ENGINEERING TOMORROW

Danfoss

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.

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 wellbeing 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.

Danfoss supports the establishment of a global regimen through the Montreal Protocol to phase down emissions of high GWP refrigerants.

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Executive Summary

Danfoss, world leader in the supply of compressors and controls to the refrigeration and air conditioning industry, has a product range that is among the most complete globally. You will find our products within a number of business areas, such as food retail, commercial- and industrial refrigeration as well as air conditioning, products for the wholesale refrigeration market and automation in various specific industrial sectors. More than eight decades of experience has made Danfoss the leader in developing products using refrigerants and evaluating the viability of new refrigerants.

This paper contains a condensed look at our experience and knowledge. It describes the background, the trends, and drivers that frame the scenarios for present and future refrigerant selection. While selecting new alternatives implies investments, cost and burdens, we strongly believe that if these selections are made correctly it can open doors for bridging new opportunities. These include combining heating and cooling systems, which is becoming a very efficient driver for CO_2 technologies.

The history of refrigerants is a long and cyclic story. It is believed that vapour compression systems will remain the primary technology used now and in the near future. It is anticipated that the consumption of refrigerants will grow strongly following the increasing demand from emerging economies. But the selection of refrigerant is a crucial decision since it will impact emission directly and indirectly.

Never has the refrigerant situation been so complex as it is now. EU has taken a clear direction towards phasing down HFCs while developing countries are expected to phase in HFCs as replacement for R22. This creates a dilemma in the Industry and among policy makers that has yet to be solved. In the meantime, in addressing long term sustainability, we must ensure sound decisions in the selection of the future refrigerants that encompass safety, environment and affordability. Many parameters should be assessed and monitored before taking a decision . In the meantime, present barriers can be overcome by advances in technological development, which in turn can systematically trigger a sound discussion. Our model for taking this discussion, as well as the description of some of the main decisive factors for the Industry, are outlined below.

History

One hundred-eighty years have passed since Jacob Perkins patented the vapour compression cycle, which launched the history of refrigerants. The vapor compression ensures and uses refrigerant as a fluid that transports heat from the cold to the hot side of a refrigeration system, heat pump, or air conditioning system. We use essentially the same thermodynamic cycle to this day, but the refrigerants have changed throughout time.

The figure 1 shows the development of refrigerants throughout 180 years. In the beginning all refrigerants were environmental friendly by definition as they could be found in nature. In the thirties, it became obvious that there were safety issues involving many of these refrigerants. There were many examples of fires and poisoning based on leakage of these refrigerants. At this time, the synthetic safety refrigerants called the CFCs were invented and were widely used on a global basis. During the 50's partly chlorinated refrigerants (HCFC) and the well known R22 were introduced.

In the early seventies, it was discovered that these refrigerants not only have a very long breakdown time in the atmosphere, they also cause destruction of the ozone layer. The CFCs have a particularly high Ozone Depleting Potential (ODP) while HCFC's are modest. As a consequence the Montreal protocol on Substances that Deplete the Ozone Layer was established, which is considered as a real global success on reducing dangerous chemical substances. The substitute refrigerants, called HFCs, have zero ODP but unfortunately medium to high Global Warming Potentials (GWP). Due to the threat of climate change, usage of HFCs is now being scrutinized to reduce their impact on the environment. Scientific investigations show that while the impact of HFC leakages may not be a major contributor to global warming presently, their growing consumption, especially within air conditioning in developing countries, will eventually make HFC a top contributor. The question of how to phase out high GWP HFC's with low GWP alternatives is the subject of an ongoing debate. This already led to the reintroduction of natural refrigerants and to the development of low GWP unsaturated HFC's referred to as HFO's, which due to their unstable chemical nature, have very short atmospheric life times and never reach the higher atmosphere.

In summation, if not handled properly, refrigerants may cause fatal short or long term consequences. History has been a learning path away from the flammable and toxic refrigerants to safe but long term not sustainable solutions. Technology developments together with safety standardization have eventually made it possible to move towards real long term solutions with zero ODP and low GWP refrigerants. At the same time energy efficiency measures have been developed to decrease the indirect emissions.

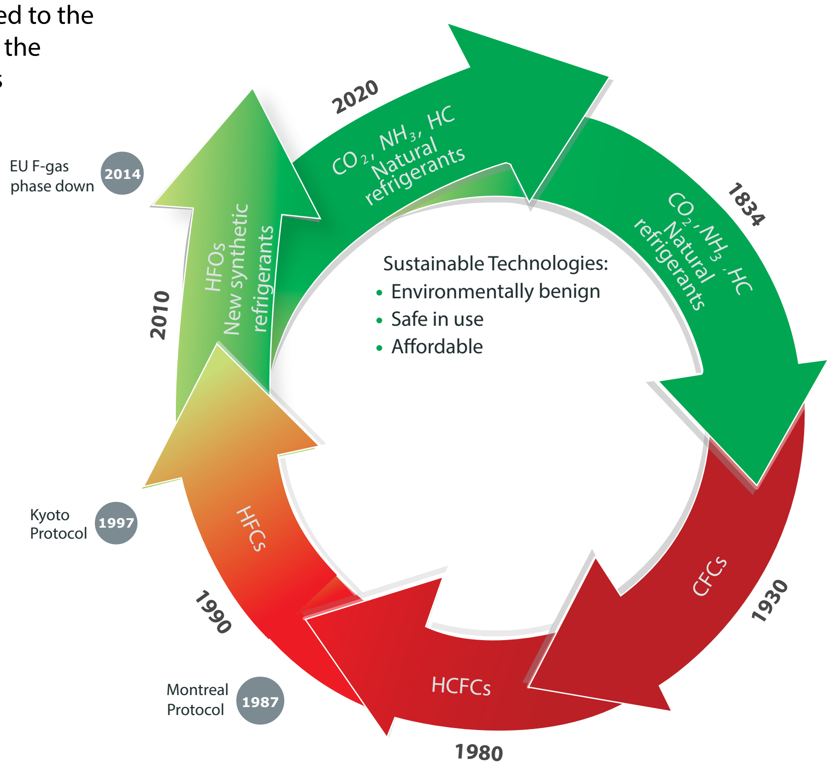


Figure 1: The historical cycle of refrigerants

Sustainability is the Key

Sustainable solutions are in the best interests of all stakeholders in our industry. Basically they safeguard long-term investments and ensure compliance with Corporate Social Responsibility (CSR). In retrospect it is clear that the refrigerant choices once regarded as sustainable were not. So when talking about refrigerants and long term sustainability, Danfoss considers three main parameters which must be aligned to accomplish a real sustainable balance: affordability, safety and environment.

