ENGINEERING
TOMORROW

Refrigerant options **now** and in the **future**

A white paper on the global trends within refrigerants in air conditioning and refrigeration seen from a Danfoss perspective.
Update August 2018

Achieving sustainable HVAC/R through intelligent solutions, energy efficiency and **low GWP** refrigerants

www.refrigerants.danfoss.com

Policy Statement

Danfoss encourages the further development and use of low GWP refrigerants to help slow, and ultimately reverse, the process of global warming while helping to ensure continued global well-being and economic development along with the future viability of our industry.

We will enable our customers to achieve these refrigerant goals while continuing to enhance the energy efficiency of refrigeration and air-conditioning equipment.

Danfoss will proactively develop products for low-GWP refrigerants, both natural and synthetic, to fulfil customers' needs for practical and safe solutions without compromising energy efficiency.

Danfoss will lead and be recognized in the development of natural refrigerant solutions. Danfoss will develop and support products for low GWP synthetic refrigerants, particularly for those applications where natural refrigerant solutions are not yet practical or economically feasible.

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Executive Summary

Danfoss, world leader in the supply of compressors and controls, has one of the most extensive and complete product ranges in the HVAC/R industry. Our products are found in numerous business areas, such as food retail, commercial and industrial refrigeration, and air conditioning, products for wholesale refrigeration, and automation in various specific industrial sectors. More than eighty years of experience has put Danfoss at the forefront in developing products using refrigerants and evaluating the viability of new refrigerants as they are introduced. This paper contains a summarized look at our experience and knowledge, describing the background, trends, and drivers that frame the scenarios for present and future refrigerant selection.

The history of refrigerants is a long and cyclical story. We predict that vapor compression systems will remain the primary technology for the foreseeable future and anticipate that refrigerant consumption will increase dramatically with the growing demand from emerging economies. Pairing systems and technologies with the most suitable refrigerant is a decision that will impact users for years to come. Most experts point to safety, affordability, and environmental friendliness as the most important factors to consider when building a system. The balance of these factors is rarely found by only targeting one refrigerant.

Selecting new alternatives implies investments, costs, and burdens, but we believe that if these selections are made correctly, and with an innovative approach, they can open doors to new opportunities. By developing new safe technologies and procedures for handling systems, we know that we will continue to move towards much lower GWP refrigerants than are currently in use today. We foresee a decade of complex development but the global agreement on an orderly phase-down of high GWP refrigerants has finally made sure we are heading in the right direction.

History

Nearly two hundred years have passed since Jacob Perkins patented the vapor compression cycle, which began the history of refrigerants. The vapor compression cycle uses the refrigerant to transport heat from the cold side to the hot side of a refrigeration system, heat pump, or air conditioning system. We use the same thermodynamic cycle today, though the refrigerants have changed.

Figure 1 shows the development of refrigerants since 1835. In the beginning, all refrigerants were easily obtainable as they existed in nature or were already used in industrial processes. By the 1930s, it became obvious that there were critical safety issues involving many of these early refrigerants, including cases of fires and poisonings caused by refrigerant leaks. It was at this time that synthetic safety refrigerants called chlorofluorocarbons (CFCs) were invented and began to be used on a global scale. Development of synthetic refrigerants continued in the 1950s, when partially chlorinated refrigerants (hydrochlorofluorocarbons or HCFC) were introduced, including R22.

In the early 1970s, it was discovered that CFC and HCFC refrigerants caused a breakdown of the ozone layer. CFCs have a particularly high Ozone Depleting Potential (ODP) and while HCFCs are comparatively lower in ODP', they still wreaked havoc. As a consequence, the Montreal Protocol—the global phase-down mechanism on substances that deplete the ozone layer—was established and has since been regarded as a global success on reducing dangerous chemicals. In addition to reducing the ODP load in the atmosphere, the reduction of CFC emissions has also considerably decreased the global warming impact. Substitute refrigerants, called hydrofluorocarbons (HFCs), have an ODP of zero, but medium to high Global Warming Potential (GWP) though still lower than phased-out CFCs. Due to the growing threat of climate change, usage of HFCs has been scrutinized in an attempt to reduce their impact on the environment. Scientific investigations show that while the impact of HFC leaks may not currently be a major contributing factor to global warming, their growing consumption, especially within air conditioning units in developing countries, will eventually make HFCs a top global warming contributor if phasedown measures were not introduced. In October 2016, the parties of the Montreal Protocol agreed on a phasedown for HFCs. That plan is scheduled to go into effect in 2019 and should create more certainty in the quest to reduce the use of these high GWP gasses.

In summary, if we do not practice environmental stewardship, refrigerants may cause severe, long-term environmental consequences. History has been a learning curve away from the flammable and toxic refrigerants towards safe solutions, but ones that were environmentally destructive, making them only short-term solutions. Technological developments, together with recognized safety standards, have finally made it possible to begin moving towards real long-term solutions with zero ODP, low GWP refrigerants.

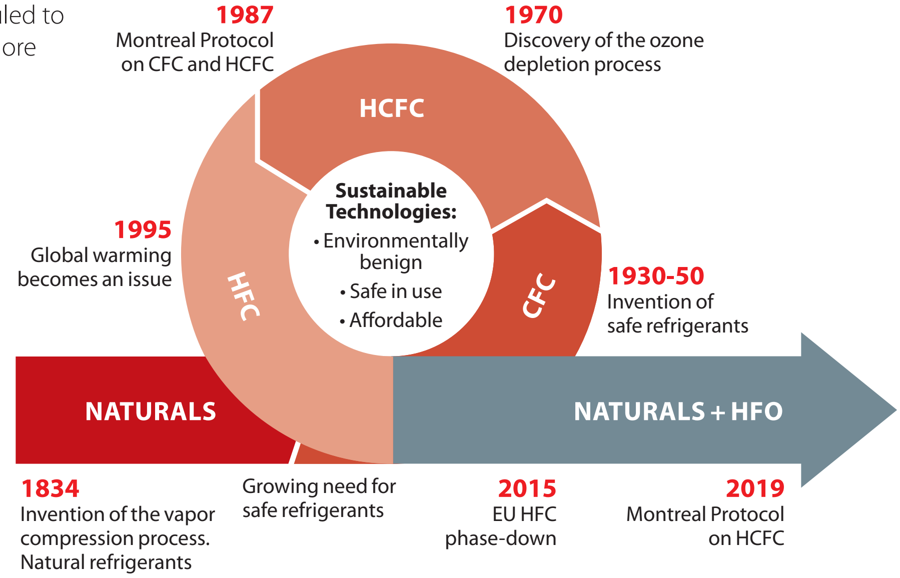


Figure 1: The historical cycle of refrigerants

Sustainability is the Key

Sustainable solutions are in the best interests of all stakeholders in our industry. Sustainability safeguards long-term investments and ensures compliance with Corporate Social Responsibility (CSR). Looking back, it is clear that the refrigerant choices made in the past were not sustainable. Regarding long-term sustainable refrigerants, Danfoss considers three main parameters that must be aligned to accomplish a real sustainable balance: affordability, safety and environmental friendliness.

When choosing a new refrigerant for an application, all three parameters need to be considered together. If not, it will be impossible to achieve long-term, sustainable results. It is important to look at the underlying parameters such as lowest life cycle cost, service availability, operational efficiency and safety, and the GWP of the refrigerant. A sustainable solution will be achieved only when all of these parameters are balanced. Achieving this balance will require a thorough evaluation factors which influence these parameters as shown in figure 2.

While we can engineer a sustainable solution, there are more factors that will determine if new refrigerant solutions are viable. In order to quantify the industrial viability of developing new sustainable solutions for new refrigerants, Danfoss has developed a model that breaks down the main parameters.

We call this the 7 Force model, seen in figure 3. The red arrows refer to economic factors and the grey arrows are cultural factors such as knowledge, education, and legislation. When the balance between the red and grey forces reaches the viability level, it becomes much more likely that the industry will start investing in new solutions and technologies. When investing in new technologies and building up competencies, legislation and derived standardization are the major drivers.

Over the past ten years, the viability level has been increasing for many low GWP refrigerants. Good examples are CO2 applications for commercial refrigeration, especially supermarkets.

