including:

- Type and size of application
- System configuration and location
- Geography and ambient temperature
- Safety of the system including toxicity, flammability and pressure
- System reliability
- Energy efficiency
- Total equivalent warming impact (TEWI)
- Cost to implement and operate
- Technical support
- Ease of maintenance
- Regulatory Compliance

In addition, countries with emerging economies that are just beginning to transition from hydrochlorofluorocarbons (HCFCs) require the flexibility to retrofit existing equipment to lower-GWP alternatives. In most cases, cost-effective retrofitting of existing HCFC equipment requires a refrigerant of the same ASHRAE safety classification and would typically mean replacing the HCFC fluid with a hydrofluorocarbon (HFC)/hydrofluoro-olefin (HFO) blends. Other alternatives, which are available for use in new equipment, may be incompatible with existing equipment designs (e.g. R-404A equipment does not have a design compatible with carbon dioxide [CO_2]).

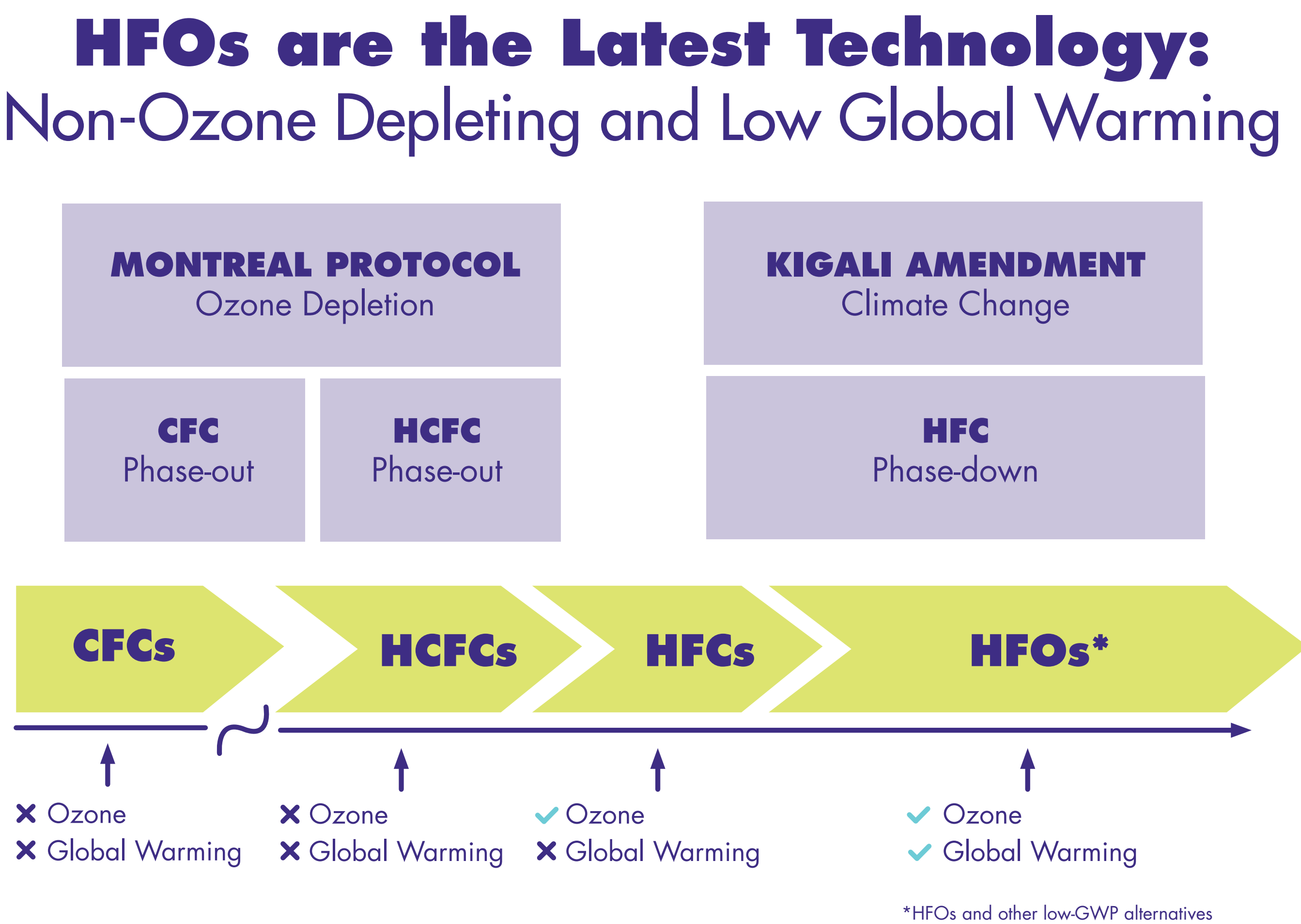
In short, selecting the right replacement refrigerant will be situational, and the importance of each factor in a particular situation will drive the decision-making process.

Products cited in this paper are for illustrative purposes only and are not intended to promote specific refrigerants or producers.