When choosing a new refrigerant for an application all three parameters have to be considered simultaneously. If only one parameter is optimized, it will not be possible to achieve a sustainable result. It is important to look at the lowest life cycle cost, service availability for systems, COP of the system, flammability issues, toxicity, leak tightness and of course, the global warming potential. A sustainable solution will be achieved only when all these parameters are in balance. Creating this balance requires thorough evaluation and consideration of regional differences which influence these parameters as shown in Figure 2.

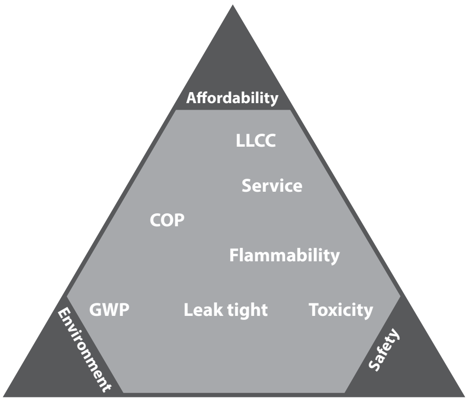
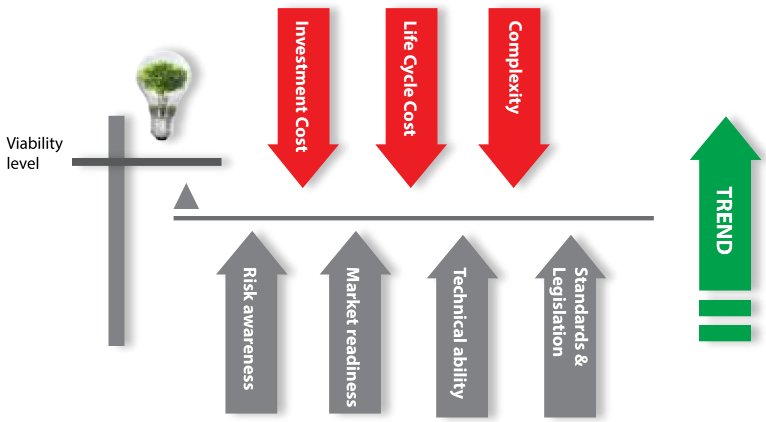


Figure 2: Refrigerant Sustainability Triangle

While sustainable outlooks seem clear, there are more influencing factors triggering industrial development and investments. To quantify the Industrial viability of developing new sustainable solutions to specific refrigerants, Danfoss has developed a model which breaks down the main parameters.

We call this the 7 Force model and is shown in figure 3. The red arrows refer to economics while the grey arrows relate to knowledge, education and legislation. When the balance between red and grey forces reaches the viability level there is a high potential for industry to invest in new solutions. When investing in new technology and competence build up, major drivers ensuring the certainty for industry are legislation and derived standardization.
The viability level has been increasing for many low GWP refrigerants during the last 10 years. Good examples are CO_2 for commercial refrigeration, especially supermarkets, and hydrocarbons for low charged vending machines.



1.	Investment cost	Investments in Product development
2.	Life cycle cost	Life cycle cost for the consumer. Contains up front cost and running cost
3.	Complexity	Complexity associated with manufacturing and marketing of the product
4.	Risk Awareness	Difference between perceived and actual risk using the product
5.	Market Readiness	Market competence in save 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

Regulatory certainty is, of course, vital. In figure 4 we chart an overview of phase outs and phase downs that have been imposed to the industry during the last years, and its projection into the future. The first phase out initiatives concerning the ozone depleting substances were regulated through the Montreal protocol. The dotted line shows the phase out of the developed countries in the EU. The second gray line shows the phase out of developed countries not part of the EU. The full phase out was accomplished in the EU in 2010 and will be achieved in the rest of the developed countries around the year 2020. The developing countries have begun the final phase out of R22, which will run until 2030. It is important to remember that R22 is a refrigerant used in many different applications, which makes achieving compliance a challenge.

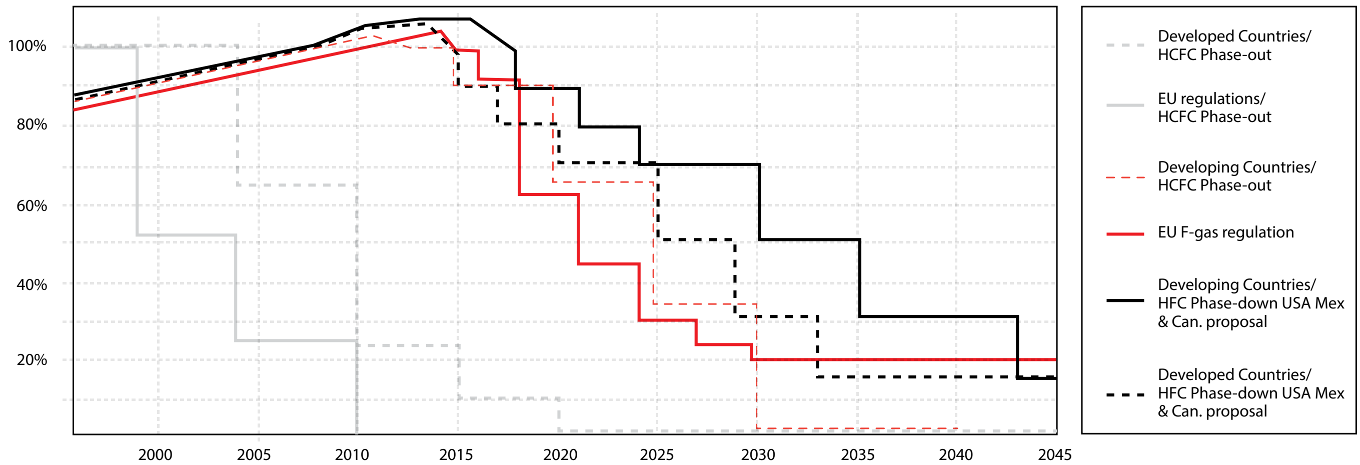


Figure 4: Refrigerant regulation timeline

For the last 5 years, it has been debated whether HFCs should be phased down under the scope of the Montreal Protocol. The proposed phase down is shown in dark violet for the developed and developing countries. Unfortunately there has not yet been a global agreement to ensure compliance. An agreement would be a strong signal to industry to develop low GWP products.

In Europe, in the spring of 2014, a new amended F-gas regulation was adopted as shown with the red line on the graph. This indicates that by 2015 there will be a phase down on HFCs. By 2018 is expected to it fall to 63% of current usage, a significant drop. The final target of 21% of today's usage is expected by 2030. This once more creates a significant challenge for industry. The phase down is managed by quota allocations and specific sectorial bans on high GWP HFC's.

Besides the refrigerant phase down and phase out mechanisms already discussed, governments are applying other measures for reducing environmentally heavy impacting refrigerants. In North America, the Significant New Alternatives Program (SNAP), includes hydrocarbon R290 as an alternative for small charge refrigeration applications, while it is proposing delisting the HFC R134a in favour of the new HFO R1234yf for mobile air conditioning.