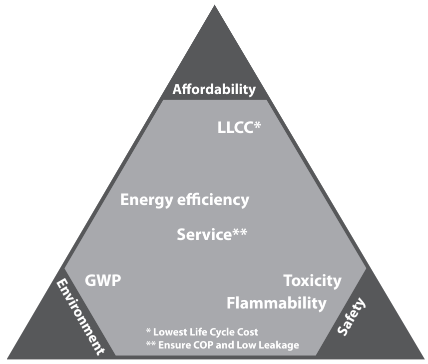
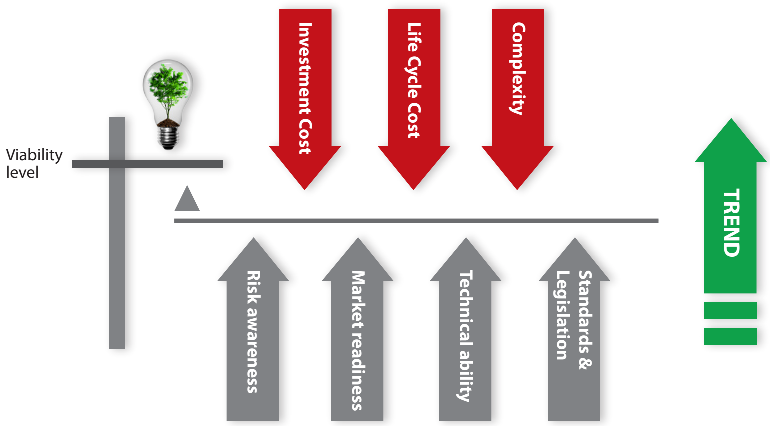


Figure 2: Refrigerant Sustainability Triangle

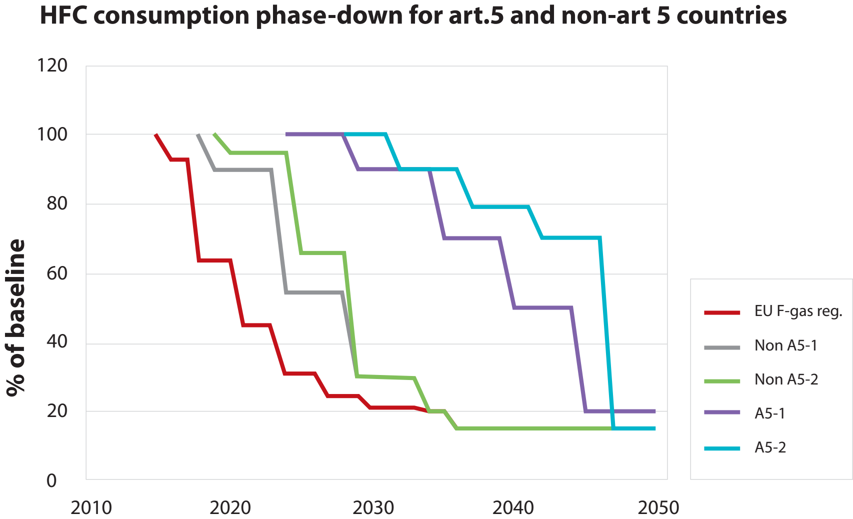


1.	Investment cost	Investments in Product development
2.	Life cycle cost	Life cycle cost for the user. Contains up front cost and running cost
3.	Complexity	Complexity associated with manufacturing and marketing
4.	Risk Awareness	Difference between perceived and actual risk using the product
5.	Market Readiness	Market competence in safe adoption of new technologies and products
6.	Technical Ability	Ability and competence in developing new products
7.	Standard & Legislation	S&L includes bans taxes and voluntary agreements.

Figure 3: The Seven Forces model

Regulation

Regulation, both national and international, has been one of the most important drivers for spurring investment in new technology. Figure 4 charts an overview of HFC phase-downs that have already been imposed on the industry—see also the section on standards and legislation later in this paper. The measures for reducing HFC consumption can be voluntary or imposed by regulation (the red triangle), but they all mean to place limits within the market. Specific guidance measures on market development—like GWP limits for certain applications—cause an underlying concern of the availability of sustainable solutions (the green triangle). When new regulations are made, they are intended to encompass and balance the guidance measures and concerns, and predict reasonably successful outcomes but, after all, there are always a number of challenges that need to be solved by industry leaders and legislators along the path of change. In Annex 1, a detailed overview is made for the main regulations including the Montreal protocol, the EU F-gas regulation, and the US SNAP.



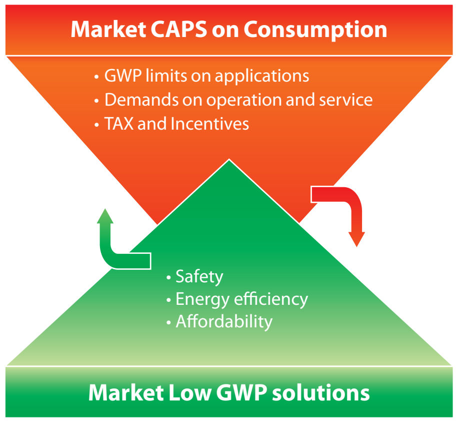


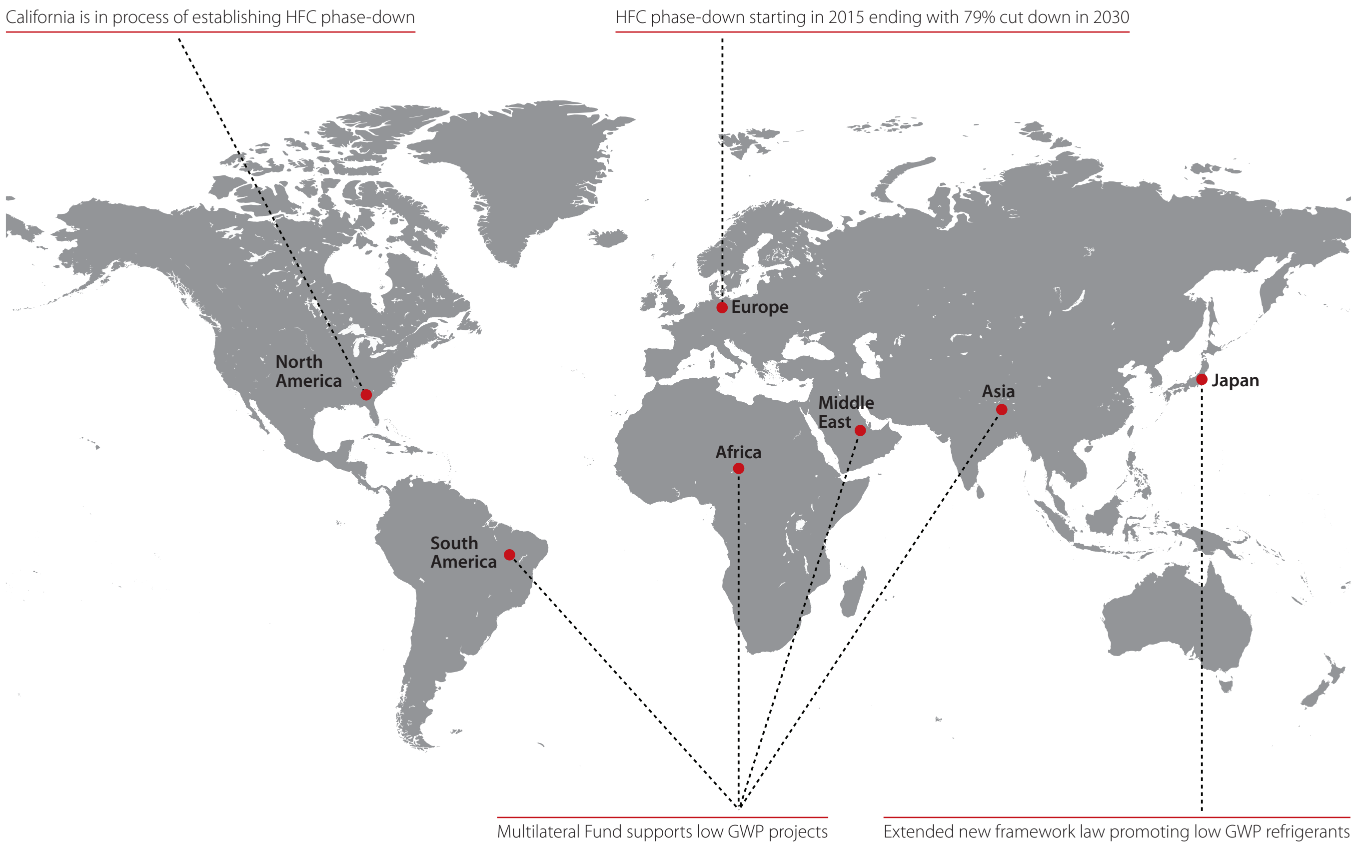
Figure 4: Refrigerant phase-down (MP and EU) and the underlying measures
See more details in Annex A.

HCFCs, particularly R22, have already been phased out in the EU and the phase-out is close to being finalized in the US and other developed countries. Developing countries began phasing out HCFCs in 2015 and will continue until 2030. It is important to remember that the HCFC R22 is used in many different applications, which makes the phase-out a challenge as no single non-flammable low-GWP refrigerant can replace it (Annex 1 table 2 shows the HCFC phase-down steps).

In October 2016, the HFC phase-down steps were agreed upon and became part of the Montreal Protocol, (also called the Kigali amendment). If ratified by a country after that date, the Kigali amendment will enter into effect in the country 90 days afterwards (see Annex 1 table 3 for the HFC phasedown steps). There is a special activity aimed at improving energy efficiency while phasing down HFC's called the Kigali Cooling Efficiency Program (KCEP). The KCEP is expected to spur the introduction of sustainable technologies in the fast-growing cooling segment.

Besides the phase-down and phase-out mechanisms discussed above, many governments are applying measures for reducing high GWP refrigerant consumption, such as GWP weighted taxes. Spain, Denmark, Norway, and Sweden have imposed taxes on HFCs. Additionally, national incentives in the form of subsidies on low-GWP refrigerants are currently being used in many other countries.

Annex 1 is an overview of the phase-outs and phase-downs that have already been imposed on the industry in some of the main markets.