NECESSARY EVOLUTION

The commercial refrigeration industry is familiar with transition driven by the need to address environmental challenges. Indeed, significant progress has already been made in the past 70 years, as shown in Figure 1, with several generations of refrigerants—each offering improved attributes and performance over its predecessors.

Figure 1: Refrigerant Transition



In fact, in some cases historic refrigerants such as CO_2, which was used as a refrigerant in the 1950s and previously discarded due to poor energy efficiency performance, are now in use in some specific applications (e.g. low-temperature distributed systems) in innovatively designed equipment. The search for lower-GWP refrigerants has also led to the more recent development of new alternatives, such as HFOs and HFO/HFC blends.

AVAILABLE CLASS OF REFRIGERANTS

Refrigerants in use today include industrial chemicals, HFC refrigerants, HFC/HFO blend refrigerants, and pure HFO refrigerants, as described below. Each type of refrigerant can offer a longer-term solution, depending on the desired attributes in a particular application.

1. Industrial Chemical Refrigerants

Industrial chemicals were used as refrigerants at the beginning of the last century. Industrial chemicals include hydrocarbons (e.g., propane [R-290], isobutane [R-600a], CO_2 [R-744] and ammonia [R-717]), and have GWPs in the range of 0 to 4. In some cases, safety standards are under evaluation to upgrade equipment requirements to safely increase charge size limits (such as for propane and isobutane). Industrial chemical refrigerants are synthetically produced and processed to achieve the quality and purity required for refrigeration using chemical plants (in the case of ammonia) or petrochemical plants and refineries (in the case of propane, butane and isobutane). As with all refrigerant manufacturing, this processing consumes energy and raw materials on the front-end, and the products are subject to environmental, health, and safety standards in transportation, storage, use and end-of-life treatment. Industrial chemicals are sometimes referred to as "naturals" since the named substances can be found in nature.

Use of industrial chemicals requires modification of existing equipment designs to allow safe use, but doing so allows for the following advantages:

- Ammonia is a highly energy efficient refrigerant, and is a good choice for certain large industrial applications where the toxicity and flammability of ammonia can be tolerated.
- Hydrocarbons have good energy efficiency under most ambient conditions but are highly flammable and must have specific equipment designs and charge size limits for safe use and handling.
- CO_2 has acceptable energy efficiency at lower ambient temperatures but loses efficiency at higher ambient temperatures. It was used at the beginning of the 20th century, but was replaced by HCFCs due to reliability issues and other challenges (such as high pressures and leak rates).

2. Fluorinated Refrigerants

Fluorinated refrigerants such as HFCs have GWPs ranging from a few hundred to thousands. Various regulatory structures are being used to phase out or phase down some of the highest-GWP refrigerants, depending on the region.

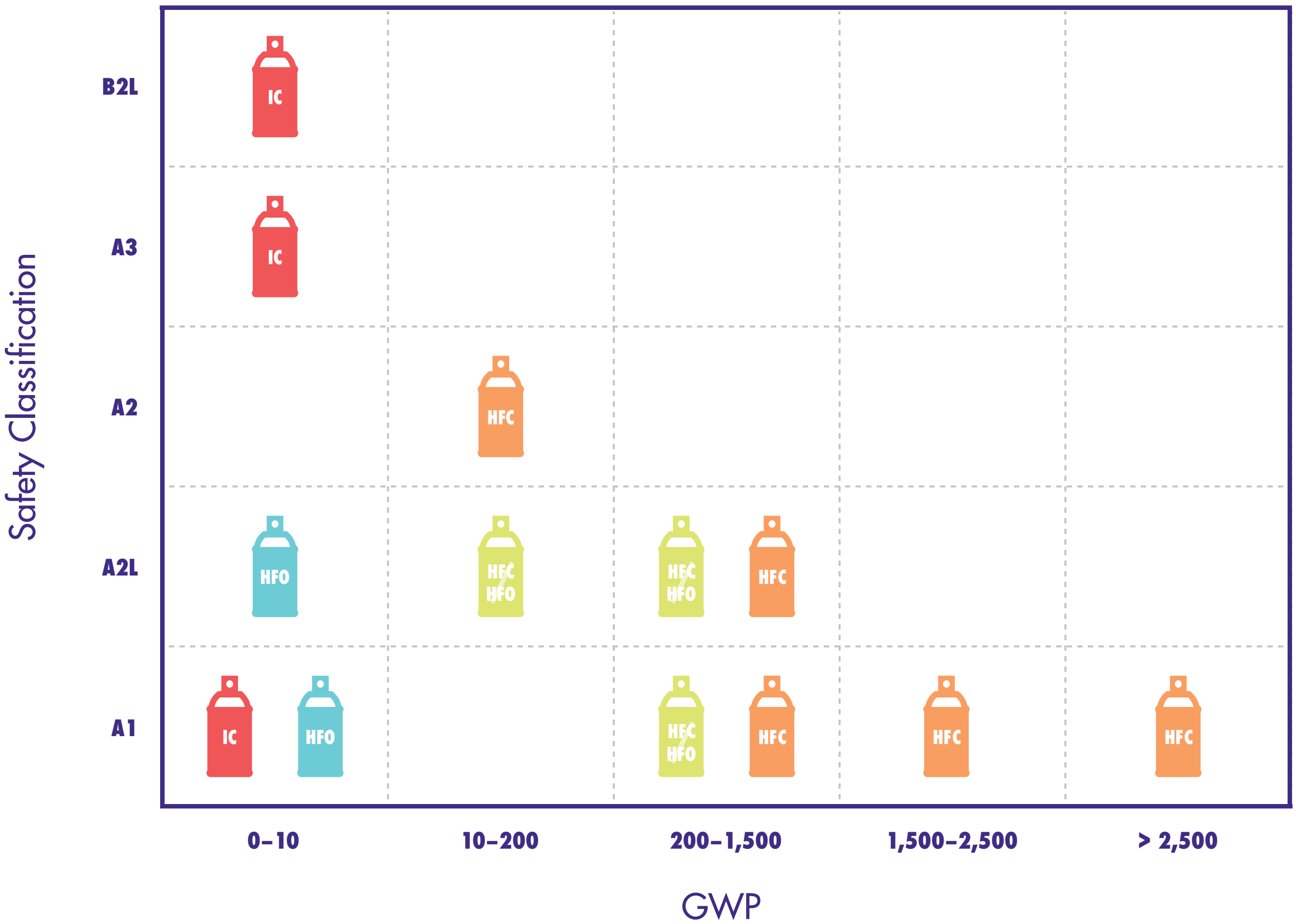
HFOs are characterized by the double-bond in the molecule. While stable during use, these molecules break down quickly when exposed to ultraviolet radiation in the stratosphere, resulting in very low GWP of 1 (like CO_2) or lower and a very low atmospheric lifetime (e.g., HFO-1234yf [11 days]) compared to the much longer, 500-year atmospheric lifetime, of CO_2.

