Reducing the global warming impact of supermarket refrigeration systems

Note to the reader:

This paper has no specific geographical scope and the status of the refrigerant transition can differ significantly between countries. For example, in some countries certain high GWP refrigerants may already be banned, while they can still be used in others. However, the principle pathways for supermarkets to reduce their energy consumption, emissions and cost are the same everywhere. This is what this paper aims to demonstrate.

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Key highlights

Supermarkets are increasingly integrating sustainabilty practices into their operations, driven by consumer preferences, voluntary commitments such as Science Based Targets, sustainability rankings, and regulatory pressures including mandatory carbon disclosure, energy efficiency and refrigerant transition requirements. Almost 100 major food retailers globally have already made commitments under the Science Based Targets Initiative (SBTi).

Adopting the best greenhouse gas (GHG) emissions reduction strategies can make a significant contribution to the mitigation of climate change and is a major opportunity for supermarkets to achieve sustainabilty commitments and reduce cost. In the long-term, near zero emissions are possible. In the short- and medium-term, significant emission reductions and cost savings can be achieved.

Refrigeration systems are the largest source of GHG emissions on site from most supermarket companies. They create two distinct types of GHG emissions: Direct emissions through the leakage of refrigerants into the atmosphere (Scope 1), and indirect emissions related to the use of electricity to operate the refrigeration systems (Scope 2).

There is no silver bullet: Strategies to reduce GHG emissions from supermarket refrigeration systems depend on the type of equipment used; local regulations and constraints related to flammability and safety concerns; economic considerations, and climate zones.

The main strategies to reduce GHG emissions for supermarket refrigeration include the phase-out of high GWP refrigerants such as R-404A and R-507A; the transition to low GWP refrigerants in new and existing equipment; leakage reduction and design for low leakage; refrigerant recovery and recycling; cooling load reduction; improved maintenance and operation; high energy efficiency; heat recovery and low carbon electricity.

An "R-404A management plan" is an effective strategy that has an immediate impact on emission reduction via refrigerant use and energy savings, especially in large supermarket estates. Over a period of 5 to 10 years, all the R-404A can be replaced, without the need for costly early retirement of refrigeration equipment.

High leakage levels lead to high emissions, poor energy efficiency and high cost. Maintenance contractors should be strongly incentivised to make efforts to reduce leakage rates. A leak rate of below 5% per year is a practical target to set in central systems. For stand-alone systems, leakage rates of well below 1% apply.

Service-based business models facilitate the access to state-of-the art technology without significant upfront investment. This supports a shift from capital expenditure (CAPEX) to operational expenditure (OPEX), fosters energy savings and refrigerant transition and allows food retailers to leverage best-in-class technology to decarbonize their operations' Scope 1 and Scope 2 emissions.

Sustainability in supermarkets: A major global trend

In recent years, priorities of businesses across industries have shifted towards an ever-growing emphasis on sustainabilty factors. Supermarkets are no exception to this trend. Driven by consumer preferences and regulatory pressures to address factors such as climate change and ethical supply chains, these companies are increasingly integrating sustainability practices into their operations.

Voluntary programs, such as the Science Based Targets Initiative (SBTi), where companies set ambitious and measurable targets aligned with the objectives of the Paris agreement clearly illustrate this trend. Almost 100 food retailers from across the globe have already made commitments under the SBTi.

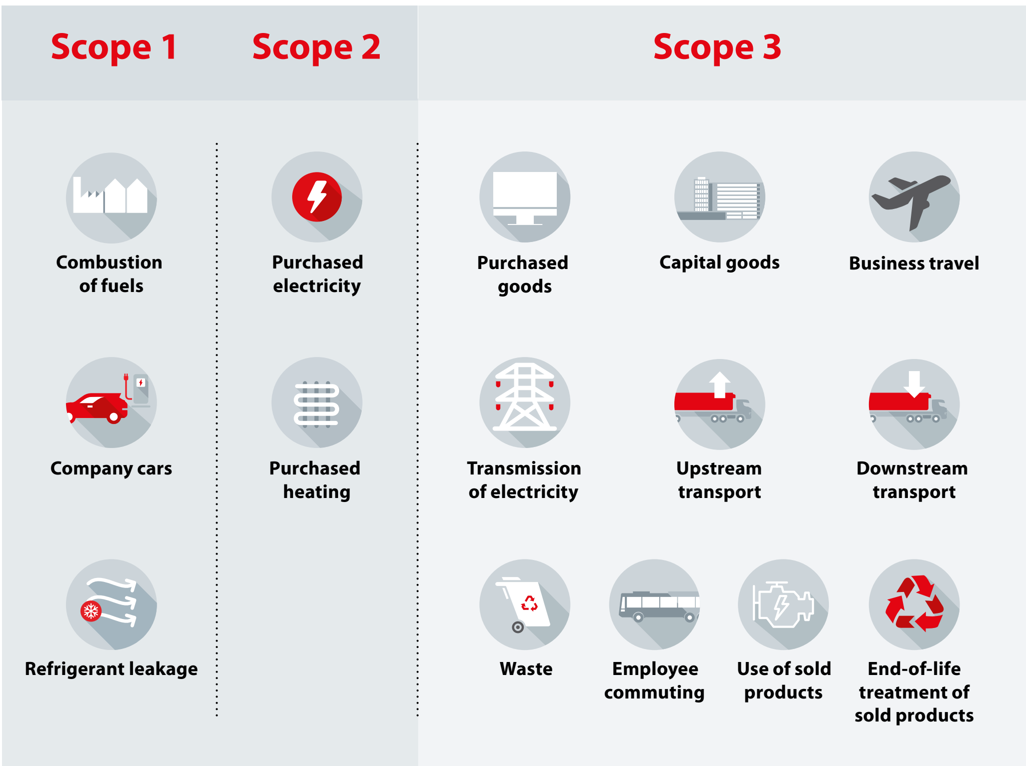
Mandatory sustainability reporting for companies, already applicable in numerous countries worldwide, is another important factor accelerating sustainable business practices in food retail. Prominent examples of such requirements include the Corporate Sustainability Reporting Directive (CSRD) in Europe and the SEC rules for climate related disclosures in the USA. Such reporting requires transparent disclosure of sustainabilty performance metrics, ranging from GHG emissions and other environmental parameters to labour practices and diversity initiatives. Sustainabilty rankings and ratings complement the picture. Specialized research firms and rating agencies use these tools to rank companies based on a range of criteria, including environmental footprint, social impact, governance structures, and risk management practices.