Worldwide:

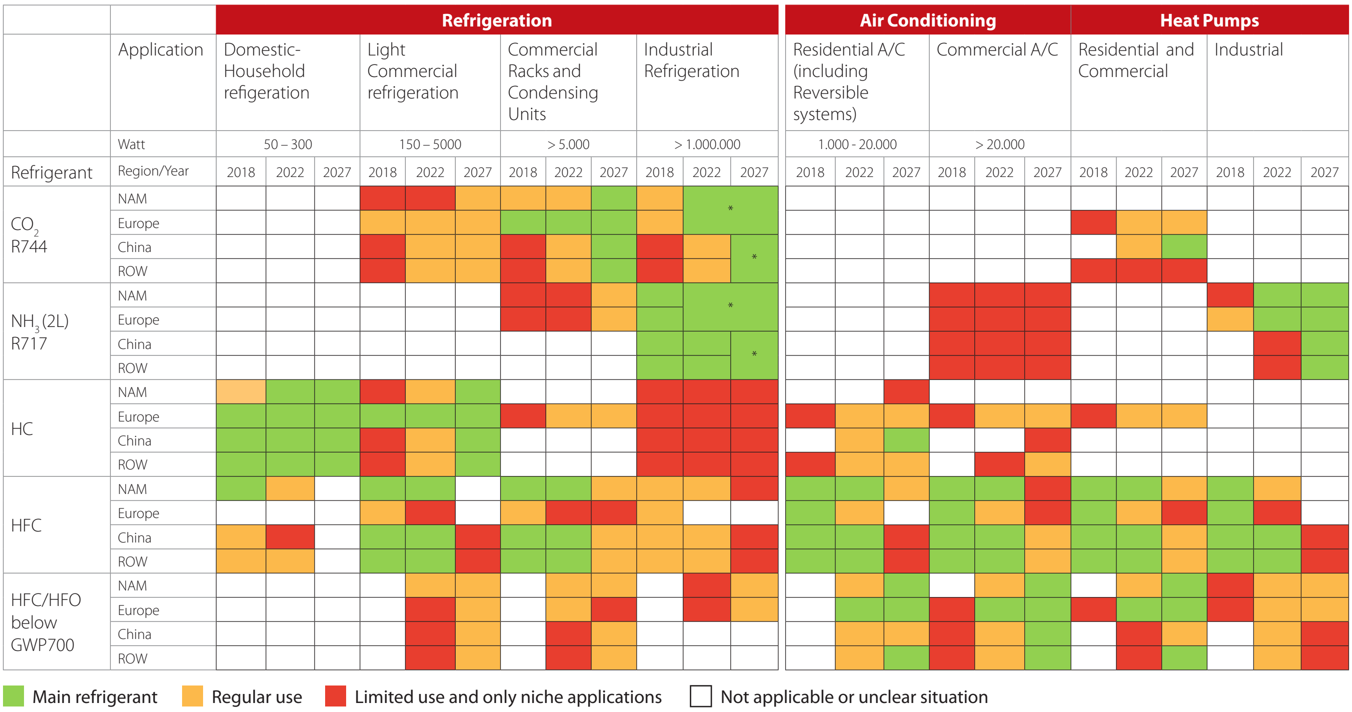
Montreal Protocol agreement on HFC phase down in 2016 starting in 2019
National tax schemes on HFC
National incentives and subsidies
National research and demonstration support for low GWP refrigerants

Figure 5: Global overview of refrigerant regulations

The Outlook

Our sustainability triangle (figure 2) shows that the environment plays an important role when developing and using refrigerants. Both system manufacturers and users want long-term solutions that are environmentally benign, safe, and affordable. Looking at various alternatives, everything points to lower GWP solutions. Natural refrigerants have a low GWP and are efficient, and we expect them to become the preferred choice whenever possible, though safety will still be an important factor in regulating the usage of natural and some HFC / HFO refrigerants. The trend shows a growing acceptance of mildly flammable, A2L refrigerants, especially now that they have been incorporated into the new ISO and IEC standards. We also see highly flammable, A3 refrigerants increasingly being used in smaller systems. In the context of being able to handle flammable refrigerants, two important initiatives were launched in 2015 by the United Nations: the Global Refrigerant Management Initiative (GRMI) and the Refrigerant Driving License (RDL). Both initiatives aim to develop the service sector to encourage competent and safe servicing and installations. These initiatives address the main barriers that currently inhibit the mass introduction of low-GWP refrigerants and as such become important in the global phase-down of HFCs.

Our international group of experts within Danfoss has projected what we see as the likely refrigerant outlook. This outlook is summarized in the Table 1 below. CO_2 is widely used industrial refrigeration and commercial refrigeration racks and we believe that this trend, which started in Europe, will extend to the rest of the world. We foresee ammonia continuing to be a very well accepted, particularly in industrial refrigeration applications, though its toxicity means requires unique safety measures. We expect that a solution using both CO_2 and ammonia will be mainly used at some point in the future. We see the very energy-efficient hydrocarbons playing an important role in low-charge systems around the globe. We believe that HFCs will not disappear, but will be limited to those with the lowest GWP and will be combined with HFOs as is already happening. HFC and HFO are now moving towards more environmentally friendly, but often mildly flammable, versions, making safety precautions all the more important. The demand for low-GWP refrigerants will continue to challenge our current perception of which refrigerants can be used in certain applications, but will also drive innovations in system design.



** Ammonia/CO_2 cascades will dominate industrial refrigeration*

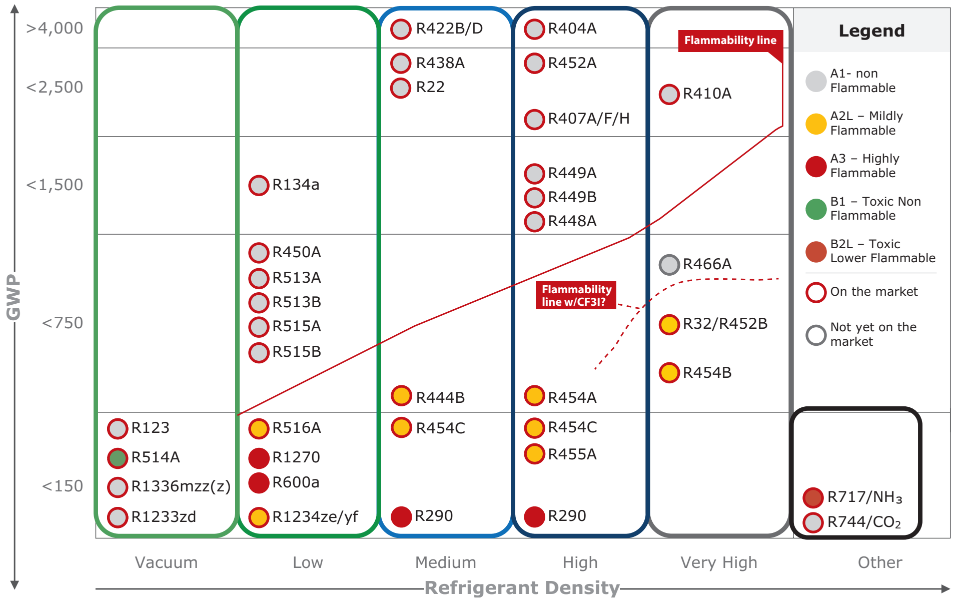
Table 1: Global trends in refrigeration and air conditioning (Status in Aug 2018)

Refrigerant Options

Facing the regulatory pressures to eliminate high GWP refrigerants, many alternatives are being proposed to replace HFCs. 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, are non- or only mildly flammable, and belong to a group of low density refrigerants. R1233zd has a very low ODP value (only a small percentage of R22) but this remains a problem in a few countries like Denmark. To lower the GWP of higher density HFCs, HFOs are mixed in HFC. As seen in Figures 7a and 7b, the proposed blends are similar to each other, with the main differences being based on which R1234 type is used and the exact refrigerant it is replacing.

However, there is a trade-off between a lower GWP and flammability – see Figure 6. As seen in Figures 7a and 7b, most of the current refrigerants have no simple low GWP drop-in solutions: flammability is linked to GWP and refrigerant capacity. The lower the GWP and higher the capacity comes with increased flammability.