In the developing countries in South America, Africa, the Middle East and Asia, the multilateral fund and the Montreal protocol are only supporting low to medium GWP projects in moving away from R22. This means that projects using R410A cannot get support while refrigerants around a GWP value of 700, such as R32, seem to have a good chance. R32 has a GWP of approximately one third of R410A.

As previously mentioned, Europe has only begun to phase down HFCs aiming to achieve a reduction of 79% by 2030. In addition to the F-gas regulation, national tax schemes on HFCs are also used as a tool in order to reduce the impact of refrigerants on the environment. For example, Spain, Denmark, Norway and Sweden have imposed taxes on HFCs. Additionally, national incentives in the form of subsidies on low GWP refrigerants are currently incorporated in Germany, Canada and many other countries.

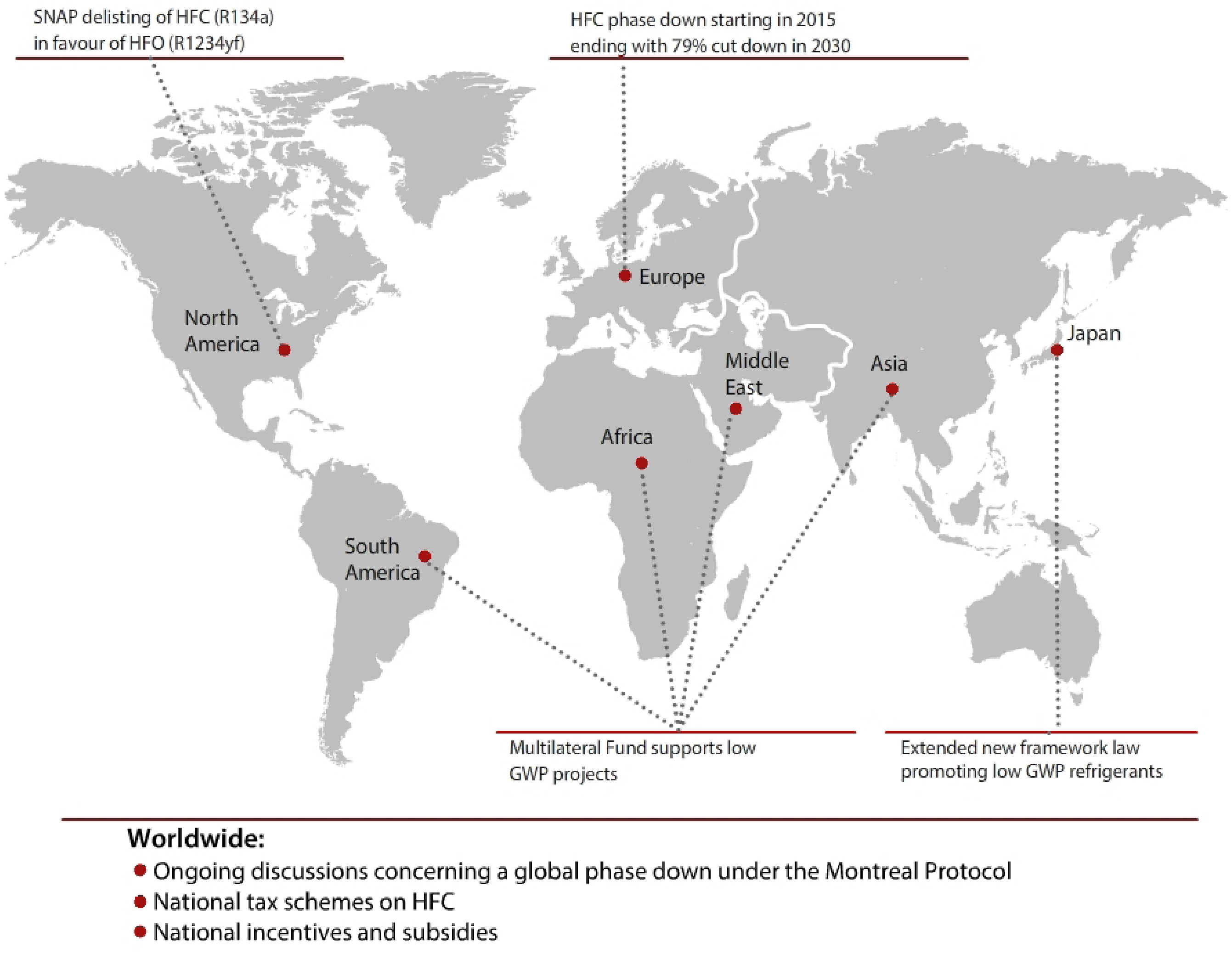


Figure 5: Global overview of refrigerant regulations

The Outlook

Our sustainability measure tells us that there is no doubt that the environment will continue to play a very important role when defining the development of the usage of refrigerants. System manufacturers require long-term solutions which are environmentally friendly. In looking at the different alternatives, everything points to lower GWP solutions. Natural refrigerants are by definition low GWP solutions and they will become the preferred choice whenever possible. However, safety will still be an important factor in regulating the usage of certain refrigerants. We foresee a wider acceptance of lower flammable refrigerants, especially now that they have been acknowledged by the new ISO standards. However, time will tell.

Our international group of experts within Danfoss has made a projection on the refrigerant outlook within the main sectors and regions. This outlook is condensed into the table shown below. As you can see CO_2 is a widely used refrigerant in industrial refrigeration and commercial racks. We believe that this trend that started in Europe will reach the rest of the world. Regarding the use of ammonia, we foresee that it will continue to be a very well accepted