As a result of these trends, sustainability considerations have become an integral part of strategic decision making in food retail. By embracing these principles, food retailers mitigate risks associated with climate change and increasing complex rules and regulations. They can achieve cost savings and unlock opportunities for innovation, differentiation, and long-term value creation.

This paper will provide strategies for food retailers on how to address their direct and indirect emissions related to refrigerant use and energy consumption on site (Scope 1 and Scope 2 emissions). Dedicated regulations and policies represent additional strong drivers in this context. These include, for example, refrigerant related regulations such as the F-Gas Regulation in Europe, the AIM Act and Technology Transition Rule in the USA and, globally, the Kigali Amendment to the Montreal Protocol. In terms of energy efficiency, already wide spread measures include Minimum Energy Performance Standards (MEPS), such as the Ecodesign Rules in Europe or the DOE's (Department of Energy) energy efficiency standards in the USA.

Decarbonizing Scope 1 and Scope 2 are no-regret options, which can be directly controlled by the food retailers whether it's in their stores, warehouses, fleets or manufacturing (for vertically integrated retailers). Even though Scope 1 and Scope 2 emissions on average represent less than 10% of a food retailer's typical total carbon footprint (compared to upstream and downstream value chain – Scope 3 – emissions), they represent a strong lever to move the needle on the decarbonization of our food systems. Technologies are readily available and can make a tangible contribution towards food retailers reaching their decarbonization targets.

› Simplified representation of scope 1, 2, 3 emissions according to the Greenhouse Gas Protocol



Spotlight on CO_2 as a refrigerant

Driven by increasingly stringent regulations worldwide, the transition towards refrigerants with a low global warming potential (GWP) is a major and fast-moving trend.

On a global level, the Kigali Amendment to the Montreal Protocol which has to date been ratified by over 150 nations, sends a strong signal and provides the framework for a global phase-down of HFCs. On national, regional and sometimes even local levels, governments are implementing GWP restrictions, bans and HFC phase-down steps which can go far beyond those set by the Kigali amendment.

Selecting the right refrigerant for the coming decades has therefore moved high up on the agenda of many food retailers - for sustainability and for cost reasons. Experiences from Europe provide some useful lessons learned. Back in 2014, it was the first region in the world to implement the phase-down of HFCs via its F-Gas Regulation. When the first phase-down steps kicked in, prices for higher GWP refrigerants literally exploded, with increases of 400% and more for refrigerants such as R-404A (GWP: 3,922). Making the right refrigerant choice became an economic imperative as well as a sustainability one.

CO_2 has a GWP of 1. It is non-flammable, non-toxic and from a technical perspective very well suited for food retail applications, as will be explained in this paper. As a low GWP solution, it is widely available and not threatened by HFC phase-down or any other restrictions, such as the ones on PFAS, which are currently being discussed in certain jurisdictions.

CO_2 has several unique thermo-physical properties, such as its excellent heat transfer coefficient and high energy content. With the right system configuration and operating conditions, it is a very efficient refrigerant and a unique solution for heat recovery – an excellent and innovative opportunity for food retailers to save energy and costs while contributing to their sustainability agenda. The heat recovered can be used on site, for heating purposes or hot water, or, if applicable, be fed into a district energy system. You can read more about these opportunities in the case studies at the end of this paper.

Find more information about CO_2 on the **Danfoss Website** and in the Danfoss dedicated **whitepaper**.

AIM Act and Technology Transition

The American Innovation and Manufacturing (AIM) Act was enacted on December 27, 2020. It includes three main pillars:

1. **HFC production and consumption phase-down**

2. **HFC reclamation and reduction of releases**, ensuring the safety of technicians and consumers

3. **Sector based restrictions** to facilitate the transition to next-generation technologies

HFC phase-down: Pressure on high Global Warming Potential (GWP) Refrigerants

With the HFC phase-down, the total quantity of allowed HFC production and consumption will have to be reduced by 70% versus the historic baseline, by 2029. This means that the higher the Global Warming Potential (GWP) of a refrigerant, the more it will come under pressure via the HFC phase-down.

Sector based prohibitions

The Sector Based GWP limits are intended to support the implementation of the HFC phase-down, by transitioning sectors or subsectors to lower GWP solutions. Food Retail is among these sectors with several restrictions applying, some of them as early as of 2025. The prohibitions apply to the manufacture, distribution, sale, installation, import, and export of products containing restricted HFCs and on the installation of new systems that use restricted HFCs.

For further information and the full table of restrictions please consult the EPA's dedicated website.

Key restrictions with relevance for food retailers in chronological order

1 January 2025	
Food Refrigeration stand-alone units	GWP 150

1 January 2026	
Cold storage - Ware Houses	
With 200 or more lb refrigerant charge, excluding high temperature side of cascade system	GWP 150
With less than 200 lb refrigerant charge	GWP 300
High temperature side of cascade system	GWP 300
Retail Food – Remote Condensing Units	
With 200 or more lb refrigerant charge, excluding high temperature side of cascade system	GWP 150
With less than 200 lb refrigerant charge	GWP 300
High temperature side of cascade system	GWP 300

1 January 2027	
Retail Food – Supermarkets	
With 200 or more lb refrigerant charge, excluding high temperature side of cascade system	GWP 150
With less than 200 lb refrigerant charge	GWP 300
High temperature side of cascade systems	GWP 300

Tackling refrigerant and energy emissions under Scope 1 and Scope 2

The Greenhouse Gas Protocol differentiates between Scope 1, Scope 2 and Scope 3 emissions[1]. All of them are essential for food retailers to comprehensively address their carbon footprint and develop effective strategies for reducing GHG emissions throughout their value chain. By identifying and quantifying emissions across these scopes, supermarkets can implement targeted initiatives to mitigate their environmental impact, enhance operational efficiency and save cost. This paper will focus on Scope 1 and Scope 2 emissions from the refrigeration systems in supermarkets.