HFC/HFO blends leverage the advantages of both technologies to provide the best performance profile based on lower-GWP, low flammability, capacity, efficiency and ease of use.

IS GWP THE ULTIMATE DIFFERENTIATOR?

One way to understand the available options is in terms of GWP as shown in Figure 2 below. Importantly, there is no single solution for every application; however, for every application there is a smart solution for both the environment and the user. Making the right choice requires a holistic understanding of global warming contributors, knowledge of the characteristics of each material, and recognition that many variables can impact success.

Figure 2: GWP Ranges for Commercial Refrigeration Application



ASHRAE STD 34 SAFETY CLASS

A1	Lower Toxicity	No Flame Propagation
A2L	Lower Toxicity	Lower Flammability
A2	Lower Toxicity	Flammable
A3	Lower Toxicity	Higher Flammability
B2L	Higher Toxicity	Lower Flammability

REFRIGERANT TYPE

IC — Industrial Chemical

HFC — HFC

HFC/HFO — HFC/HFO Blend

HFO — HFO

THE REALITY OF CHOICE:
The Right Solution that Minimizes Greenhouse Gas Footprint Depends on Many Factors

Due to the vastness and complexity of the available refrigerants options, there will never be one solution for all situations, but rather preferred solutions for specific applications—all with the aim of lowering the climate impact and providing safe and efficient operation and ease of use. A holistic approach is critical to making the right choice, including the evaluation of life-cycle metrics such as:

- Total Equivalent Warming Impact (TEWI)—The sum of direct emissions (leaks) and indirect emissions (energy use) during operation of the equipment over its lifetime; and
- Life Cycle Climate Performance (LCCP)—Greenhouse gas emissions described in CO2-equivalent units over the lifetime of the system, including the emissions during production and end-of-life of the system and refrigerant.

Energy consumption contributes to CO_2 emissions, the dominant greenhouse gas (GHG) which contributes to climate change. This "indirect" effect can represent more than 80% of a refrigeration system's impact on the environment; the remaining 20% is the direct effect of emissions from leakage of the refrigerant into the atmosphere when it is not recovered or recycled.

Although they are being phased down, HFCs facilitate a reduction in the net emission of GHGs where high-GWP HCFCs are still being used. For example, in supermarket refrigeration, HFC/HFOs blends can be a winning solution, particularly for retrofit applications. Specialized blends with a 60% lower GWP than R-404A can be used as a replacement in existing equipment. They are non-flammable, and have been shown to improve energy efficiency by approximately 10%, which is a critical cost-saver for applications like supermarkets.

As shown in Table 1, no single lower-GWP solution—non-fluorinated or fluorinated—will solve all refrigerant needs for all users.