Main refrigerants at Play
A Complex Picture in Continuous Evolution

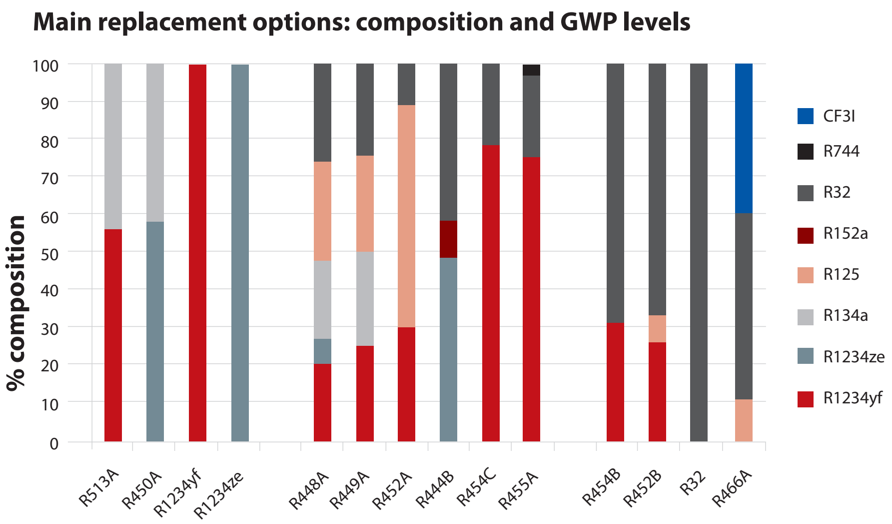


GWP versus Density (pressure) of the main refrigerant groups

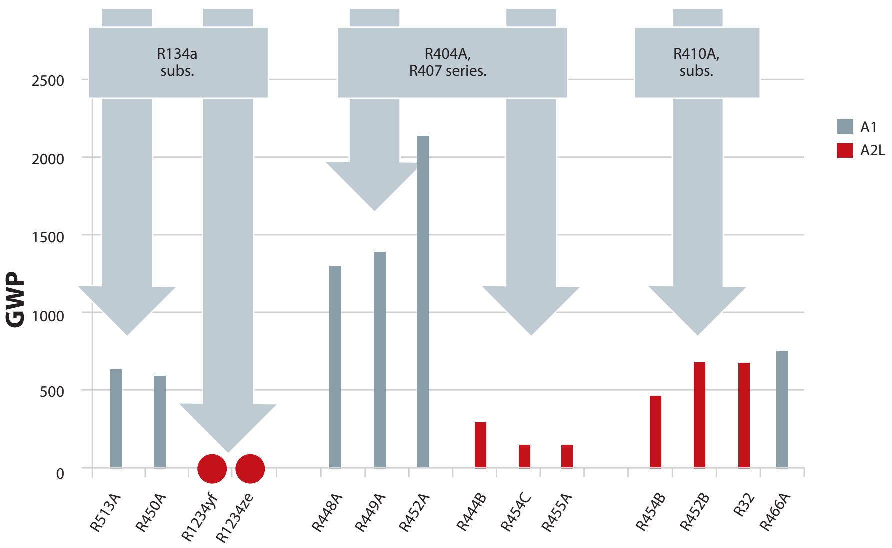
Figure 6: Carbon Chain Based Refrigerants (HCs, HFCs, HCFCs), GWP versus Density (pressure) of the main refrigerant groups

There are application pros and cons for using specific refrigerants and some considerations relating to product strategy. How do the energy-efficiency improvement schemes match? Is it intended for a fast drop-in or is it part of a major redesign cycle? What are the climate conditions and will the local markets be ready to handle the refrigerant? What is the impact of glide in a service perspective? Will it make sense to go for one type refrigerant or will a dual strategy be better? The latest trade fairs show that A2L refrigerants are ready, efficient, and available and components are currently or will soon be available. For R1234ze some special conditions apply. R1234ze is categorized as an A2L refrigerant but only flammable above 30 °C. This is why the EN 378, which is harmonized with the EU PED Directive, does not recognize R1234ze as a hazardous substance, but as a PED group 2 fluid. This has the positive effect that it avoids material traceability for pipes and components until 100 mm in normative diameter while the other flammable refrigerants need traceability at 25 mm.

During refrigerants change, the challenge has been to develop a non-flammable low-GWP R410A substitution. This was impossible with H, C and F based molecules, but this has changed in recent years. R466A is a refrigerant designed for R410 drop-in, with a GWP of 730, and it's composed by R32, R125, and CF3I. The CF3I molecule contains Ionide, and is known as flammability suppresser, but it also has an ODP value. Material compatibility, development, and testing of components is ongoing, and full regulatory acknowledgement is still pending.



Figures 7a and 7b: The main replacement options and their composition and GWP levels



Paving the way

– Standardization and risk assessment

All refrigerants can be safe if standards and safe handling guidelines are followed. Standards ensure common practices, technological alignment, and legal conformity. This last point being important from the industry's point of view since it reduces risk and provides legal assurance when new products are developed. Danfoss participates in the standardization task-forces that contribute to the development of important safety standards such as ISO 5149, EN378, and ASHRAE 15.

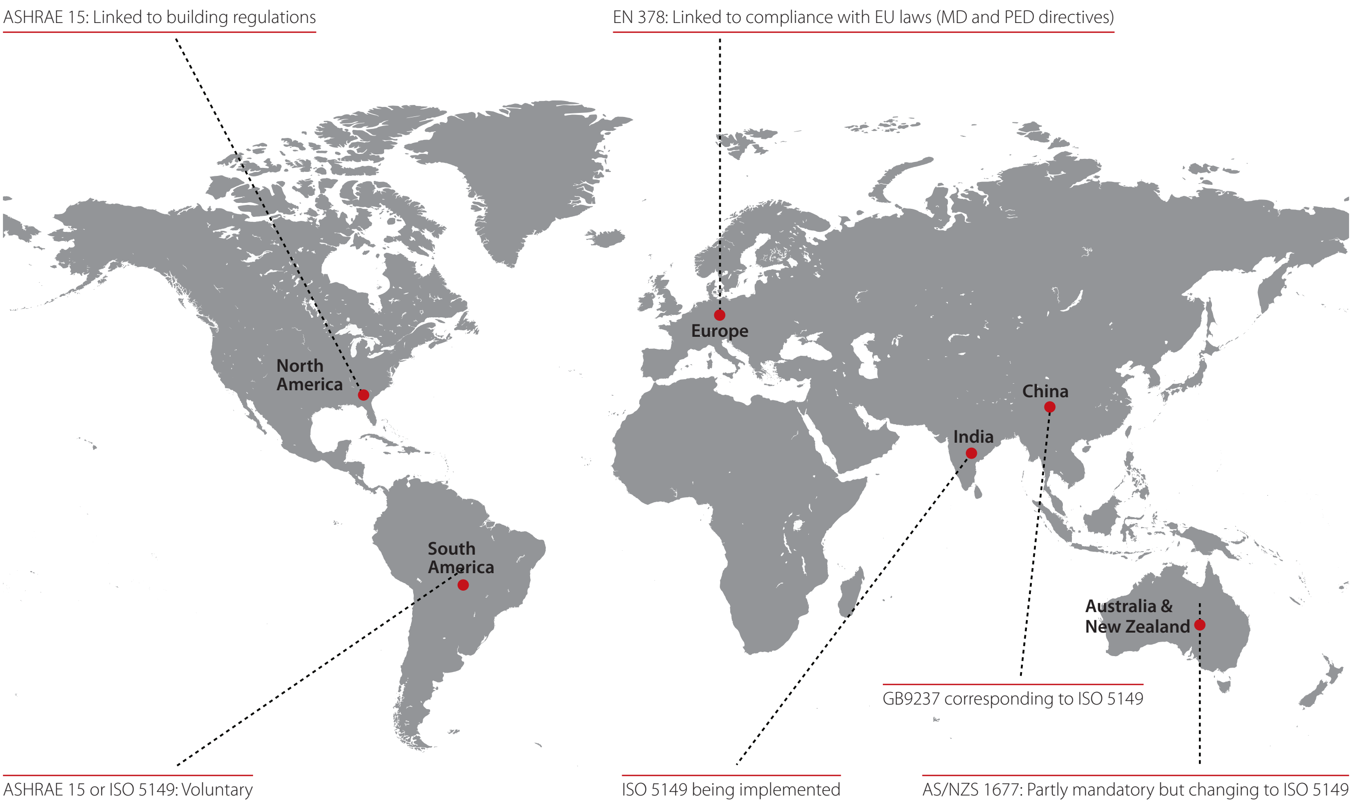


Figure 8: Global overview of Standards

In figure 9 below and according to ASHRAE 34, refrigerants are divided into classes depending on toxicity and flammability. A1 refrigerants are non-flammable and have very low toxicity. On the other end of the scale, with high flammability and high toxicity, no B3 refrigerants are available. Hydrocarbons, characterized by low toxicity and high flammability, require special precautions. Ammonia, on the other hand, is a highly toxic and has low flammability. It is widely used, especially in industrial refrigeration, and is very efficient.

The A2L subgroup is made up of refrigerants with a low flammability. Flame propagation speed is low, less than 10 cm/s. These refrigerants are expected to play a significant role in the future as we move away from the old high GWP HFCs.

Increasing Flammability	Increasing Toxicity	
	Lower Toxicity	Higher Toxicity
No flame Propagation	A1: CFC, HCFC, most HFCs	B1: Seldom used
Lower Flammability	A2L: Most HFOs, R32	B2L: Ammonia
Flammable	A2: R152	B2: Seldom used
Higher Flammability	A3: Hydrocarbons	B3: no refrigerants

Figure 9: Refrigerant classes

Figure 10 shows how refrigerant standards are connected with safety standards. For example, ASHRAE 34was used in ISO 817 to create the refrigeration classifications. These classifications are in turn used in safety standards like ISO 5149, ASHRAE 15, and the European safety standard EN 378.

When evaluating refrigerants, risk awareness is always a crucial parameter. Ask yourself, "What level of risk is acceptable?" Before answering, keep in mind the difference between perceived and actual risk. Perceived risk of the new refrigerant tends to be seen as higher than the actual risk. As industry competence and user experience increase, we will see a reduction in the perceived risk of using a refrigerant. Compare this to the perceived risk of flying versus driving a car: driving a car is often perceived as being safer than air travel, while the opposite is actually true.