Refrigeration systems are the largest source of GHG emissions in most supermarkets. They create two distinct types of GHG emissions:

A

Direct emissions – via the leakage of refrigerants into the atmosphere (Scope 1)

Many supermarket refrigeration systems use the refrigerant R-404A or the nearly identical refrigerant R-507A. Both of these refrigerants have a very high global warming potential (GWP) of just under 4,000. That means that emitting just 1 kg of R-404A is equivalent to emitting 4,000 kg of CO_2. Direct GHG emissions will be high when these high GWP refrigerants are used and when leakage rates during operation and at end-of-life are high.

B

Indirect emissions – via the electricity used to operate the refrigeration systems (Scope 2)

Refrigeration is energy intensive and usually represents over half the electricity used in a supermarket. This creates indirect GHG emissions at the power station supplying the electricity used. The quantity of indirect GHG emissions depends on the energy efficiency of the equipment and on the way the electricity is generated, with high levels of CO_2 emissions created when fossil fuels (including coal, oil and natural gas) are used.

There are excellent opportunities to significantly reduce the GHG emissions from supermarket refrigeration. Adopting the best GHG emission reduction strategies saves cost, helps mitigate climate change and contributes to sustainability commitments such as those under SBTi.

1. Scope 1: Direct emissions from owned or controlled sources l Scope 2: Indirect emissions from purchased energy l Scope 3: Other indirect emissions from value chain

The best emission reduction strategy depends on the type of equipment used

The best strategy to reduce GHG emissions from supermarket refrigeration systems depends on the type of equipment used. Most supermarket refrigeration systems fall into three categories, related to size and construction. These are:

1

Small stand-alone systems. Small sealed systems, combining all the refrigeration components in a factory-built unit such as a plug-in display case.

2

Remote condensing units. Consisting of a factory built condensing unit (with a compressor, condenser and various system controls) that is located outside of the sales area and is connected by site-installed refrigerant pipework to one or more refrigerated display cases.

3

Central systems. Numerous display cases and back-of-store storage rooms are connected in parallel to a multi-compressor rack with externally located condensers.

All these equipment types can be used either for chilled or frozen products. Stand-alone systems require no specialized refrigeration skills for installation, whereas condensing units and central systems require on-site installation of refrigerant pipework to connect the various components. This must be carried out by suitably skilled technicians.

Large supermarkets are usually cooled using central systems. For example, a store might have two independent central systems for chilled products and a third central system for frozen products. They might also use a number of stand-alone systems and some remote condensing units.

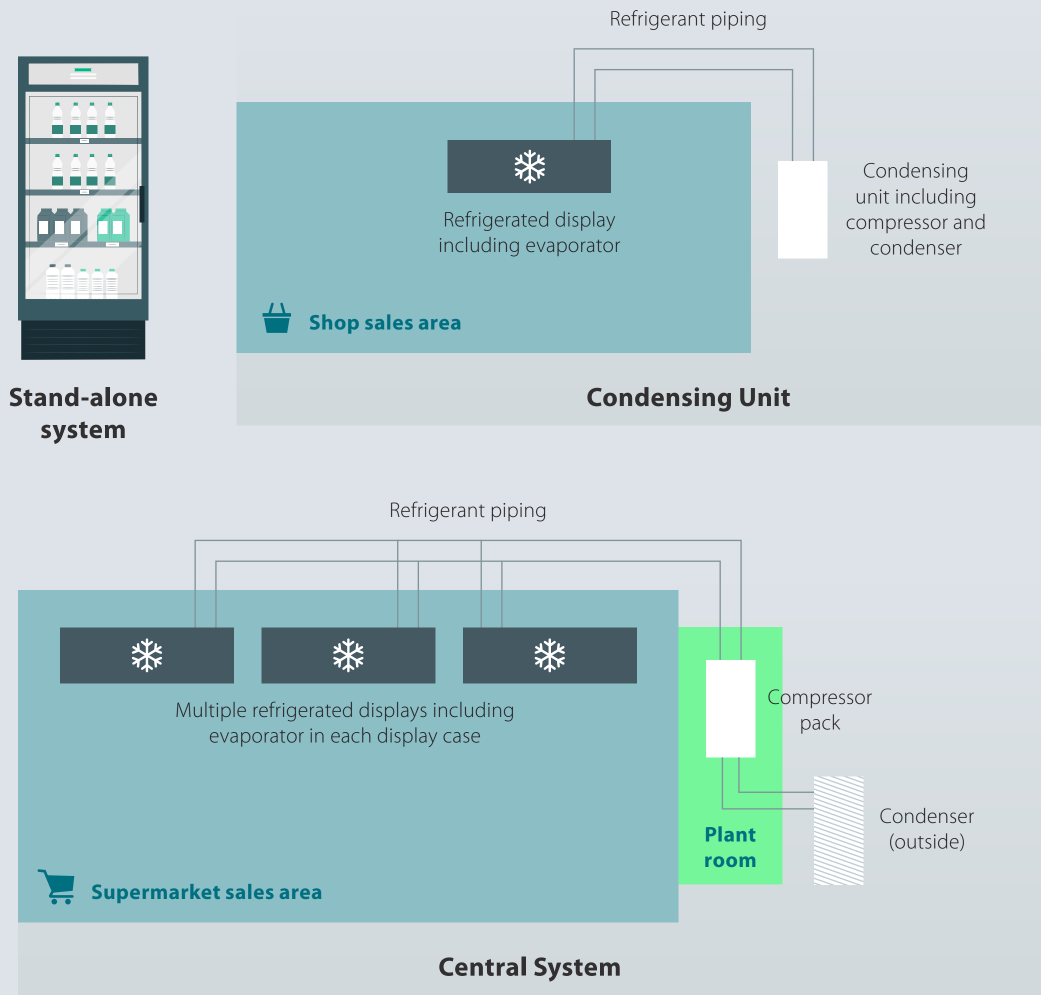
Small shops often only use stand-alone systems or might use remote condensing units. Convenience stores often have small central systems.