Table 1: Commercial Refrigeration Refrigerants: Comparison on Four Major Criteria: Safety, Cost, Environment and Performance

Material	Safety	Cost	Environment	Application
Ammonia (R-717) GWP = 0	Heavily regulated in most countries B2L — higher toxicity (the key issue) and lower flammability	Cannot be retrofit to existing systems, replacing entire system is very costly Requires special handling and trained technicians — of which a limited pool exists Requires more expensive steel piping and components — more than offsets low refrigerant cost	Lower GWP Higher toxicity Good energy efficiency	Restricted to larger, cold storage industrial spaces with constant supervision by skilled, well-trained personnel
Hydrocarbons (R-290/propane, R-600a/isobutane R-1270/propylene) GWP=1-4	A3 — lower toxicity, high flammability — safety is a key issue Maximum allowable charge sizes limited due to flammability; unsuitable for majority of split systems	Cannot be retrofit to existing systems, replacing entire system is very costly Requires additional equipment for safe use Requires special handling and trained personnel Low refrigerant cost	Lower GWP Contribute to urban pollution, triggering the generation of tropospheric ozone in the lower atmosphere (volatile organic compound) Good energy efficiency under most conditions	Very small, hermetic refrigeration systems and cabinets requiring <150 g of refrigerant Vending machines, small ice cream freezers where charge size allows

Material	Safety	Cost	Environment	Application
Carbon Dioxide (R-744) GWP=1	A1 — lower toxicity, non-flammable Small increases in temperature can result in significant increases in pressure — which creates a rupture risk	Low refrigerant cost Requires new equipment, cannot retrofit existing systems, replacing entire system is very costly Operates at very high vapor pressures (10x), which requires heavy, high pressure rating equipment High discharge temperature compromise compressor life Expensive and complex designs are necessary to overcome low thermodynamic efficiency of CO_2 Components required for pressure safety / venting Higher system costs more than offset low refrigerant cost, plus CO_2 can have long lead times Requires knowledgeable engineers and trained personnel for design, start-up and maintenance — of which a limited pool exists	Significant efficiency issues in high ambient temperatures (very sensitive) translates to higher energy usage, demand charges, emissions and utility bills; cascade design solutions expensive and complex Relatively good efficiency in lower ambient temperatures Proposed measures to reduce the efficiency penalty at high ambient increase the overall system cost	Colder climates, larger systems such as freezers Transcritical systems under 88°F (31°C) (otherwise inefficient) Cascade, sub-critical direct expansion (DX) Cascade, secondary loop Chillers
HFO/HFC Blends GWP<1500	A1 — lower toxicity, non-flammable	Low cost to retrofit from legacy refrigerants such as R-404A Fast and easy drop-in solution for R-404A at one third of the GWP equals to faster solution to marketplace	High energy efficiency, leading to lower energy consumption compared to R-404A, particularly in high ambient temperatures	Supermarkets, new and retrofit Ice machines Transport refrigeration Industrial chillers Cold Storage
HFO/HFC Blends GWP<750	A1 — lower toxicity, non-flammable	Replacement for R-134a Similar pressures Slightly higher refrigerant cost	Similar or better efficiency Slightly lower capacity	Supermarkets new (Med Temp) Vending machines Plug-in cabinets
Pure HFO GWP<2	A2L — mildly flammable	Replacement for R-134a Requires designs for A2L	Similar performance to R-134a	Vending machines Plug-in retail Home refrigerators Medium-temp supermarket refrigeration Industrial refrigeration and supermarket cascades Transport refrigeration
HFC Blends, GWP<1700	A1 — nonflammable, nontoxic Easy and safe to operate, maintain	Low cost to retrofit	Good energy efficiency	Supermarket refrigeration Industrial refrigeration Ice rinks

TRADE-OFFS: GWP vs. Safety and Efficiency

Safety

In recent years, HFCs have been a leading refrigerant choice, as they have a very good balance of properties, including energy efficiency, safety, cost, reliability and ease of use. The development of HFO refrigerants has introduced a new class of low-GWP fluids, some of which are mildly flammable. These flammability characteristics must be considered when designing safe systems and may require risk-mitigating measures depending on the charge size and installation situation of the desired application. The industry is currently working on implementing these considerations into standards and guidelines by carefully evaluating safety requirements and limitations by application. Mildly flammable (A2L) refrigerants have been successfully adopted in several applications, with the partnership of industry to ensure safe use. For example, HFO-1234yf has become the refrigerant alternative of choice for new mobile air-conditioning systems, and R-32 for some small air-conditioning systems. Since 2012, HFO-1234yf and R-32 have been in commercial use. There are over 120 million systems with these refrigerants with few, if any, reported safety incidents in use.

Other low-GWP alternatives also require risk-mitigating measures depending on the charge size and installation situation of the desired application to prevent safety concerns that put workers and the public at risk (e.g. ammonia toxicity, hydrocarbons flammability and the high operating pressures of CO_2). The push for an undiscerning low-GWP limit for all applications must, naturally, consider public welfare to prevent health and safety concerns in the workplace. Concerns about accidents and risk of legal liability[1] related to leaks and improper use and/or system configuration restrict the use of ammonia to certain applications where highly qualified personnel are available day and night to respond to emergencies. For these reasons, ammonia-based systems, even with low charge size, are not a wide-spread solution.

Safety standards are under development to support designs and charge-size limits for the use of hydrocarbons (A3s) and other industrial chemicals that would reduce risk. It will be important to educate system designers, users, service technicians and others in the value chain to safely design and maintain equipment to minimize the risks associated with the improper use of these products.