		Refrigeration												Air Conditioning						Heatpumps					
	Application	Domestic-Household refigeration			Light Commercial refrigeration			Commercial Racks and Condensing Units			Industrial Refrigeration			Residential A/C (including Reversible systems)			Commercial A/C			Residential and Commercial Heatpumps			Industrial Heatpumps		
	Watt	50 - 300			150 -5000			> 5.000			> 1.000.000			1.000 - 20.000			> 20.000								
Refrigerant	Region/Year	2015	2020	2025	2015	2020	2025	2015	2020	2025	2015	2020	2025	2015	2020	2025	2015	2020	2025	2015	2020	2025	2015	2020	2025
CO_2	NAM				Red	Yellow	Yellow	Red	Yellow	Green	Yellow	Green *	Green												
	Europe				Red	Yellow	Yellow	Yellow	Green	Green	Yellow	Green	Green							Red	Yellow	Yellow			
	China				Red	Yellow	Yellow	Red	Yellow	Green	Red	Yellow	Green												
	ROW				Red	Yellow	Yellow	Red	Yellow	Green	Red	Yellow	Green							Red	Red	Red			
NH_3 (2L)	NAM							Red	Red	Yellow	Green	Green *	Green				Red	Red	Red				Red	Yellow	Yellow
	Europe							Red	Red	Yellow	Green	Green	Green				Red	Red	Red				Yellow	Green	Green
	China										Green	Green	Green				Red	Red	Red						
	ROW										Green	Green	Green				Red	Red	Red						
HC	NAM	Red	Yellow	Green	Red	Yellow	Green				Red	Red	Red												
	Europe	Green	Green	Green	Green	Green	Green	Red	Yellow	Yellow	Red	Red	Red	Red	Yellow	Yellow	Red	Red	Red	Yellow	Yellow	Yellow			
	China	Green	Green	Green	Green	Green	Green				Red	Red	Red		Yellow	Green									
	ROW	Green	Green	Green	Green	Green	Green				Red	Red	Red	Red	Yellow	Yellow									
HFC	NAM	Green	Yellow	Red	Green	Yellow	Red	Green	Green	Yellow	Yellow	Yellow	Red	Green	Green	Yellow	Green	Green	Yellow	Green	Green	Yellow			
	Europe	Red	Red	Red	Yellow	Red	Red	Green	Yellow	Red	Yellow			Green	Yellow	Red	Green	Yellow	Yellow	Green	Yellow	Red	Green	Red	Red
	China	Yellow	Red	Red	Green	Yellow	Red	Green	Green	Yellow	Yellow	Yellow	Red	Green	Green	Red	Green	Yellow	Yellow						
	ROW	Yellow	Yellow	Red	Green	Yellow	Red	Green	Green	Yellow	Yellow	Yellow	Red	Green	Green	Red	Green	Green	Yellow						
Mildly flammable HFC	NAM					Yellow	Yellow		Yellow	Yellow					Yellow	Green		Yellow	Green		Yellow	Green			
	Europe					Red	Yellow		Yellow	Red					Green	Green	Red	Yellow	Green	Red	Green	Green			
	China					Red	Yellow		Red	Yellow					Yellow	Yellow	Red	Green	Green						
	ROW					Red	Yellow		Red	Yellow					Yellow	Green	Red	Yellow	Green						

Ammonia/CO_2 cascades will dominate industrial refrigeration

Green: Main refrigerant
Yellow: Regular use
Red: Limited use and only niche applications
White: Not applicable or unclear situation

Table 1: Global trends in refrigeration and air conditioning (Status per 2014)

refrigerant particularly in Industrial Refrigeration. However, its toxicity means that safety measures will also have to be considered. It is very likely that in the future a cascade solutions of CO_2 and ammonia will be used. We still see that hydrocarbons, which are very efficient refrigerants, will play an important role in low charge systems around the globe. Regarding the use of HFCs, we believe that they will not disappear, but those being used will be with a much lower GWP. HFCs will experience a transition moving towards more environmentally friendly, but mildly flammable, versions. When dealing with mildly flammable refrigerants safety has to be addressed as a key parameter.

Refrigerant Options

Facing regulatory pressures to eliminate refrigerants with high GWP, many alternatives are being proposed to replace the current high GWP HFCs.

To date, most attention has been given to new unsaturated fluorochemical molecules, especially R1234yf and R1234ze, both also known as HFOs. There are also other molecules proposed such as R1233zd and R1336mzz(Z), which have not yet received as much attention.

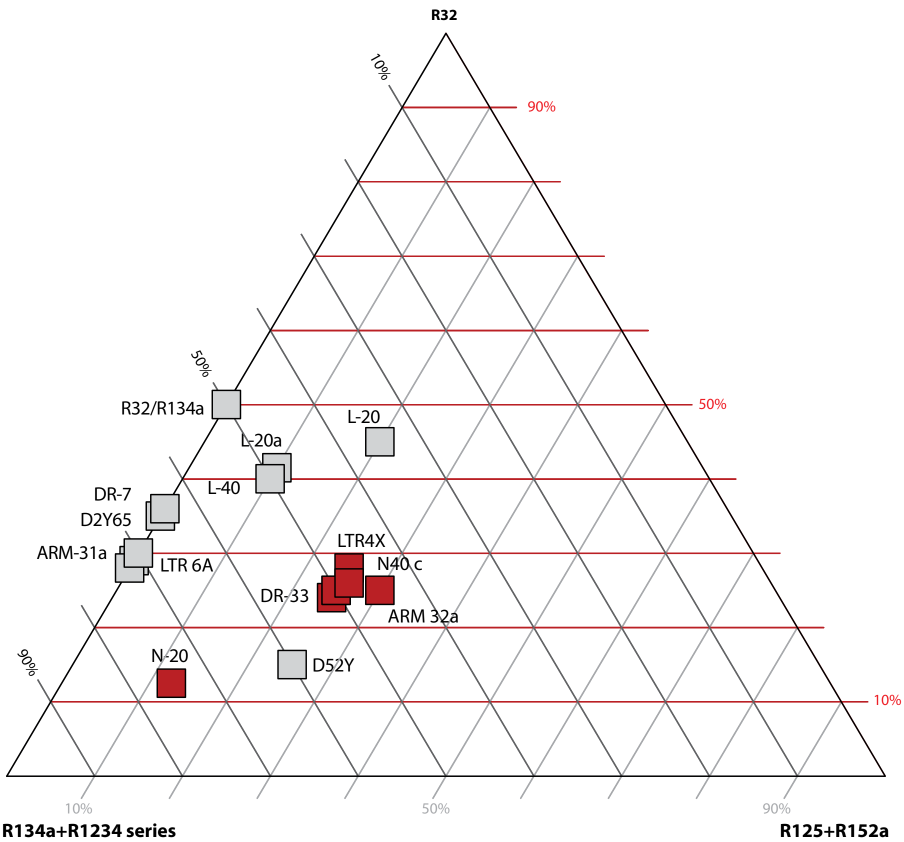


Figure 6: Refrigerant blends proposed to replace R22, R404A, and R407C

Most of the proposed refrigerants are blends. The blends are composed of R1234yf and/or R1234ze with already established HFCs. As seen on the figure 6 the many proposed blends are similar in composition with differences mainly based on which R1234 type is used and the exact refrigerant to replace.

There is, however, a trade off between lower GWP and flammability. As seen on the figure 7, for most of the popular refrigerants there are no simple low GWP drop-in solutions. When low GWP substitutes are chosen flammability needs to be considered. The flammability seems to be linked with the capacity of the refrigerants; higher capacity comes with a higher flammability, while low capacity refrigerants like the HCFC R123 have non-flammable substitutes.