The typical characteristics of the three equipment types are shown in Table 1 and they are illustrated in Figure 1.

> **Table 1:** Characteristics of Supermarket Refrigeration Systems

Characteristic		Stand-alone	Condensing Unit	Central System
Typical cooling capacity	kW	0.1 to 1	2 to 20	30 to 200
Typical refrigerant charge	kg	0.1 to 0.5	1 to 10	20 to 300
Typical annual leak rate	%	<1%	5% to 20%	10% to 30%
Main type of refrigerant emissions		At end-of-life	Operating leakage	
Manufacture / installation		Factory built	Site installed refrigerant pipework	
Commonly used refrigerants NB: In the EU, the predominant refrigerant in supermarkets is R-744 (CO_2), GWP: 1.		R-404A (GWP: 3,922)	R-507A (GWP: 3,985)	R-134a (GWP 1,430)

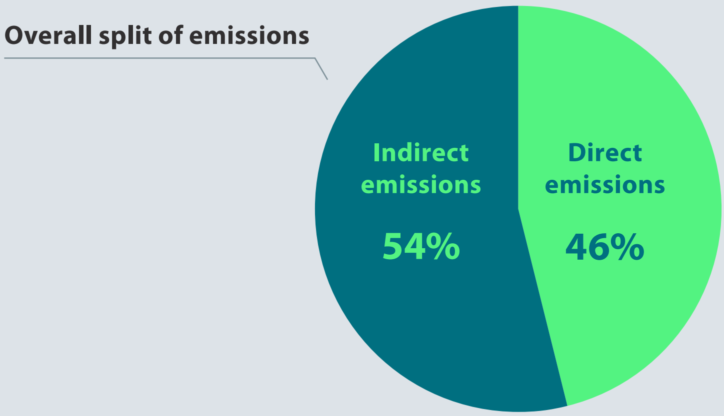
Figure 1: Layout of Supermarket Refrigeration Systems

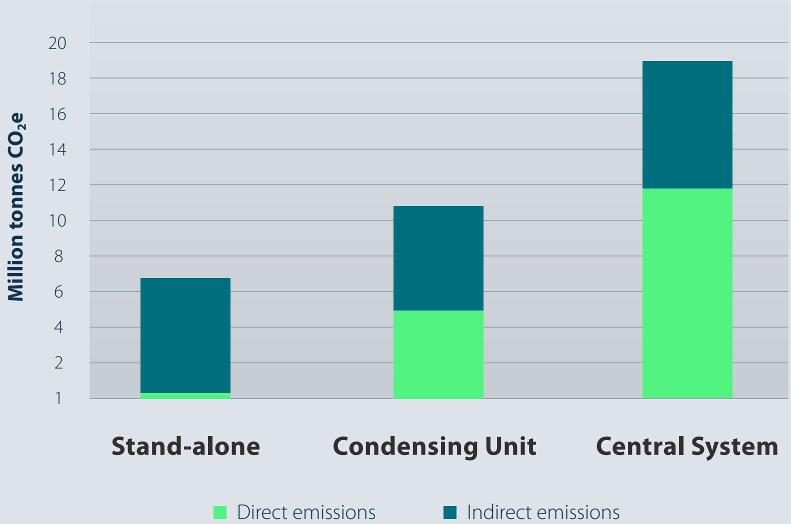


The different characteristics of these three supermarket refrigeration equipment types have a significant impact on the current GHG emissions and on the strategies that can be applied to reduce emissions. For example, stand-alone systems have a very small refrigerant charge and very low levels of leakage – that makes it relatively easy to consider using a low GWP higher flammability refrigerant such as R-290 (propane) in new equipment. However, for safety reasons that would not be an appropriate choice for a central system with a large refrigerant charge.

Figure 2 illustrates how the split between direct and indirect GHG emissions varies for the three equipment types. For stand-alone units, it is the energy related indirect emission that is dominant, whereas for condensing units and central systems, the direct refrigerant emissions are comparable to the indirect emissions. The estimates in Figure 2 are for the EU in 2022. The level of GHG emissions and the split between direct and indirect vary significantly in different geographic locations and different supermarket companies because of (a) the source of the electricity used and (b) the progress towards good lifecycle refrigerant management.

Figure 2: GHG emissions from Commercial Refrigeration in the EU, 2022





Source: EU HFC Outlook Model

The pathway to near-zero GHG emissions in supermarket refrigeration

There is excellent potential to reduce GHG emissions from refrigeration systems. In the long-term, near zero emissions are possible. In the short- and medium-term, significant emission reductions can be achieved. Strategies that can be considered to reduce emissions are summarized in Table 2.