1 See, "Alternative refrigerants or HFCs: an obvious choice? Safety first when choosing a refrigerant!" EFCTC, updated Jan. 2016, https://www.fluorocarbons.org/wp-content/uploads/2016/09/EFCTC_Learn_about_Safety_first_choosing_refrigerant.pdf

Efficiency

Higher ambient temperatures (above the critical temperature of CO_2 when more energy is required to operate the system) limit the energy efficiency of CO_2, which then increases the carbon footprint over the long-term. This increased energy use drives additional emissions that partially offset the low-GWP benefit, and result in higher energy bills. Thus, some apparently low-GWP alternatives can contribute significantly to climate change because, as demonstrated in TEWI and LCCP analyses, reducing energy consumption is a critical factor in minimizing greenhouse gases.

There are a number of R-22 and R-404A alternatives available now for supermarket refrigeration systems such as R-448A, R-449A and R-407H, which all have a GWP of less than 1500 and an ASHRAE A1 classification. The data provided in Figure 3, 4 and 5 is one example of comparative studies for these alternatives.

Figure 3, below, shows the energy efficiency performance of lower-GWP solutions in supermarket refrigeration. A common perception is that reducing the GWP of the refrigerant will automatically lead to a significant reduction in environmental impact of the entire system. However, this reasoning leaves out the influence of the energy efficiency that determines the indirect emission impact, which is responsible for a major part of overall emissions.

The figure shows energy efficiency for varying temperatures for a baseline system architecture using the high-GWP refrigerant R-404A compared to lower-GWP alternatives, including a non-flammable lower-GWP HFC/HFO blend (a retrofit solution for existing systems, as well as an option for new systems), a R-744 booster, and a cascade concept with an A2L HFC/HFO blend.

The lowest GWP alternative among these options is the R-744 system, with a GWP value of 1. However, R-744 has efficiency-limiting aspects that need to be considered when it is operating transcritically at higher ambient conditions. Only at lower ambient temperatures can a net benefit be obtained when using R-744 compared to the other options.

The system concepts using HFC and HFC/HFO blend refrigerants can achieve improved performance by applying electronic expansion valves, which improves energy efficiency at lower ambient temperature conditions.

Figure 3: Cooling efficiency of supermarket refrigeration systems at different ambient temperatures