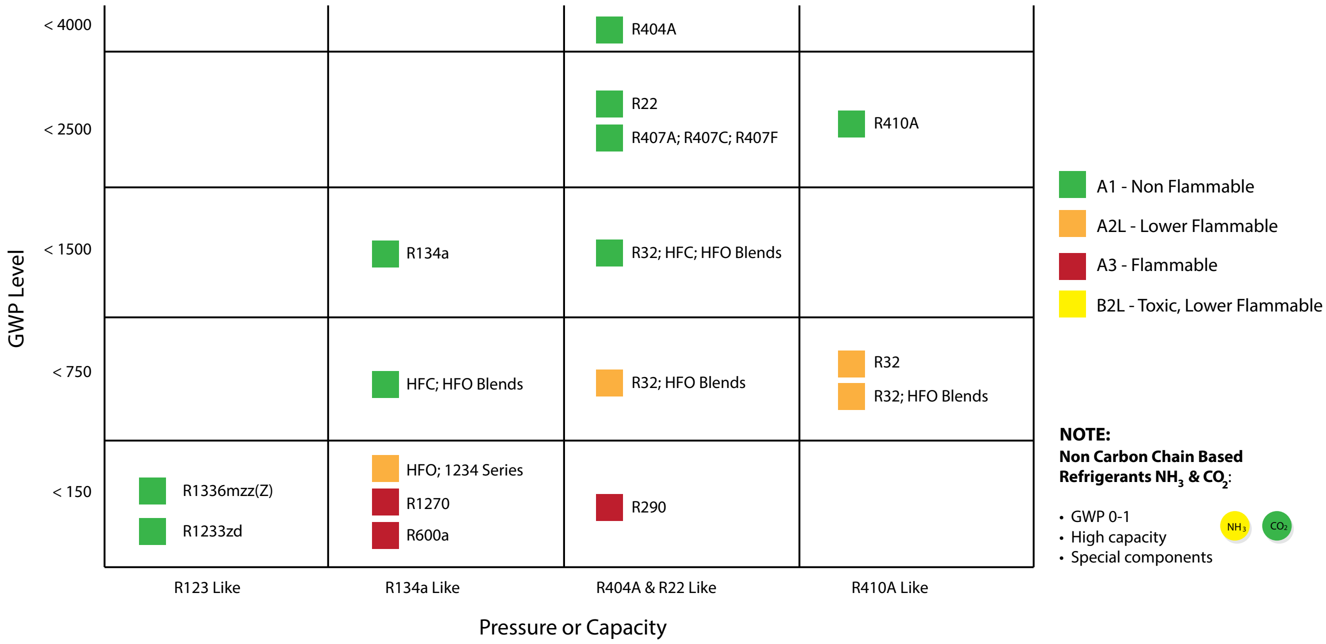


Figure 7: Carbon Chain Based Refrigerants (HCs, HFCs, HCFCs)

Paving the way
– Standardisation and risk assessment

All refrigerants are safe if standards are followed. The big question is always: are you are able to follow the standards?

In order to deal with Standards, it is important to have a good understanding of their scope and structure. There are different types of standards, including international, regional and national standards. Normally, these are all interconnected. The development of international standards is reflected in the national and regional standards, and those are adopted according to the specific circumstances of the country or region.

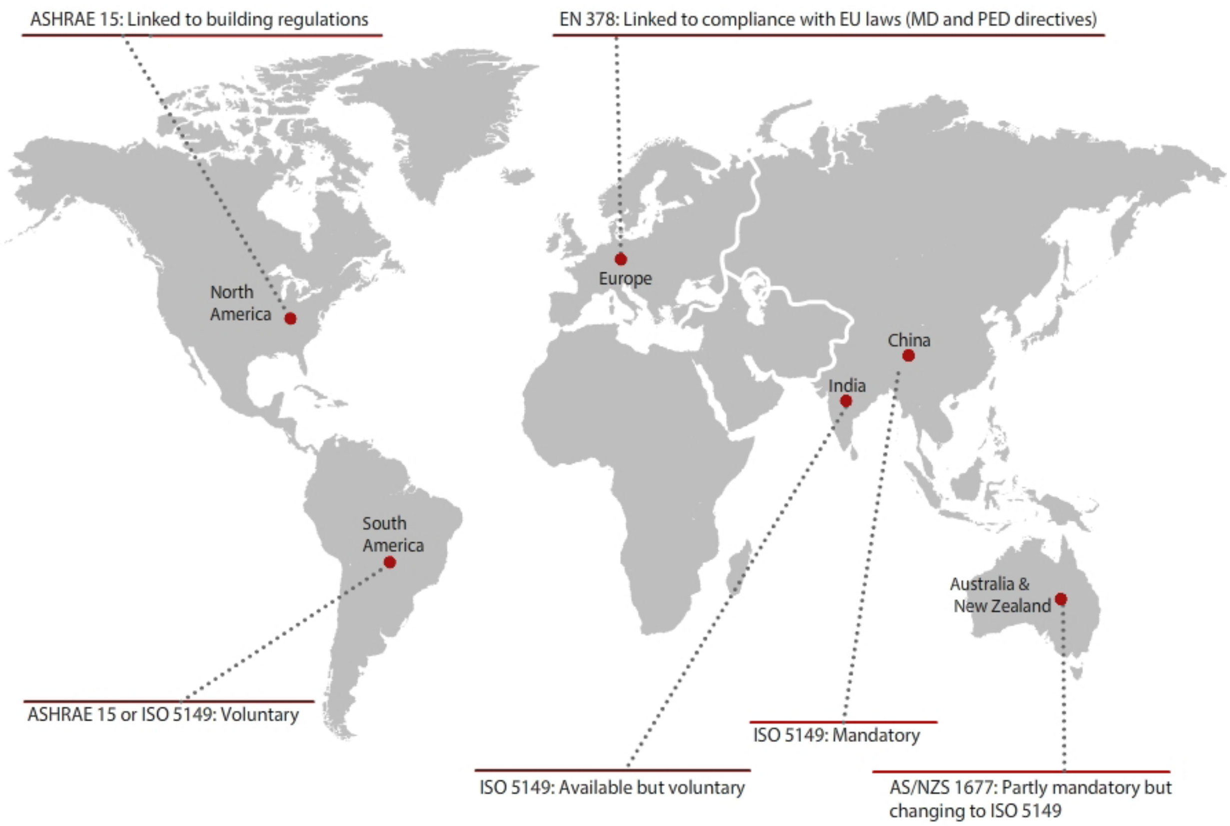


Figure 8: Global overview of Standards

Standards ensure common practice, technological alignment, and legal conformity, the last point being very important from an industry point of view since it reduces the risk and provides legal certainty when new products are developed. Danfoss participates in the standardization task forces taking part in developing important safety standards like the ISO 5149 and EN378.

In the graphic below, you can see an overview of refrigerants divided into classes depending on toxicity and flammability. A1 refrigerants are also called safety refrigerants. They have no flame propagation and have very low toxicity. On the other end of the scale, with high flammability and high toxicity, no refrigerants are available. Hydrocarbons are characterized by low toxicity and high flammability; special precautions have to be taken when dealing with these. Ammonia, on the other hand, has a high toxicity and low flammability. Ammonia is widely used, especially in industrial refrigeration, and is a very efficient and effective refrigerant.