Table 2: Strategies to Minimize GHG emissions from Supermarket Refrigeration

Emission Type	Strategy		Comments
Direct	All new equipment	Use natural refrigerants where possible	No R-404A or R-507A in new equipment. In some regions already banned or restricted (e.g. EU, USA).
		Design for low leakage	E.g. Use improved pipe connections
	Existing Central Systems and Condensing Units	Leakage reduction	Invest to reduce leakage
		Refrigerant retrofit	Retrofit R-404A or R-507A systems with much lower GWP available alternatives
	All existing equipment	Refrigerant recovery	Always recover refrigerants during servicing and at end-of-life
Indirect	New equipment	Cooling load reduction	E.g.: Use cabinets with doors; use high efficiency lights and fans
		High energy efficiency	Ensure maximum efficiency of main plant items. Add heat recovery systems.
	Existing Equipment	Cooling load reduction	Retrofit doors onto cabinets; replace inefficient lights and fans
		Improved operation	Monitor performance and ensure all control settings are always optimized
		Improved maintenance	Ensure that efficiency is optimized e.g. cleaning condensers
	Electricity supply	Low carbon electricity	Use a low carbon electricity supply; invest in on-site renewables e.g. solar PV

Low GWP refrigerants for new equipment

The commonly used high GWP refrigerants (R-404A, R-507A) should never be used in new equipment as there are various good lower GWP alternatives available to suit all applications. The higher GWP refrigerants such as R-134a, R-448A or R-449A should be avoided. The best refrigerant choice depends on the equipment type and on any local regulations related to flammability and safety. Many of the low GWP alternatives have some level of flammability – this must carefully be taken into account when selecting the best refrigerant.

In refrigeration and air-conditioning safety standards (such as ISO 5149; ASHRAE 15; EN 378), refrigerants are categorized with three different levels of flammability, as shown in Table 3. The high GWP refrigerants are all non-flammable. Some medium GWP refrigerants are also non-flammable and can play a useful interim role in situations where flammable refrigerants are unacceptable. The natural refrigerant R744 (CO_2 GWP=1) is one of the only low GWP refrigerants that is also non-flammable (A1).

It is important to recognize the big difference in flammability between Class 2L and Class 3 refrigerants. Class 2L refrigerants are very difficult to ignite (a naked flame is required) and, if ignited, they burn gently with low flame speed. Class 3 refrigerants are very easily ignited (e.g. by a small electrical spark) and they can burn explosively. Class 3 refrigerants are suitable for stand-alone, low charge systems but not for larger condensing units or central systems. Class 2L refrigerants are suitable for most condensing units and for small central systems.

> **Table 3:** Refrigerant Flammability Classes

Class	Name	Example refrigerants
1	Non-flammable	R-404A, R-507A, HFC-134a, R-448A, R-449A, R-450A, R-513A, R-744 (CO_2)
2L	Lower flammability	R-32, R-1234yf, R-454A, R-454C, R-455A, R-717 (ammonia)
2	Flammable	R-152a
3	Higher flammability	R-290 (propane), R-600a (isobutane), R-1270 (propene)

Some examples of low and medium GWP refrigerants that can be used in new equipment are shown in Table 4. This table provides a non-exhaustive overview of refrigerants. **It is to be noted that the higher the GWP value of a refrigerant, the more it will be under pressure by phase-down schemes and GWP restrictions. It is therefore recommended to always opt for the lowest possible GWP while taking into account safety and efficiency requirements.**

› **Table 4:** Low and Medium GWP Refrigerants currently available for Supermarket Refrigeration

Refrigerant	GWP	Flam-mability class	Stand-alone	Condensing Unit	Central System	Comments
R-717 (ammonia)	0	2L	No	No	Possible	Only if used with secondary fluid as it is toxic
R-744 (CO_2)	1	1	No	Yes	Yes	Efficiency optimization at high ambient temperatures
R-290 (propane)	3	3	Yes	No	Possible	Hydrocarbons are well suited to stand-alone systems. R-290 chillers can be used for central systems that use glycol as indirect cooling fluid.
R-600a (iso-butane)	3	3	Yes	No	No	
R-1234yf	4	2L	Yes	Yes	Possible	2L refrigerants can only be used in small central systems with suitable safety precautions
R-454C	148	2L	Yes	Yes	Possible	
R-454A	239	2L	Yes	Yes	Possible	
R-455A	148	2L	Yes	Yes	Possible	
R-450A	605	1	Yes	Yes	Yes	Nonflammable alternatives to HFC-134a. These refrigerants will be increasingly under pressure due to their higher GWP.
R-513A	631	1	Yes	Yes	Yes	
R-448A	1,387	1	Yes	Yes	Yes	Nonflammable alternatives to R-404A and R-507A. These refrigerants will be increasingly under pressure due to their higher GWP.
R-449A	1,397	1	Yes	Yes	Yes	
R-452A	2,140	1	Yes	Yes	Yes	Alternative to R-404A, mostly used in transport refrigeration. This refrigerant will be increasingly under pressure due to its higher GWP.

STAND-ALONE SYSTEMS

R-290 (propane) is becoming widely used and is expected to dominate this market. Where higher flammability is not acceptable, lower flammability blends like R-454C and R455A are suitable. R744 (CO_2) was trialled in some stand-alone systems 10 years ago but proved to be less suitable than the other alternatives.

CONDENSING UNITS

R-744 condensing units are now being produced in increasingly higher volumes and are a good low GWP option. Blends such as R-454C and R-455A are technically well suited to condensing units. R290 is a very effective refrigerant for condensing units but, due to safety constraints, it is only applied for smaller capacities.

CENTRAL SYSTEMS

Many central systems are being installed using R-744, especially in Europe. R-744 has significantly different thermodynamic properties from all the other refrigerants listed in Table 4, such as a very low critical temperature (31°C versus 70°C to 130°C) and a very high operating pressure (60 to 120 bar versus 15 to 25 bar). There are a number of different R-744 configurations available such as subcritical systems and transcritical booster systems. Energy efficiency is an important consideration. Standard R744 booster systems are more efficient than conventional HFC systems at low ambient temperature, but can be less efficient at higher ambient temperatures. In climate zones with hot summers and cold winters, these effects balance out and R-744 systems have a good year-round efficiency. In warmer climates, more complex system configurations with ejectors and parallel compression may need to be adopted. However, such extra investments come with short payback times due to the lower operating cost.

In addition, adopting heat recovery can further reduce the energy consumption. This makes R-744 a great choice for central systems as the thermodynamical properties of R744 lend itself perfectly for heat recovery.