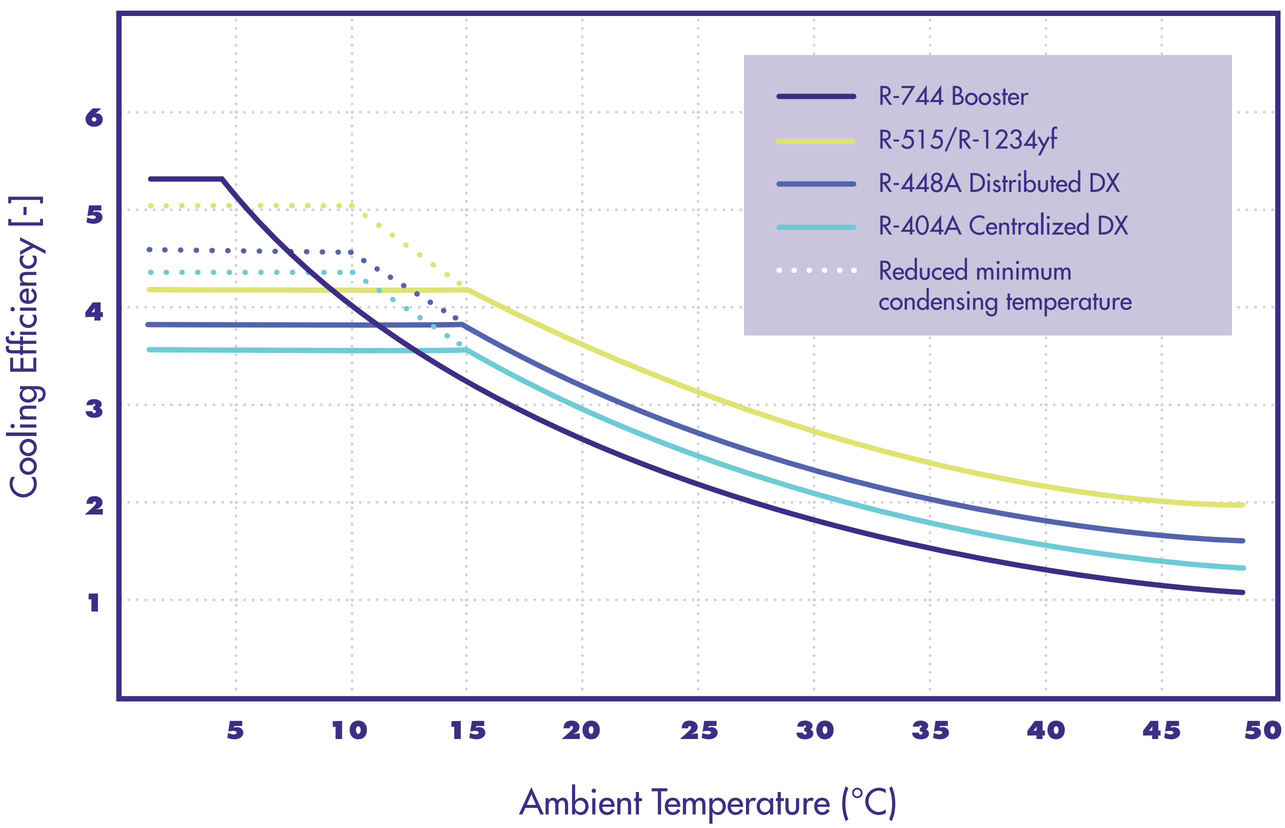
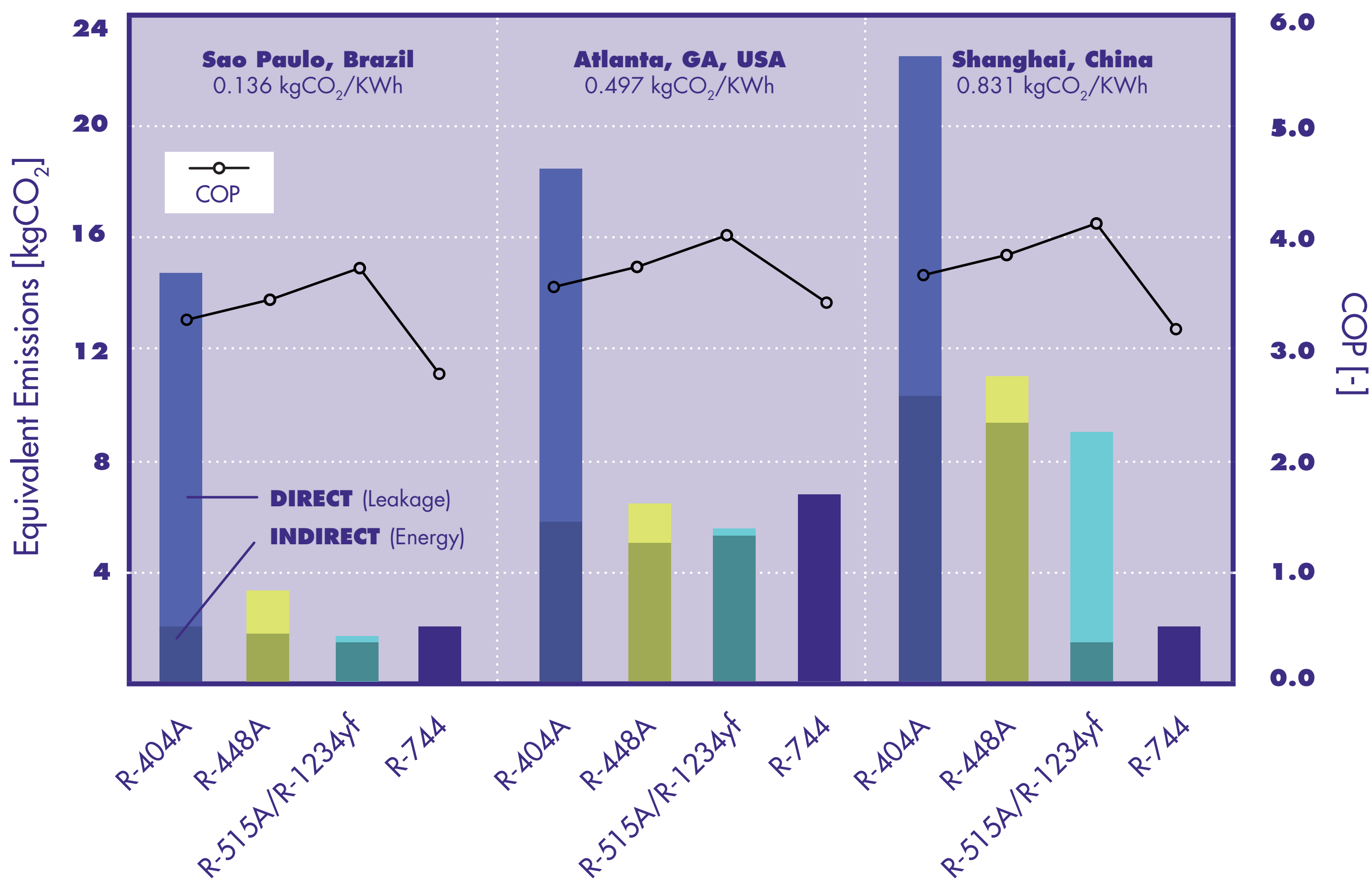


Figure 4, below, shows the environmental impact of the same system described above, in terms of the energy efficiency performance of the equipment in three specific geographic locations around the globe. The A2L HFO/HFC blend system using R-1234yf has the best overall efficiency, which reduces the operating cost of the equipment compared to other system options. It also results in the lowest overall emissions for all investigated locations, demonstrating that the lowest-GWP alternative does not necessarily yield the lowest environmental impact and that energy efficiency is a key factor that users should consider when deciding which technology to select.