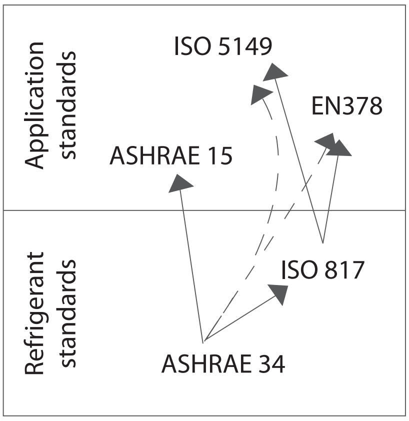


Figure 10: Refrigeration and Application Standards

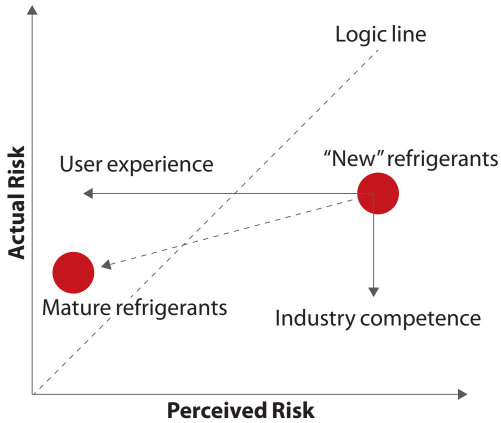


Figure 11: Perceived and Actual Risk

The development of standards is moving towards a wider acceptance of flammable refrigerants. Figure 12 presents an overview of the development of the main standards and the inclusion of flammable refrigerants.

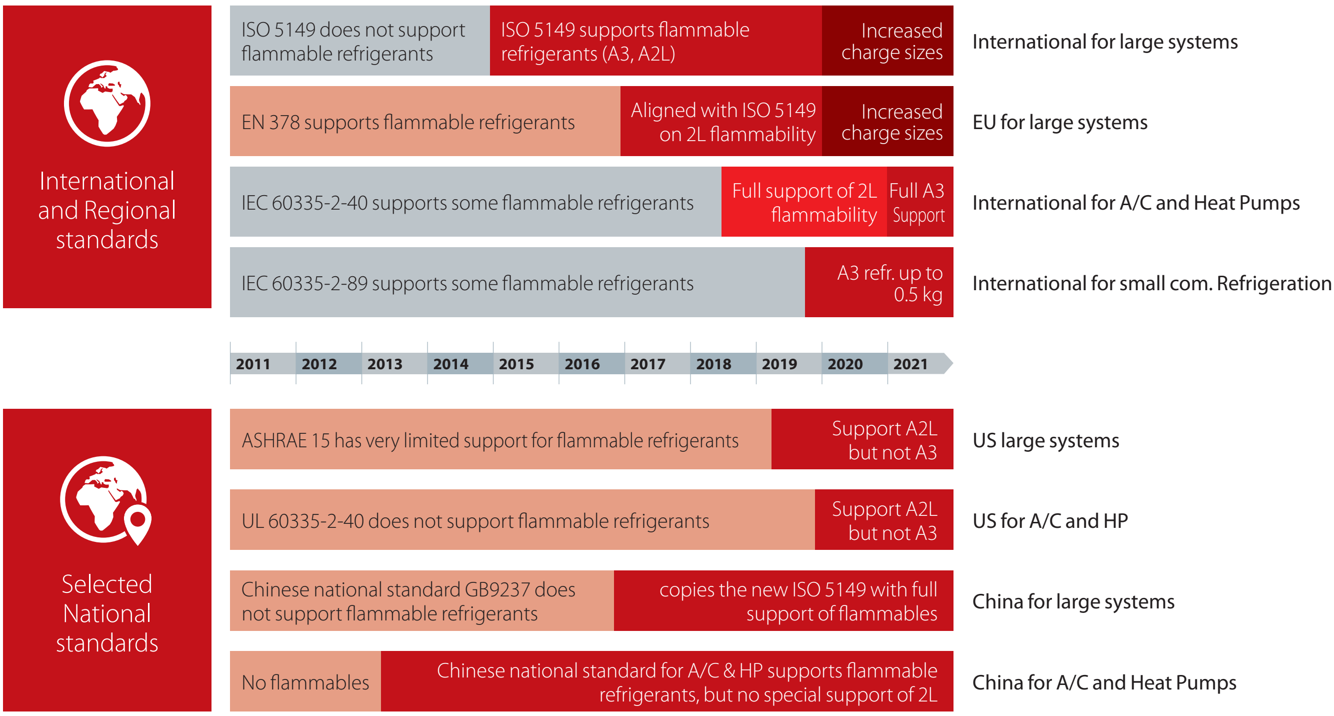


Figure 12: Timely – Safety Standards Development.
Recognising the need for flammable refrigerants.

Before shifting to a new refrigerant with a higher flammability, a comprehensive process should be followed. For more than a decade, Danfoss has been developing products to be used with hydrocarbons. By performing risk assessments, we are able to predict the likelihood of hypothetical failures, the results of which are used to develop internal standards to regulate products that use flammable refrigerants. We then consult with insurance providers and obtain approval for the new refrigerant. Finally, upper management approves the refrigerant and the results are implemented by the relevant product manager. As a result of continuously developing refrigerant failure scenarios, we have adjusted our internal standards on flammable refrigerants to reflect the actual risk of using them. Today, we offer a comprehensive program of controls for flammable refrigerants on a global scale.

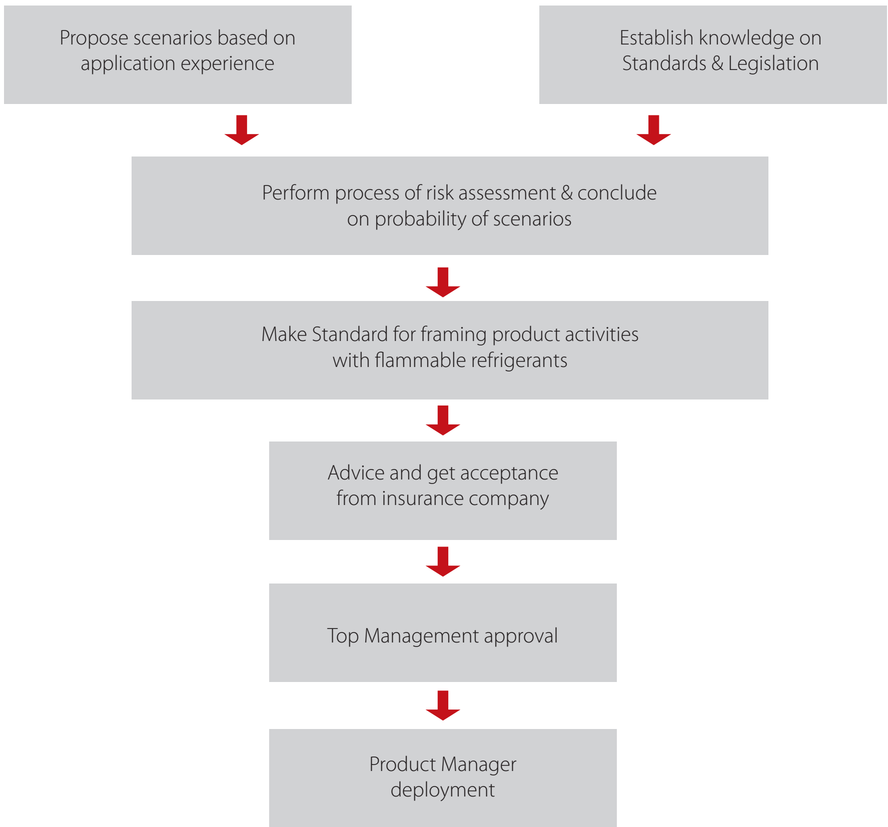


Figure 13: Danfoss' approval process

Conclusions

Refrigerants are a necessity in today's world and they will have a great impact on the world to come. While some of yesterday's solutions have had consequences for today's environment, it is imperative that the industry looks ahead to find future-proof solutions to current challenges. Doing so effectively will require a solid working partnership with a company that not only possesses a dynamic history and a comprehensive knowledge of the current standards, legislations, and emerging technologies, but also maintains an eye on the future in terms of safety and environmental responsibility.
Danfoss is just such a company.

With over eighty years of experience, combined with our willingness to meet the challenges of the future, we are an industry leader that is poised to offer our partners reliable solutions. Danfoss is ready to work with you in defining and implementing the best alternative for your applications. Together we can conquer today's challenges while addressing the needs of tomorrow.

Annex 1.

Legislation and regulation

Montreal Protocol

With the 2016 inclusion of a global HFC phase down the Montreal Protocol now has two regimes to control; the ODP and the GWP substances. The phase out schedule for the HCFC can be seen in table 2 and the phase down schedules for HFC can be seen in table 3. It is worth noticing that the non-A5 countries rely on baselines that are frozen already while the A5 countries has a combination of the HCFC quota (already frozen) and a HFC consumption which has yet to come. This has triggered some speculation on the incentives for A5 counties to have an early move to low GWP refrigerants as this would decrease their baseline.

Annex C – Group I: HCFCs (consumption)

Non-Article 5(1) Parties: Consumption (Developed Countries)		Article 5(1) Parties: Consumption (Developing Countries)	
Base level:	1989 HCFC consumption + 2.8 per cent of 1989 CFC consumption	Base level:	Average 2009 – 2010
Freeze:	1996	Freeze:	January 1, 2013
35% reduction	January 1, 2004	10% reduction	January 1, 2015
75% reduction	January 1, 2010	35% reduction	January 1, 2020
90% reduction	January 1, 2015	67.5% reduction	January 1, 2025
100% reduction	January 1, 2020, Allowance of 0.5% of base level consumption untill January 1, 2030 for servicing of refrigeration and air-conditioning equipment existing on 1 January 2020.	100% reduction	January 1, 2030, Allowance of 2.5% of base level consumption when averaged over ten year 2030 – 2040 untill January 1, 2040 for servicing of refrigeration and air- conditioning equipment existing on 1 January 2030.