Lower flammability blends such as R-454C and R-455A can be used in small central systems with a low refrigerant charge and suitable safety precautions such as leak detectors and refrigerant isolation valves.

R290 and R744 chillers are used in combination with secondary glycol loops either for direct cooling or for condenser cooling of stand-alone units (plug-ins): However, the pump power required to circulate the fluid leads to lower energy efficiency.

Some supermarket companies are making greater use of stand-alone systems in place of central systems. To avoid too much heat being rejected into the sales area, it is essential that water cooled condensers are used. Cooling water can be circulated to all the stand-alone systems and can be cooled with a cooling tower, although some supermarkets are concerned about the risks of legionella and prefer to use an air-cooled chiller to cool the condenser cooling water.

R-404A management plans and retrofitting R-404A systems

Larger supermarket estates should establish an "R-404A management plan". Each year, the oldest systems reaching retirement age should be systematically replaced with new equipment using a low GWP alternative, as discussed in the previous section. Systems that have been installed recently and still have a long lifetime, can be retrofitted with a medium GWP non-flammable refrigerant such as R-448A or R-449A. Both have a GWP just under 1400 which is only 35% of the GWP of R-404A (GWP=3922). The R-404A recovered from all the systems being retired can then be reclaimed and re-used to service the remaining fleet of R-404A systems. Retrofits are not suitable for stand-alone systems.

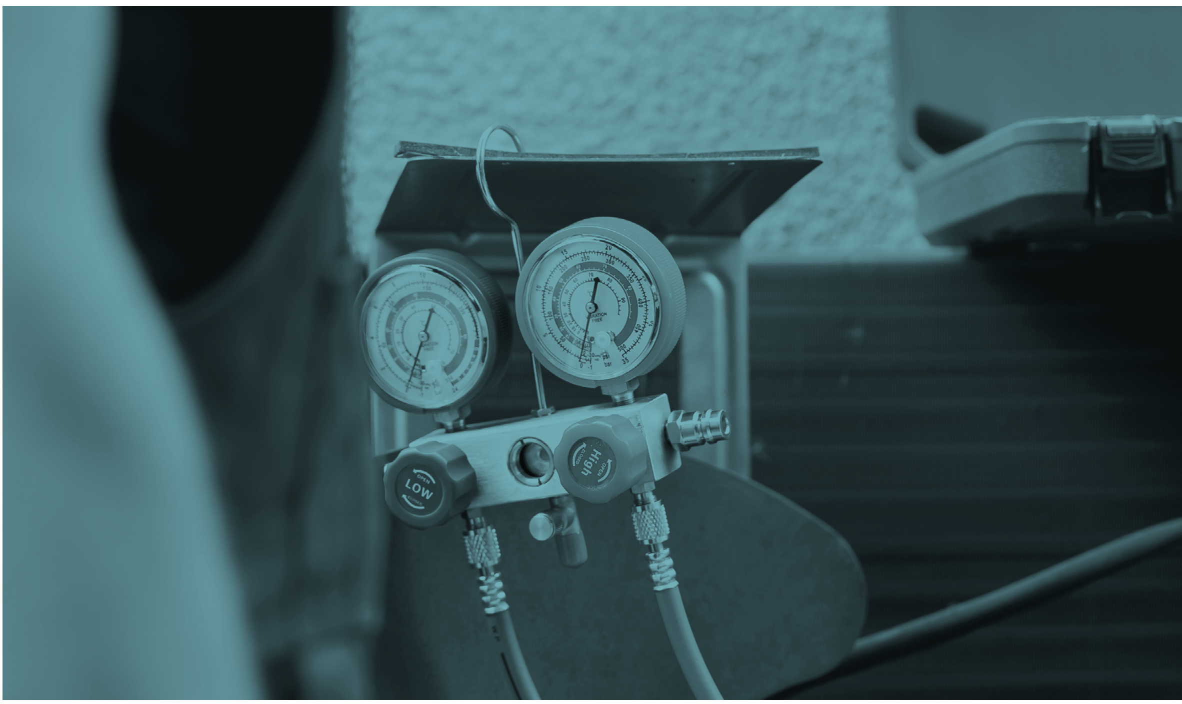
Over a period of 5 to 10 years, all the R-404A can be replaced without the need for costly early retirement of refrigeration equipment. Data collected from supermarket companies that have carried out retrofit programmes indicate that energy efficiency improves by 5% to 10% following a retrofit. This is partly because R-404A is a less efficient refrigerant than the alternatives and partly due to the retrofit process itself, where the system is carefully recommissioned and all control settings are optimized.

Nevertheless, it should be noted that retrofits should only be used if there is no opportunity to retire existing R-404A systems. It is always preferable to switch to new, future-proof low GWP equipment.

Leakage reduction initiatives

As illustrated in Table 1, central systems have historically suffered from very high levels of refrigerant leakage – typically in the range 10% to 30% per year. These are unnecessarily high leakage levels which are often caused by poor installation of the complex refrigerant pipework used in a central supermarket system. Maintenance contractors should be strongly incentivized to make efforts to reduce leakage rates. Extra budget should be made available so that they can address leakage problems (e.g. replacing faulty components). A leak rate of below 5% per year is a practical target to set for central systems. In stand alone systems, leak rates well below 1% apply.

Analysis of leakage from similar central systems in a large supermarket estate has shown that, although the average leakage rate is often around 25%, the leakage from individual central systems varies from less than 1% per year to over 200%. A small number of "rogue" systems are likely to represent a significant proportion of the total leakage, especially if they exhibit one or more "catastrophic failures" where all the refrigerant charge is lost from a system. A leak reduction campaign should try to identify these rogue systems and investments should be prioritized to replace the faulty components.



Gas recovery and recycling

Refrigerants should never be vented to the atmosphere during servicing or at end-of-life, especially if they have a high GWP such as R-404A. The old refrigerant should be carefully recovered to the maximum extent possible. It can then be sent to be reclaimed and re-used or destroyed.