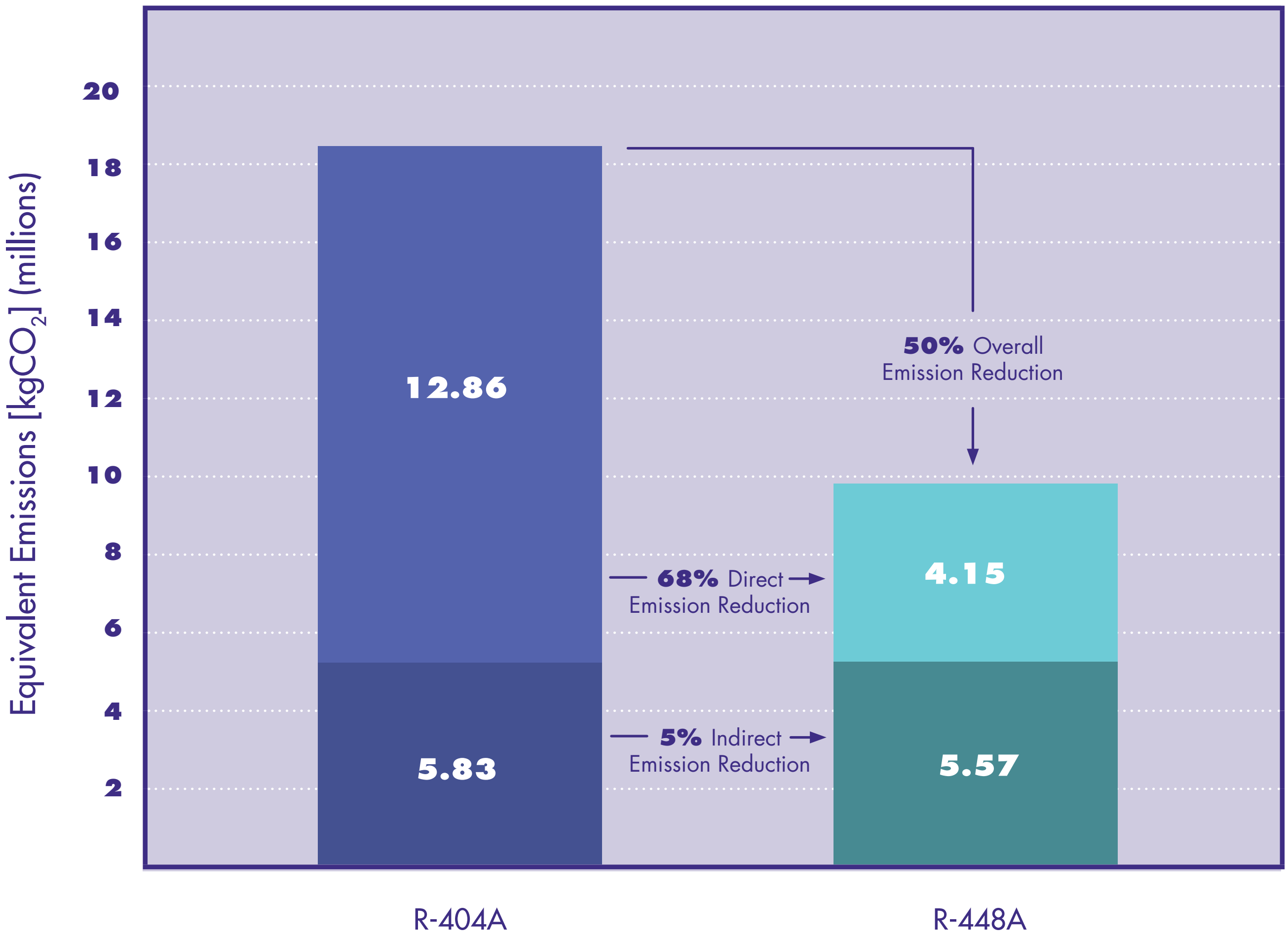
Figure 4: Emissions and energy efficiency for a typical supermarket refrigeration system at global locations



As is illustrated above, HFOs and HFO/HFC blends can provide a lower overall carbon footprint versus industrial chemical refrigerants, given the improved energy efficiency and versatility of the HFO system. HFOs and HFC/HFO blends are becoming widely adopted because they can help speed up the implementation of lower-GWP systems, particularly in developing countries at the start of their phase-out cycle and where it would be more cost-effective to retrofit equipment with a new fluid rather than to replace it. Retrofitting existing systems can allow for rapid reduction of climate impact across the large base of installed systems. (Unfortunately, it is not possible to retrofit existing HFC systems to CO_2, hydrocarbons or ammonia.)

For example, Figure 5 shows a comparison of the lifetime emissions of a R-404A system and a system retrofitted with lower-GWP R-448A, taking into account GWP and energy efficiency improvements, in equipment operating in Atlanta, GA.