Table 2: HCFC phase out schedule and baselines
Source: UNEP

	Non A5-1	Non A5-2	A5-1	A5-2
Freeze	–	–	2024 (100%)	2028 (100%)
Step 1	2019 – 90%	2020 –95%	2029 – 90%	2032 – 90%
Step 2	2024 – 60%	2025 – 65%	2035 – 70%	2037 – 80%
Step 3	2029 – 30%	2029 – 30%	2040 – 50%	2042 – 70%
Step 4	2034 – 20%	2034 –20%	–	–
Final	2036 –15%	2036 –15%	2045 – 20%	2047 – 15%
Countries	All non A5 except non A5-2 and the EU	Belarus, Russia, Kazakhstan, Tajikistan, Uzbekistan	All A5 expect A5-2	India, Pakistan, Iran, Iraq, Bahrain, Kuwait, Oman, Qatar, Saudi, Arabia, UAE
Baseline	HFC-average (2011 – 2013) + 15% of HCFC baseline (non-A5)	HCFC-average (2011 – 2013) 25% of HCFC baseline (non-A5)	HCFC-average (2020 – 2022) 65% of HCFC baseline (A5)	HCFC-average (2024 – 2026) + 65% of HCFC baseline (A5)
Comments	HCFC phase out plan does not correspond to the 15% in 2011 - but likely reflects actual consumption	HCFC phase out plan corresponds to the 25% in 2010 – 2014	HCFC phase out plan corresponds to the 65% in 2020 – 2024	HCFC phase out plan corresponds to the 65% in 2020 – 2024

Table 3: HFC phase down schedule and baselines
Source: UNEP

MAC Directive (EU)

This directive bans the use of any refrigerant with a GWP above 150 in air conditioning systems in motor vehicles starting from:

- January 2011 for new models of existing vehicles
- January 2017 for all new vehicles

The directive does not cover other applications.

R134a, still the globally most common refrigerant in MACs, has a GWP of 1430 and is thus affected by the ban as well. R1234yf is increasingly being introduced and today several millions of cars are using this HFO in the US and the EU.

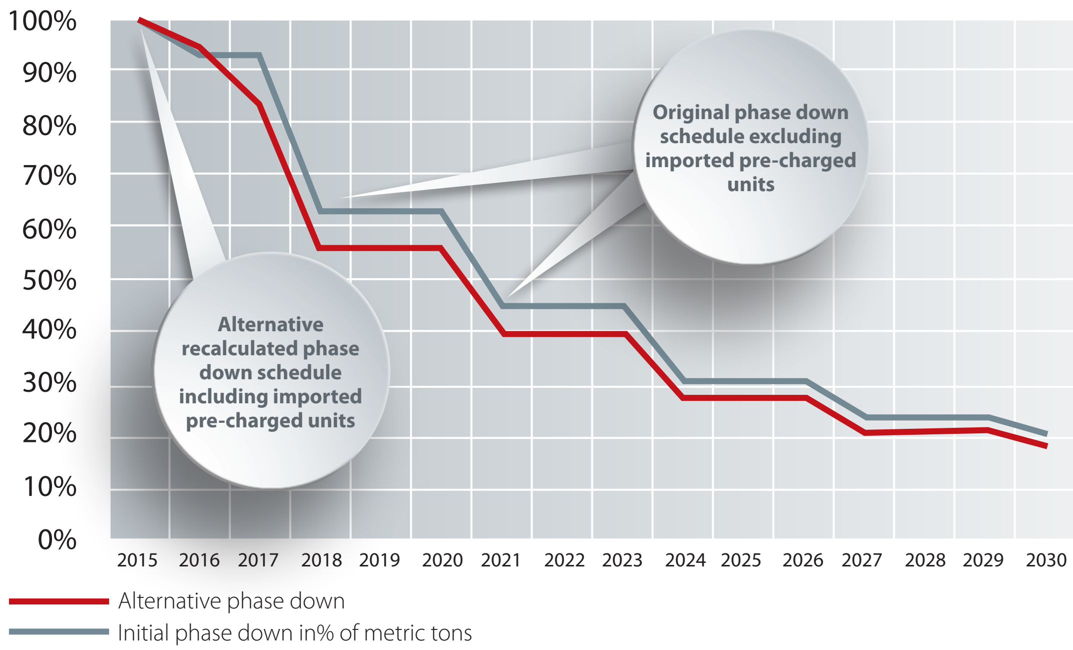
F-Gas Regulation (EU)

The F-gas regulation was implemented at January 1, 2015. The regulation put in place an HFC phase-down from 2015 to 2030 by means of a quota system and sectorial bans on high GWP refrigerants. R404A/R507 is especially under pressure and likely to be phased out of all commercial systems. A quota allocation mechanism has been made and the first phase-down step was accomplished in 2016 and 2017, with quotas reduced by 17% compared to baseline. The quota system mechanism assigns quotas to producers and importers of bulk gases. Quota holders can transfer part of their quota via authorizations e.g. to importers of pre-charged units. Authorizations can again be delegated but only ones. All operations must be reported in the central registry to ensure compliance with the regulation. For more detailed descriptions and Q&A documents please refer to the EU homepage or to the EPEE homepage.

The import of pre-charged units and the need for retrofit of R22 systems with HFC replacements are not taken into account in the baseline for the phase down. The import of pre-charged units is estimated to at 11% to the official baseline. As the amount of HFC import in pre-charged units is in the official quota from 2017, it has created extra pressure on the availability of HFCs.

By adding the pre-charged units demand into the phase down steps and assuming a constant consumption in metric tons over the years a different scenario become evident. By 2018 the quota falls to 56 percent of the baseline compared to previous 63%. The 2030 target of 21% of baseline becomes in reality around 19%. The calculations can be seen in figure 14.

The expected composition of the phase down until 2021 is outlined in figure 15. It is obvious that the Refrigeration sector will be the main contributor to the phase down while AC and HP will gain more contribution later.



Year	Original phase down schedule
2015	100%
2016	94%
2017	83%
2018	56%
2019	56%
2020	56%
2021	40%
2022	40%
2023	40%
2024	28%
2025	28%
2026	28%
2027	21%
2028	21%
2029	21%
2030	19%

Figure 14: The EU phase down depending on inclusion of pre-charged units or not.

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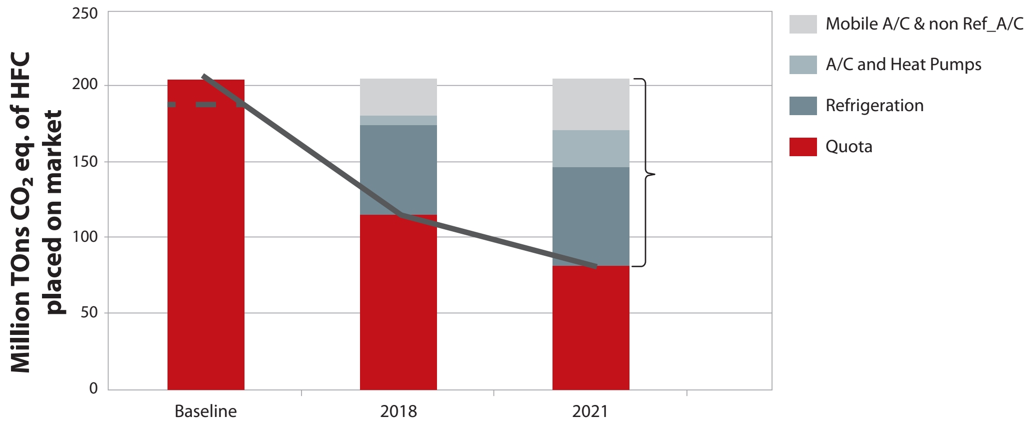

Figure 15: The sectorial contribution to the EU HFC phase down
Source Danfoss from EPEE Gapometer Project

Observations in the middle of 2018 show that refrigerant prices have increased by up to 500% for the most common types of HFC's like R404A, 134a, and recently R410A, which has taken the lead in price increases. Furthermore, it has been reported that a lot of equipment placed on the market in 2015 and 2016 still relies on a high-GWP HFC. Also bearing in mind the additional quota surge from pre-charged units from 2017, it becomes very difficult to predict how a real supply versus demand picture becomes mature. The only good advice is to make a detailed plan for replacing refrigerants with a high GWP. R410A is the only refrigerant which doesn't have an A1 class substitute with a lower GWP alternative(see figure 6). Based on that, R410A might be the only old main stream HFCs that will be used in the coming years – albeit at a higher price. A fast transition to lower-GWP alternatives is likely to happen to avoid shortages in the market.

Equipment bans

The phase down schedule is complemented with bans on new equipment and bans on servicing equipment with high GWP refrigerants, as shown in figure 16. Although the service bans are far into the future, they are within the expected lifespan of today's new equipment. This puts pressure on the industry now to stop building R404A/507 systems.