In some countries (e.g. in the EU and the USA) venting of any refrigerant is illegal, but these laws are very hard to police and venting often takes place to save costs. Historically, old refrigerant had no value – recovering old refrigerant was an extra cost. Supermarket companies need to ensure that their maintenance contractors provide evidence that they are fully adhering to refrigerant recovery rules. As shown in Table 1, large central systems can contain several hundred kg of R-404A and this should all be recovered at end-of-life.

As the HFC phase-down process proceeds, recovered high GWP refrigerants like R-404A can represent a significant value to a supermarket company; it becomes increasingly expensive to buy virgin R404A as the quota of HFCs allowed on the market steadily reduces.

Energy efficiency opportunities

There are numerous opportunities to significantly reduce the amount of electricity used by supermarket refrigeration systems. Important strategies include:

A

New Equipment Energy Efficiency

When new refrigeration systems are being installed, there is a good opportunity to ensure that the refrigeration cycle efficiency is maximized. Every component needs to be optimized and the overall refrigeration cycle selected for high efficiency. The system should be designed to maximize energy efficiency under all operating conditions. For example:

- Some supermarket refrigeration systems use head pressure control (HPC) to limit the drop in condensing pressure in cool weather conditions. Use of HPC is a very bad practice – every effort should be made to allow the condenser pressure to fall to the lowest possible level in cool weather. The use of electronic expansion valves can help avoid the need for HPC and can save as much as 25% of annual electricity consumption.
- Compressors should be selected for high efficiency at all common operating conditions, not just at the "design point" (i.e. full load on the hottest day of the year). Most supermarket systems operate under part-load conditions in cool weather for significant parts of the year and the system needs to be efficient under such conditions. The use of variable speed compressors can help keep efficiency high under such part-load conditions.
- Evaporators and condensers should be generously sized. Larger heat exchangers reduce the temperature difference between air and the refrigerant, which increases the cycle efficiency.

Cooling Load Reduction

The biggest reduction in cooling load can be achieved by using display cabinets with doors. This can reduce the cooling load by around 50%. When doors are used on new refrigeration systems, the extra cost of the doors is offset by the reduced cost of a smaller refrigeration system. Doors can also be retrofitted to existing display cases.

Other opportunities to reduce the cooling load relate to auxiliary equipment used in display cases. Energy used for such equipment is "paid for twice" – firstly to operate the equipment and secondly to remove the extra heat generated by it. Examples:

- As a direct consequence of doors on cabinets, evaporator frosting is often significantly reduced. Therefore the defrost frequency can be reduced, and possibly combined with intelligent ice detection methods to eliminate unnecessary defrost cycles. The impact is significant as not all of the heat emitted by the electric heater is absorbed by the melting ice.

- LED lights use considerably less power and generate less heat than fluorescent tubes. They should be used in all new display cases and can be retrofitted to existing ones.

- Rail/frame (or anti-sweat in the US) heaters also have an important effect on the cooling load as part of the heat is always transferred into the cabinet. Adapting the rail heat power according to the humidity/dew point in the store can reduce the direct energy use and cooling load while still maintaining the display cases condensation free.

- Evaporator fans create an unwanted cooling load – using high efficiency fans combined with high efficiency EC motors provides useful savings. The use of variable speed evaporator fans can considerably reduce the fan-related cooling load – especially at times when the store is closed, and when very slow fan speed can be sufficient to keep the display case cool.

Heat Recovery

The heat ejected from the condensers of supermarket refrigeration systems can be a useful heat source for building space heating. Heat recovery from refrigeration systems can make an important contribution to the overall efficiency of a supermarket that requires space heating in cold weather. Heat recovery is possible irrespective of the type of refrigerant used, although it is worth noting that the thermodynamic characteristics of R-744 (CO_2) make it particularly well suited to heat recovery.

In moderate climate conditions, systems operate typically at around 30% of their capacity. This spare capacity can be used for parallel heat pump operation, especially during the winter.

Operation and Maintenance

Most supermarket refrigeration systems operate well below their design energy efficiency due to incorrect control settings or poor maintenance. It is common to see 10% to 20% extra electricity being used unnecessarily.

Central systems should be fitted with monitoring systems that allow regular checks on performance to be made. Modern remote monitoring systems can allow many supermarkets to be checked from a central location. Electricity kWh meters together with other sensors (e.g. to measure parameters such as evaporating temperature, condensing temperature and ambient temperature) can be used to carry out efficiency checks and fault diagnosis, enabling rapid correction of any problems identified.

Low carbon electricity

The amount of indirect GHG emissions from supermarket refrigeration depends on the amount of electricity used and the source of that electricity. If low- or zero-carbon electricity is used. e.g. from renewable sources (such as hydro, wind power or solar PV) or from nuclear power, then indirect CO_2 emissions will be low or zero.

! It is important to note that:

1) It is very difficult to generate zero-carbon electricity due to the embodied carbon in the equipment used to generate renewable or nuclear electricity. "Near-zero carbon" is a more realistic objective.

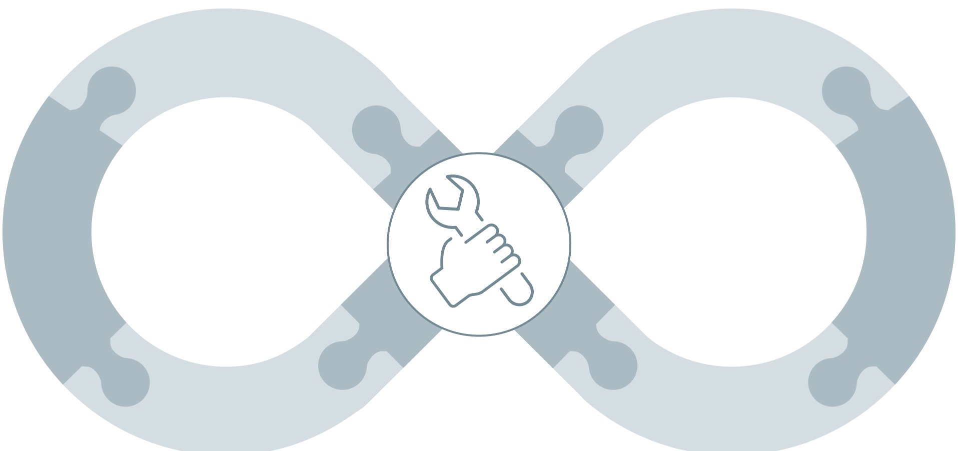
2) It is less costly to make energy efficiency improvements than it is to invest in new low carbon electricity generation to operate inefficient refrigeration plants. Hence, maximizing energy efficiency remains an important strategy.