Figure 5: Emission reduction when retrofitting R-404A with R-448A for a 15-year system lifetime in Atlanta, GA



TRADE-OFFS:
Refrigerant Cost vs. New System Installation and Maintenance

Industrial chemical alternatives, such as CO_2, ammonia, and hydrocarbons, are not "drop-in" solutions. This creates a barrier for people seeking simple, cost-effective solutions to replace high-GWP refrigerants in existing equipment. While these particular refrigerants might be less expensive to purchase, to be safely used they also may require additional safety equipment and the replacement of entire refrigeration systems. Since these installations are "new" to the industry and still being tested, qualified service and support is lacking, and more technicians need to be trained. In some parts of the country, you can find trained technicians at this web site: http://www.nasrcnetwork.org/ (from Greenchill webinar).

CO_2 systems operate under very high pressure, which requires special components, specialized piping, and qualified personnel for installation. Some companies have been early adopters and have found that conversion costs are very high. Costs are further increased by the requirement of highly-trained personnel to handle and maintain these new systems, which create significant issues in keeping them operational. Proper storage of the cylinders is also important. Large quantities are needed for maintenance, which makes the CO_2 refrigerant more expensive due to cylinder fleet rental fees. Supermarkets looking for lower GWP but lacking the resources for a complete overhaul may want to consider other alternatives.

A TRANSITION TO LOWER-GWP SOLUTIONS CAN BE ACHIEVED COST-EFFECTIVELY WITHOUT SACRIFICING ENERGY EFFICIENCY

A cost-effective balance of energy efficiency improvement and lower GWP is possible. As shown in Figure 2, on page 7, several refrigerants are available that provide an excellent and immediate alternative to higher-GWP HFCs. These refrigerants not only provide a lower GWP than traditional HFCs, but also deliver equal or better energy efficiency, safety and economics. For example, HFC or HFC/HFO blends can provide a 60% reduction in GWP and up to 15% better energy efficiency than R-404A.

Retrofitting existing systems is much less expensive than installing new equipment, which can allow supermarkets to start reducing GWP sooner than they perhaps otherwise would have.

As A1 refrigerants, HFC or HFC/HFO blends can also use existing equipment designs and do not require special handling and additional equipment for safe use and maintenance.

Improvements in technicians' skills, maintenance protocols and system configuration can reduce leakage rates, and overall carbon footprint even further for HFCs that do have higher GWP. Blending high-GWP HFCs with low-GWP HFOs can further increase environmental benefits.

SUMMARY:
The Parameters of Choice

Businesses need to stay profitable while addressing regulatory concerns and keeping workers and consumers safe. The characteristics of each application will determine the best refrigerant for the situation.

As discussed earlier, there are many factors to consider before selecting an alternative refrigerant:

- Energy efficiency: the greatest impact on climate change;
- Type and size of application—small, medium large;
- Geography and ambient temperature: ambient conditions can impact efficiency in terms of heat discharge (systems work harder in warmer climates);
- Total equivalent warming impact (TEWI);
- Cost to implement and operate—switching systems can be cost prohibitive depending on the application;
- Workplace and public safety needs;
- System configuration and location;
- Appropriate safe design for building configuration;
- Technical support; and
- System maintenance—newer technologies don't have an established support network.

Table 2, below, provides a visual guide for comparing attributes of available refrigerant options.

Table 2: Refrigerant Choice Comparison by Equipment Type on Four Major Criteria: Safety, Cost, Efficiency and GWP

Sector in Cold Chain	Current Refrigerants	AR4 GWP	New Generation Zero ODP Alternatives	Safety	System Cost	Energy Efficiency	GWP
Low & Medium Temp Standalone	R-404A	3922	High GWP HFC				
			HC				
			Lower GWP HFCs and HFC/HFO blends				
	R-134a	1430	HFO				
			CO_2				
			Ammonia				

Sector in Cold Chain	Current Refrigerants	AR4 GWP	New Generation Zero ODP Alternatives	Safety	System Cost	Energy Efficiency	GWP
Low & Medium Temp Condensing Unit	R-404A	3922	High GWP HFC				
			HC				
			Lower GWP HFCs and HFC/HFO blends				
			HFO				
			CO_2				
			Ammonia				
Low & Medium Temp Centralized Systems	R-404A	3922	High GWP HFC				
			HC				
			Lower GWP HFCs and HFC/HFO blends				
			HFO				
			CO_2				
			Ammonia				
Road Vehicles, Containers, Ships	R-404A	3922	High GWP HFC				
			HC				
			Lower GWP HFCs and HFC/HFO blends				
	R-134A	1430	HFO				
			CO_2				
			Ammonia				

CONCLUSION

While there have been significant advancements in the development of refrigerant alternatives, it is important to recognize that collaboration across industry, academia, government and NGOs can accelerate solutions that make refrigeration systems more efficient with lower environmental impact and safety risk. Since it can take a decade or more—and hundreds of millions of dollars in investments—to develop, test and commercialize a new refrigerant, it makes sense to think differently about providing climate-friendly solutions that drive industry to new innovations more quickly.

CONTACT US

info@globalfact.org

globalFACT.org

/gblFACT

@globalFACT