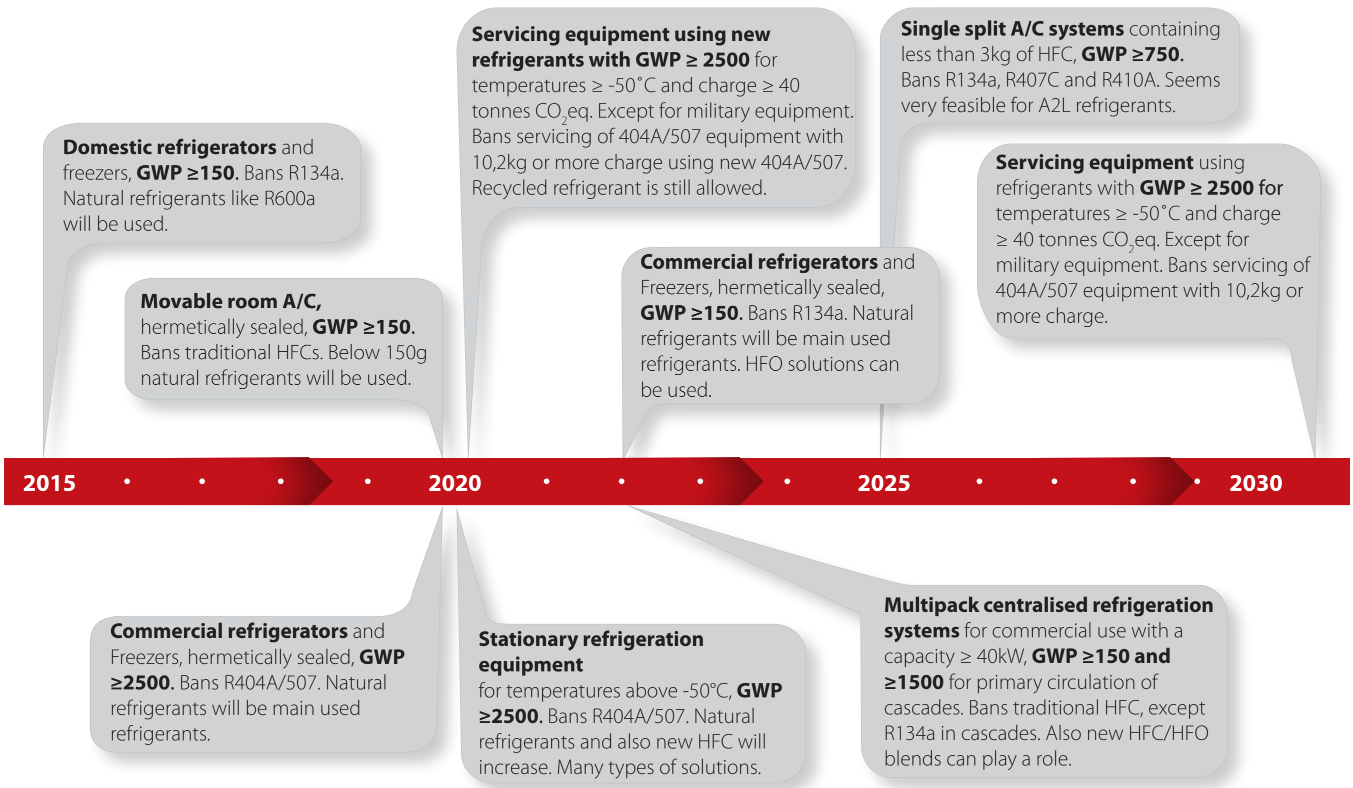

Figure 16: Bans on new equipment

SNAP (US)

As a tool for implementation of the ODP phase-out back in 1989, the Environmental Protection Agency (EPA) in the United States developed the Significant New Alternative Policy (SNAP) Program. The original purpose of the SNAP program was promoting a safe and smooth transition away from ozone depleting substances. The mechanism of SNAP is to accept, or eventually ban specific refrigerants for usage in certain applications. But between 2014 and 2016, it was also used to exclude certain high GWP HFCs once accepted. This exclusion of non ODP substances was recalled by court in 2017. There are 17 main applications in table 4 (Chillers covers 4).

During 2014 to 2016 exclusion dates of main high GWP HFCs in main application sectors were set, while new low or medium GWP HFC/HFOs and even HCs received acceptance for specific applications. To illustrate the development of synchronized delisting of high GWP refrigerants with the acceptance of lower GWP refrigerants an overview of the main sectors is outlined in table 4. For a full specific and updated list of accepted alternatives and dates of exclusion of present accepted refrigerants it is recommended to consult the SNAP homepage.

The first rule was Rule 17, which allowed four specific hydrocarbons for use in household refrigerators and freezers and retail food refrigeration. These hydrocarbons include up to 57g R600a for the household segment and up to 150g R290 for the retail segment. Since this rule several other applications have been allowed and an overview of the applications affected, with charge limits similar to Rule 17, and additional rules are being proposed.

The Clean Air Act Section 608 extends the requirements for usage of refrigerants. It lowers the leak rate thresholds that trigger the duty to repair ACR equipment:

- Lowers from 35% to **30%** for industrial process refrigeration
- Lowers from 35% to **20%** for commercial refrigeration equipment
- Lowers from 15% to **10%** for comfort cooling equipment

It requires quarterly/annual leak **inspections** for ACR equipment that have exceeded the threshold leak rate and requires owners/operators to submit **reports** to EPA if systems containing 50 or more pounds of refrigerant leak 125% or more of their full charge in one calendar year. It further requires technicians to keep a record of **refrigerant recovered** during system disposal from systems with a charge size from 5 – 50 lbs.

The California Air Resources Board (CARB) has gone ahead with an aggressive plan for an early phase-down of HFCs. The proposed regulation prohibits the use of certain high GWP and HFC substances in new and retrofit stationary refrigeration equipment, and blowing agents in foam end-uses. This regulation was originally released for public review on January 30, 2018. Final public comments on the draft regulation send out is July 2nd 2018. The planned date for the regulation to become effective is mid-2018 and the first application bans on specific HFC are due January 2019.

Note: In August 2017, the US Supreme court ruled against the practice of delisting HFCs. At present this decision has been appealed and the outcome of this is not yet known. In July 2018 it was announced that eleven US states filed suit against the EPA for "effectively rescinding" regulations prohibiting the use of HFC refrigerants.

<table>
<tr><th>Year</th><th>System limit for refrigerant containment in new stationary systems</th><th>GWP limit</th></tr>
<tr><td>2021</td><td>Refrigeration systems ≥ 50 pound</td><td>150</td></tr>
<tr><td>2021</td><td>Refrigeration systems ≥ 20 and ≤ 50 pound</td><td>1500</td></tr>
<tr><td>2021</td><td>Air-conditioning systems ≥ 2 pound</td><td>750</td></tr>
<tr><td>2021</td><td>Chillers</td><td>150</td></tr>
<tr><th></th><th colspan="2">Sales restriction on refrigerants</th></tr>
<tr><td>2021</td><td rowspan="2">No production, import, sales, distribution, or entry into commerce</td><td>2500</td></tr>
<tr><td>2024</td><td>1500</td></tr>
</table>

Table 4: Detailed view of California's regulation on HFC restrictions

<table>
<tr><th>Applications</th><th>New/ Retrofit</th><th>Prohibited Substance</th><th>Eff. Date</th></tr>
<tr><td rowspan="2">Super Market Systems Remote Condensing units</td><td>New</td><td>HFC-227ea, R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A</td><td>Jan. 2019</td></tr>
<tr><td>Retrofit</td><td>R-404A, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A</td><td>Jan. 2019</td></tr>
<tr><td>Stand-alone MTunits with a compressor capacity below 2,200 Btu/hr and not containing a flooded evaporator</td><td>New</td><td rowspan="3">FOR12A, FOR12B, HFC-134a, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03</td><td>Jan. 2019</td></tr>
<tr><td>Stand-alone MTunits with a compressor capacity below 2,200 Btu/hr containing a flooded evaporator</td><td>New</td><td>Jan. 2020</td></tr>
<tr><td>Stand-alone MT units with a compressor capacity equal to or greater than 2,200 Btu/hr (new)</td><td>New</td><td>Jan. 2020</td></tr>
<tr><td>Stand-alone low-temperature units</td><td>New</td><td>HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)</td><td>Jan. 2020</td></tr>
<tr><td>Stand-alone units</td><td>Retrofit</td><td>R-404A, R-507A</td><td>Jan. 2019</td></tr>
<tr><td rowspan="2">Vending Machines</td><td>New</td><td>FOR12A, FOR12B, HFC-134a, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407C, R-410A, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-426A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), SP34E</td><td>Jan. 2019</td></tr>
<tr><td>Retrofit</td><td>R-404A, R-507A</td><td>Jan. 2019</td></tr>
<tr><td>Refrigerated food processing and dispensing equipment</td><td>New</td><td>HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), R-404A, R-407A, R-407B, R-407C, R-407F, R-410A, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)</td><td>Jan. 2021</td></tr>
</table>

Table 5: Outline of California's restrictions on HFC

China HCFC Phase-out Management Plan (HPMP):

The HFC phase down will follow the Montreal Protocol schemes agreed in October 2016. The total picture of the HCFC phase out and the HFC phase down is seen in figure 16. To fulfil the HCFC phase out plan, the Chinese authorities are supporting projects for replacing HCFCs with alternative refrigerants according to the phase out plan which can be found on the UNEP homepage.