Increasing Toxicity

Increasing Flammability

	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

A2L refrigerants are a new classification of refrigerants with low toxicity and a low flammability. The flame propagation speed is low and often these refrigerants are not able to sustain a flame once ignited. These refrigerants are assumed to play a significant role in the future, moving away from the old HFCs.

The figure 10 shows how refrigerant standards are interconnected with the safety standards, For example, ASHRAE 34 has been used in the ISO 817 in creating the refrigeration classifications. These classifications are used in the safety standards like the ISO 5149 and the future EN 378 (European safety standard).

When evaluating refrigerants, risk awareness is always a crucial parameter. We should always ask ourselves "What level of risk is acceptable?" Before answering this question it is important to be aware of the difference between perceived and actual risk. It is important to note that the perceived risk of the new refrigerant normally tends to be seen as higher than the actual risk. As industry competence and the users experience increase, we will see a reduction in the perceived risk of using a refrigerant. This can be compared to people's perceived risk of travelling by air plane compared to driving a car. Driving in a car is considered safer, while flying is normally perceived as more dangerous than the actual risk.

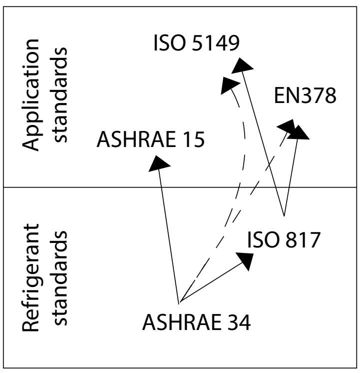


Figure 10: Refrigerants and Application Standards

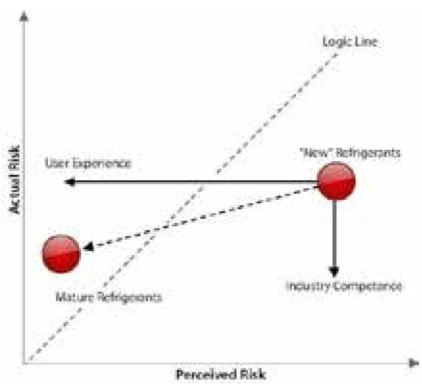


Figure 11: Perceived and Actual Risk

Before shifting to a new refrigerant with a higher flammability we have to go through a very comprehensive process. For more than a decade Danfoss has developed products with hydrocarbons. We have fine-tuned this development process by using our application experience and knowledge of current standards and legislation to establish scenarios. By performing risk assessment we can conclude on the probability of scenarios, which then makes them as an internal standard for framing product activities with flammable refrigerants. Next we consult with and achieve acceptance from our insurance company. Finally top management approves, and subsequently deploys the results through the relevant product manager.

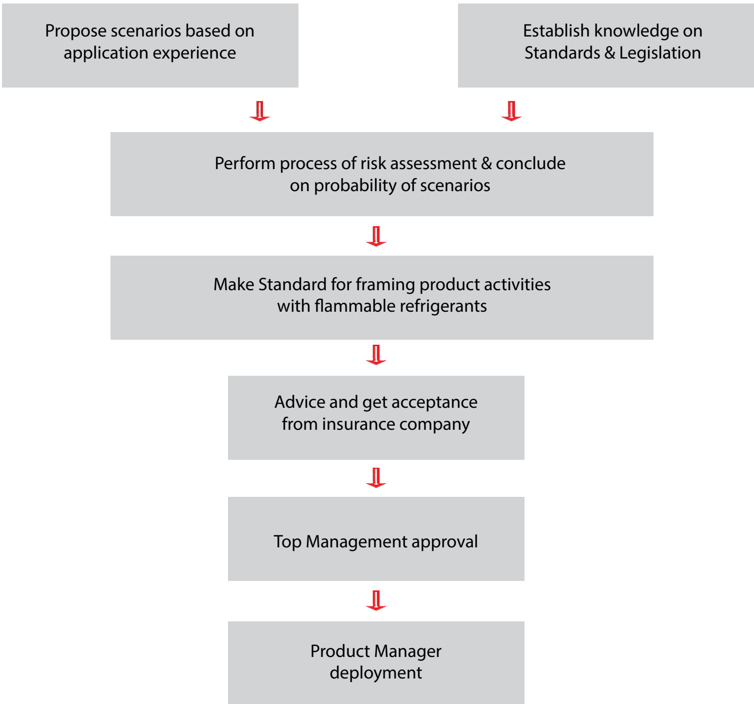


Figure 12: Danfoss' approval process

Conclusions

Refrigerants are not simply a necessity in today's world; they also hold great impact on the world to come. Because some of yesterday's solutions have proven to bear consequences for tomorrow's environment, it is imperative that the industry looks ahead to find future proof solutions to present challenges. To do 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 new technologies, but also maintains an eye on the future in terms of safety and environmental responsibility. Danfoss offers that perfect partnership. Our eighty years of experience combined with our willingness to accept and meet the challenges of the future makes us an industry leader that is poised to offer our partners solutions you can rely on. Danfoss is ready to work with you in defining and implementing the best alternative for your applications, and together we can conquer today's challenges while satisfying tomorrow's.

Annex 1.

Refrigerant properties

Refrigerant	R22	R134a	R404A	R410A	R717 (NH_3)	R744 (CO_2)	R290 (propane)	R1234ze	R407A/F	R32
Efficiency	Green	Green	Yellow	Green	Green	Green *, Yellow **	Green	Green	Green	Green
Safety	Green	Green	Green	Green	Red	Green	Red	Yellow	Green	Yellow
Environment (ODP, GWP)	Red	Red	Red	Red	Green	Green	Green	Green	Red	Yellow
Pressure & temperature	Green	Green	Green	Yellow	Green	Red	Green	Green	Green	Yellow
Chemical properties	Red	Green	Green	Green	Red	Yellow	Green	Yellow	Green	Green
Economic aspects	Green	Green, Red ***	Green, Red ***	Green, Red ***	Red	Yellow	Yellow	Green	Green, Red	Green
Availability	Yellow, Red ****	Green	Green	Green	Green	Green	Green	Green	Green	Green
Typical applications	All	Light commercial, Commercial, A/C	Commercial	Commercial, Heat pumps, A/C	Commercial & industrial refrigeration	Light commercial, Commercial, Industrial, transport, HP	Domestic, light commercial, Commercial, Heat pumps	Centrifugal Chillers, light commercial	Commercial	Heat pumps, A/C

Table 2: Properties of various refrigerants for Refrigeration, air conditioning and heat pump applications

* *Some refrigeration applications*
** *Heat pumps, secondary media, and some refrigeration applications*
*** *Higher taxes (for instance in Nordic countries and Spain)*
**** *Restricted in developed countries*

Annex 2.