The evaluation of candidates has not just focused on the ozone depletion potential (ODP), but also on GWP, safety and suitability for the application. The recommendations from the Chinese authorities depends on the application and the time perspective, see table 6. Among the recommendations are to use a variety of known low GWP refrigerants. The recommendations are backed by the adoption process of international safety standards like ISO 5149 (GB9237) and the IEC 60335 series – see table 7 for overview. These standards are under review and update as the versions indicate.

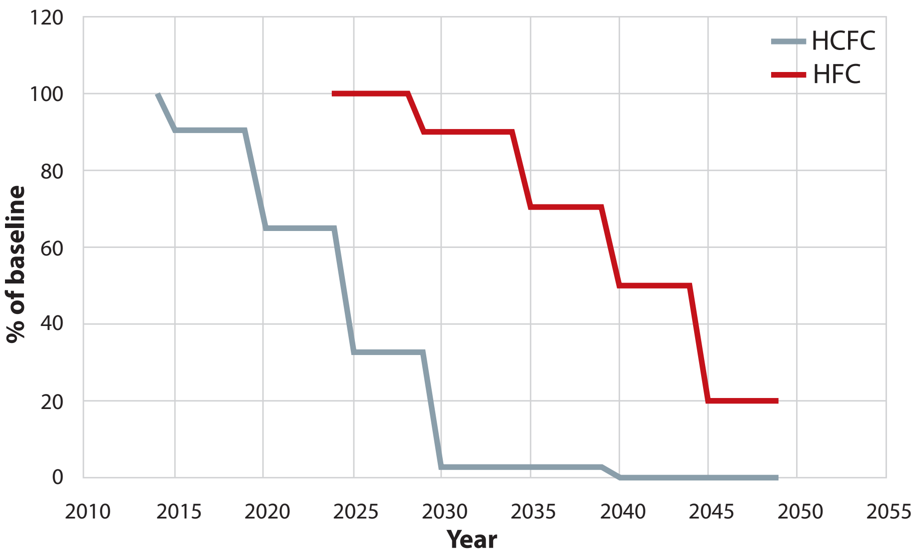

Figure 17: The HCFC phase out and the HFC phase down for China

Application	Present	Short term (-2020)	Long term (-2025)
Household refrigeration	R22 / R600a	R600a	R600a
Industrial and Commercial Refrigeration	R22 / R134a / R410A / NH_3	R134a , NH_3	NH_3/CO_2, R290, R600a, Low GWP Blends
Small and medium Chillers	R22, R410A	R410A,R32	R290, R32
Large Chillers	R22, R123, R134a	R134a, R1234ze	R1234ze, NH_3
Unitary AC / VRF / Heat Pumps	R22, R410A, R407C	R410A,R32	R32 , Low GWP blends
Room AC	R22, R410A	R410A,R290	R290, R32

Table 6: Refrigerant options per application

China standard		IEC standard		
No	latest version	Corresponding version of IEC	No	latest version
GB4706.13	2014	2012	IEC60335-2-24	2012
GB4706.32	2012	2005	IEC60335-2-40	2013
GB4706.102	2010	2007	IEC60335-2-89	2015

Table 7: The IEC60335 series versus the Chinese standards

Japan

Japan has in 2014 introduced a comprehensive program to reduce the emission of HFCs. The program is a lifecycle approach to reduce the GWP of the applied HFCs as well as to reduce the leakage of systems in the field (service and recycling) and during end of life. The system does not apply direct bans or specific quota allocation as seen in the US or the EU. Instead it targets specific GWP values for specific applications combined with a labelling program.

Application	Target GWP value (MAX)	Target year for full implementation
Room Air Conditioning	750	2018
Commercial Air Conditioning	750	2020
Commercial Refrigeration	1500	2025
Cold Storage	100	2019
Mobile Air Conditioning	150	2023

Table 8: GWP values and timeline

Other local initiatives

A number of countries and regions have already taken steps to promote low-GWP alternatives. Such steps include a cap on the refrigerant charge (Denmark), taxation of high-GWP refrigerants (for instance in Denmark, Norway and Australia), and subsidies for systems that use natural refrigerants (for instance in Germany and the Canadian province of Quebec).

Annex 2.

Impact of direct leakage as a function of the leakage rate

Example:
The following example can serve to illustrate the relationship between direct and indirect impacts.

Typical refrigerant plant in a medium sized supermarket:

- Store size: 1000 – 1500 m²
- Refrigerant: R404A
- Refrigerant charge: 250 kg
- Cooling capacity: 100 kW
- Energy consumption: 252000 kWh/year
- Service life: 10 years
- GWP: 3920
- Operating time: 19 hours per day
- Recovery/recycling: 90%

CO_2 emissions from electricity production
Country A (fossil fuels): 0.8 kg CO_2 per kWh
Country B (hydro and wind power): 0.04 kg CO_2 per kWh

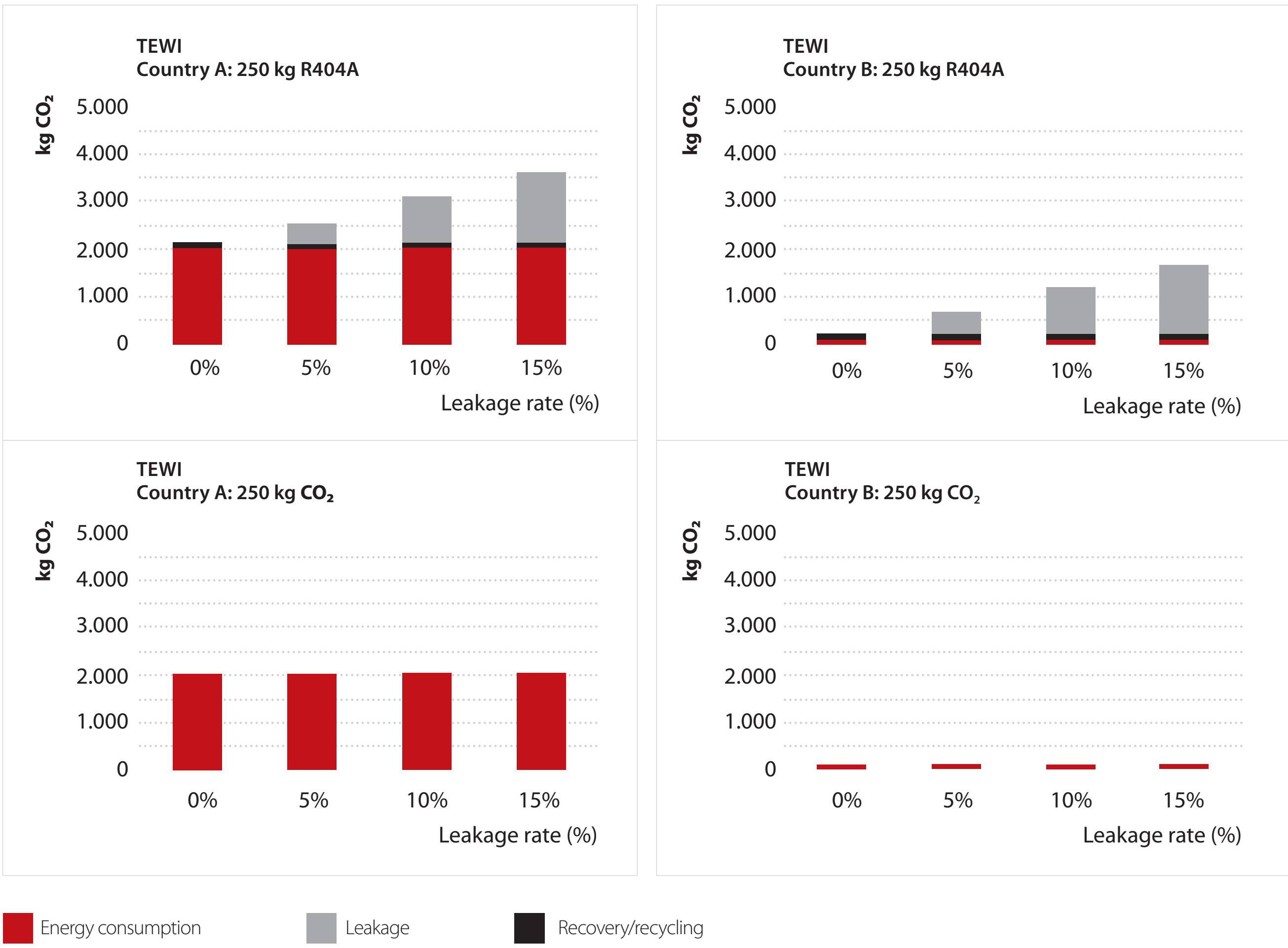

Figure 18: Relationship between the direct and indirect impacts of the refrigeration system

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Danfoss invests in development of products for low GWP refrigerants, both natural and synthetic to fulfil customers' needs for practical, safe and energy efficient solutions. Our product portfolio already offers a full programme of control components for CO_2, ammonia and hydrocarbons. The Danfoss product range is constantly developed to offer state-of-the-art energy efficiency in every component, from compressors to heat exchangers and everything in between.

Obtaining sustainable solutions is a fine balance between affordability, safety and environmental concerns. Based on our long-standing, sustainable mindset and our dedication to pioneering new technologies, we consciously pursue new developments aimed to be sustainable balance.

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