Legislation and regulation

Montreal Protocol

The latest modification of the Montreal Protocol was made in 2007. The parts most relevant to the HVACR industry are the control measures set up for the HCFCs. See table below.

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 2009–10
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
99.5 % reduction	January 1, 2020, and thereafter, consumption restricted to the servicing of refrigeration and airconditioning equipment existing at that date.	97.5 % reduction (averaged over ten years 2030–40)	January 1, 2030, and thereafter, consumption restricted to the servicing of refrigeration and airconditioning equipment existing at that date.
100 % reduction	January 1, 2030	100 % reduction	January 1, 2040

Table 3: Annex C – Group I: HCFCs (consumption)
Source: UNEP

Since 2009, proposals to include HFC refrigerants in the protocol have been and are still being considered. One proposal was jointly submitted by Canada, Mexico and USA and has gained support by most countries. The proposal focuses on phasing down the use of HFC via the Montreal Protocol Based on experience with the refrigerant's predecessors CFC and HCFC, which were phased out under the Montreal Protocol, it simply seems most effective to use the Montreal Protocol forthe HFC phase-down. The Montreal Protocol focuses on production and consumption and has several advantages for jurisdiction of HFCs. Its historic success and expertise in controlling and eliminating ozone depleting substances means it already has an infrastructure (Multilateral Fund and technical and scientific bodies) which can offer a solid foundation, in order to quickly & effectively address HFCs. Effectively and quickly are, in this matter, the key arguments.

The discussion as to whether to have an HFC phase-down and to include it in the Montreal Protocol is still on-going, although there is opposition from several Countries. It would be an advantage for developing countries to obtain clear direction of future directives within the next couple of years, so the transition away from HCFCs will not have to be followed by a second transition towards low GWP alternatives.

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

R134a, currently the most common refrigerant in MACs, has a GWP of 1410 and is thus affected by the ban as well. The directive does not cover other applications.

After the 2011 deadline dispensations have extended that deadline until January 1st 2013, and since then there has been attempts to extend the deadline even further, a discussion that is still on-going.

F-Gas Regulation (EU)

The EU F-gas regulation will take effect from 1 January 2015. The regulation implies an HFC phase-down from 2015 to 2030 by means of a quota system and sectorial bans on high GWP refrigerants. Especially R404A/R507 is under pressure and likely to be phased out of all commercial systems.

Since the regulation has just been adopted, there is still a great deal of uncertainty as to what will happen. Danfoss follows the situation closely and just like other experts we expect the use of natural refrigerants and other low GWP refrigerants to grow with intermediate solutions emerging like for instance 407A/F as substitutes for R404A; although these solutions are intermediate they are likely to be used for some years into the future. We also expect new blends to play a role yet to be seen.

What is certain, however, is the reduced availability and eventually increasing price of traditional HFCs due to the quotas is calling for changes in the refrigeration and air conditioning industry.

The phase down (figure 13) is controlled by a quota allocation system that will ensure a declining supply of HFC leading to increasing refrigerant prices. 2018 looks to be a critical year in the demand/allocation balance.

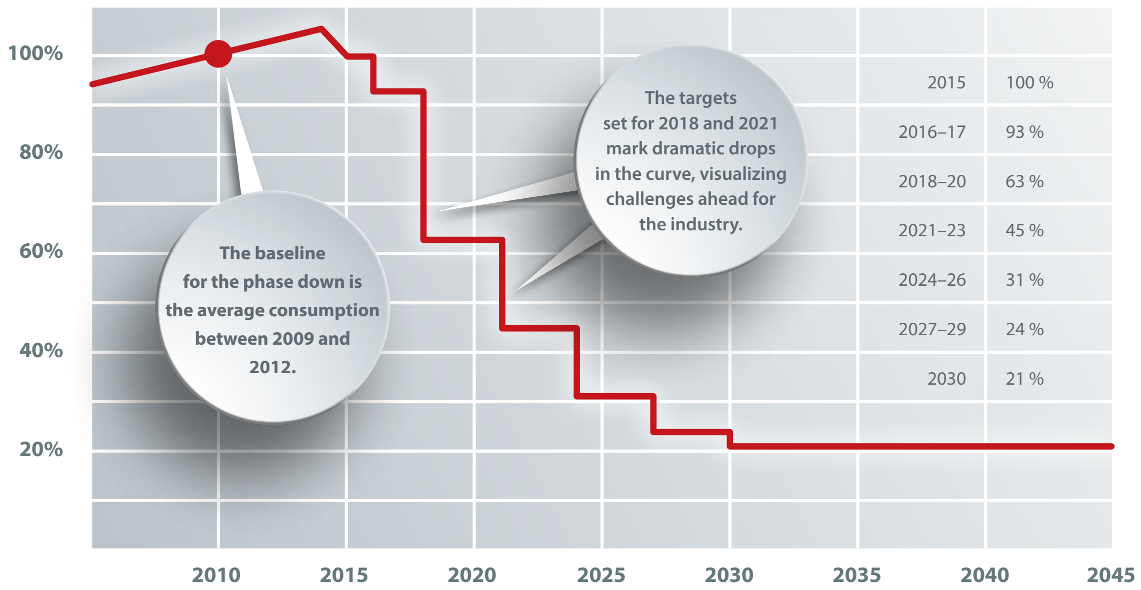


Figure 13: EU HFC Phase down schedule

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 14. Although the service bans are far into the future they are within the expected

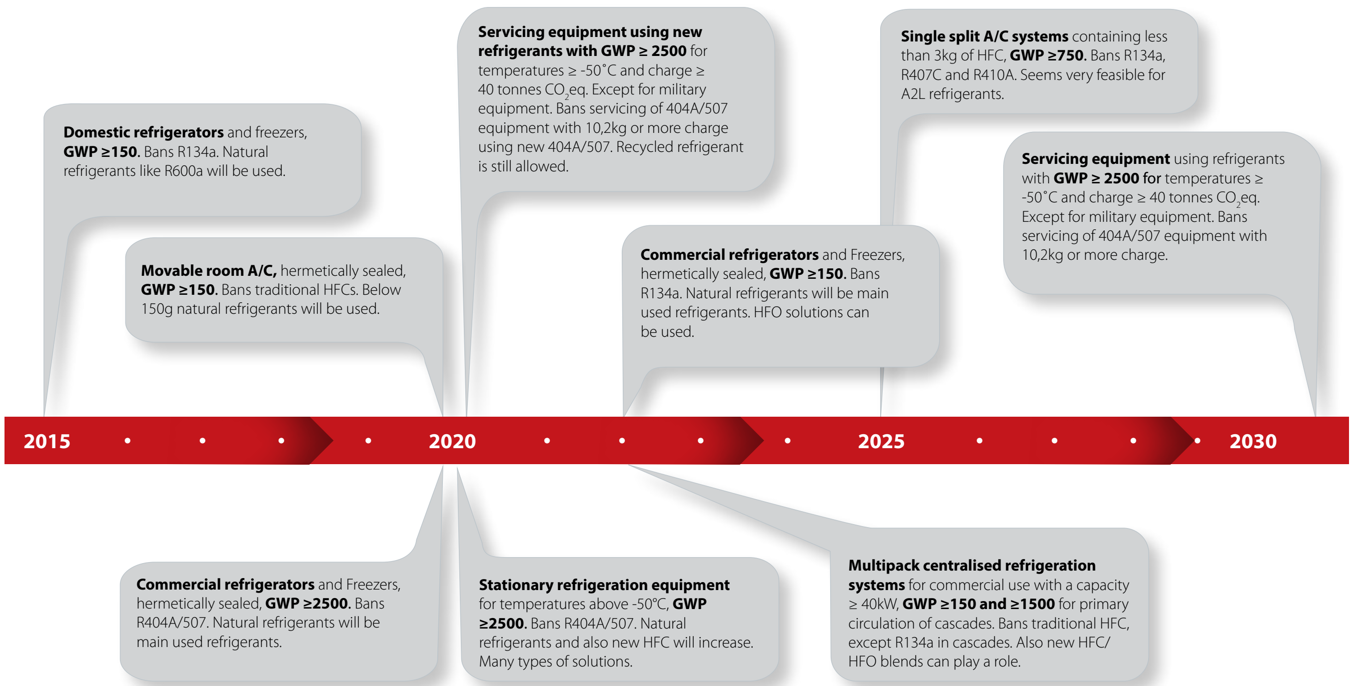


Figure 14: Bans on new equipment

lifespan of new equipment today. This puts pressure on the industry now to stop building R404A/507 systems .

SNAP (US)

The Environmental Protection Agency (EPA) in the United States has authorized hydrocarbons in selected applications through the Significant New Alternative Policy (SNAP) Program. The purpose of the SNAP program is promoting a safe and smooth transition away from ozone depleting substances.

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, with charge limits similar to Rule 17, and additional rules are being proposed.

China HCFC Phase-out Management Plan (HPMP):

To fulfill the obligation towards the Montreal protocol, the Chinese authorities are supporting projects for replacing HCFCs with alternative refrigerants. The evaluation of candidates have 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 among the recommendations are to use of R32 in chillers and R290 in household A/C. The recommendations are backed by the adoption of international safety standards.

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 the Nordic countries and Australia), and subsidies for systems that use natural refrigerants (for instance in Germany and Quebec (Canada)).

Annex 3.

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 to 1500 m^2
- 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

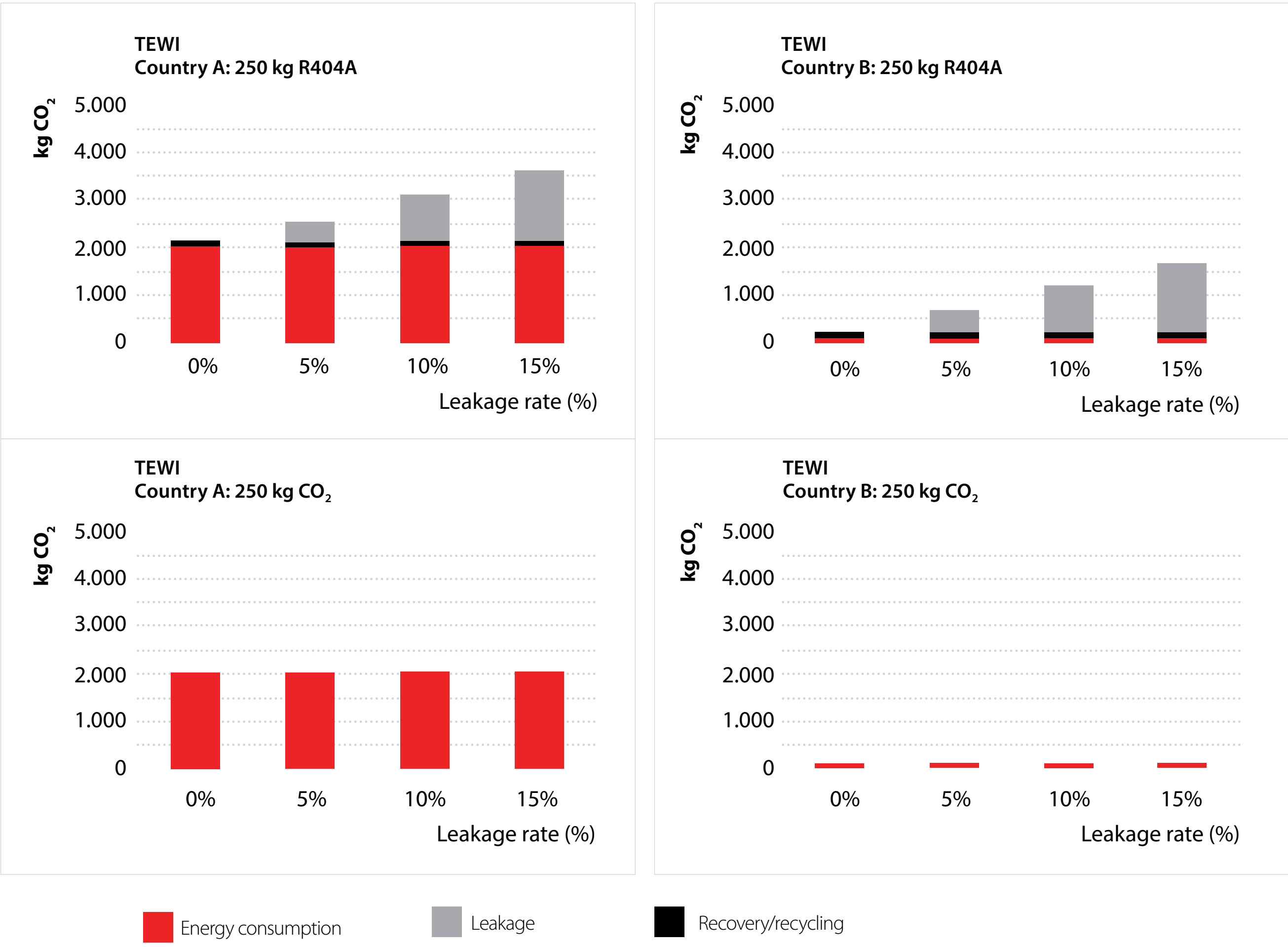


Figure 15: Relationship between the direct and indirect impacts of the refrigeration system

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Intelligent solutions, combining natural, low GWP refrigerants and high energy efficiency, are the road to sustainable refrigeration and air conditioning. Danfoss takes a proactive approach to further the development and use of low GWP refrigerants to help abate global warming and to ensure the competitiveness of the industry.

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 the sustainable balance.

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