Despite these caveats, the use of near-zero carbon electricity is an important part of the overall strategy to achieve near-zero GHG emissions from supermarket refrigeration. Decarbonizing electricity is a vital part of national programs to meet targets for reducing GHG emissions under the Paris Agreement. Supermarket companies can expect that the CO_2 emissions per kWh of electricity consumed will fall due to these national initiatives. However, it can be a good strategy to supplement this trend by direct investments in renewable electricity. Many supermarket buildings are well suited to using roof mounted solar PV, which can provide a useful amount of low carbon electricity and can also be used to illustrate to customers that efforts are being made to minimize GHG emissions.

New business models: Energy as a service

Service-based business models enable supermarket operators to focus on their core operations without having to worry about complex rules and regulations. They facilitate access to state-of-the art technology without significant upfront investment. This supports a shift from capital expenditure (CAPEX) to operational expenditure (OPEX), enables continuous performance optimization, fosters energy savings and refrigerant transition and allows food retailers to leverage best-in-class technology to decarbonize their operations' Scope 1 and 2 emissions.

Additionally, service-based business models enhance circularity and resource efficiency by shifting the focus from selling products to providing services. Instead of the supermarkets owning and eventually discarding their equipment, they pay for the services, that is for the heating, cooling, and refrigeration delivered. Manufacturers are encouraged to design products with longevity, durability and ease of repair in mind as they retain ownership and responsibility for maintenance and repair. At the end of their lifecycle, materials are more likely to be recovered and recycled rather than discarded. It is, for example, an incentive to design for refrigerant leak tightness and to ensure that refrigerants are recovered at end-of-life.



Concluding comments

Supermarket refrigeration currently creates significant GHG emissions, related to both direct refrigerant emissions and indirect electricity emissions. This paper presents a number of strategies that can help supermarket companies make significant cuts to their emissions as an integral part of their sustainabilty strategies, while also making a good business case.

An effective part of the strategy is to stop using high GWP refrigerants such as R-404A. This can be done immediately for new systems and R-404A use can be completely avoided on a supermarket estate within 5 to 10 years. For new equipment, there are a number of effective options that use refrigerants with ultra-low GWPs (below 5) or moderate GWPs (below 150). This can lead to near-zero direct emissions over the next 10 to 15 years.

Electricity-related emissions make up a significant proportion of the total GHG emissions from supermarket refrigeration systems. A number of strategies have been discussed to significantly reduce electricity consumption.These save on-going running costs as well as reducing emissions. When combined with the use of near-zero carbon electricity, it is possible for indirect emissions to reach near-zero.

Case Story

Danish supermarket **cuts heating bill and CO_2 footprint**

A busy Danish supermarket reduced its annual heating bill by 89.7% and its CO_2 footprint by 6.7 tons a year by making use of the waste heat from its refrigeration system. Instead of letting the heat simply dissipate, as most supermarkets still do, a Danfoss Heat Recovery Unit (HRU) now recycles it to heat the store's 1,900 m^2 and provide plenty of hot tap water year-round.

Case Story

New 'Smart Store' paves the way for 21st century supermarkets

The pressure is growing, both on energy demand and costs, and on the need to cut down on food loss. If food waste was a country, it would be the third largest emitter behind the US and China, contributing to up to 10% of the world's greenhouse gases.

While supermarkets and retail food stores are an integral part of communities around the world, they are also big energy consumers. The average profit margin for a large food retailer is just 1.7%, which puts every operating cost under scrutiny. Energy is an area where significant savings can be achieved with relatively low investment and good payback times.

To address these problems directly, Danfoss' new, flagship supermarket is expected to be approximately 50% more energy efficient compared to a typical supermarket with a first-generation CO_2 refrigeration system and no energy efficiency solutions. It is also expected to be approximately 20-30% more efficient than an equivalent local store already fitted with multiple energy efficiency solutions.

The installations and technologies in the supermarket are off-the-shelf and scalable. They can be applied in any food retailer, from the smallest store to the biggest hypermarket.

Climate-friendly, super-efficient and loaded with automation solutions, the new 'Smart Store' is providing inspiration for food retailers in a world of rising energy costs and emissions, and worsening food losses.

Natural refrigerants

The supermarket cooling (refrigeration and comfort cooling) systems run exclusively on natural refrigerants (CO_2). CO_2-based refrigerants do not deplete the ozone layer and have the lowest possible Global Warming Potential (GWP) score. In addition, CO_2 refrigerants outperform traditional HFC-systems when it comes to energy efficiency in different weather conditions.

Heat recovery

The supermarket is equipped with a heat recovery unit capturing excess heat from the cooling systems to provide space heating for the entire store as well as the surrounding community through the district heating network. The heat recovery unit can, by re-using the excess heat from the cooling system, reduce the external heat requirement with up to 89.7%. Furthermore, the energy pack can supply additional heating and cooling when needed.

Smart energy systems applied

100 KW solar panels on the roof help to optimize store operations. On sunny days, solar energy can be accumulated in the freezers. Turning the temperature in the freezers further down from e.g., -18 to -25 helps accumulate solar energy (while reducing battery storage). When the solar panels are less efficient due to low sunlight the temperature rises back to normal settings.

Case Story

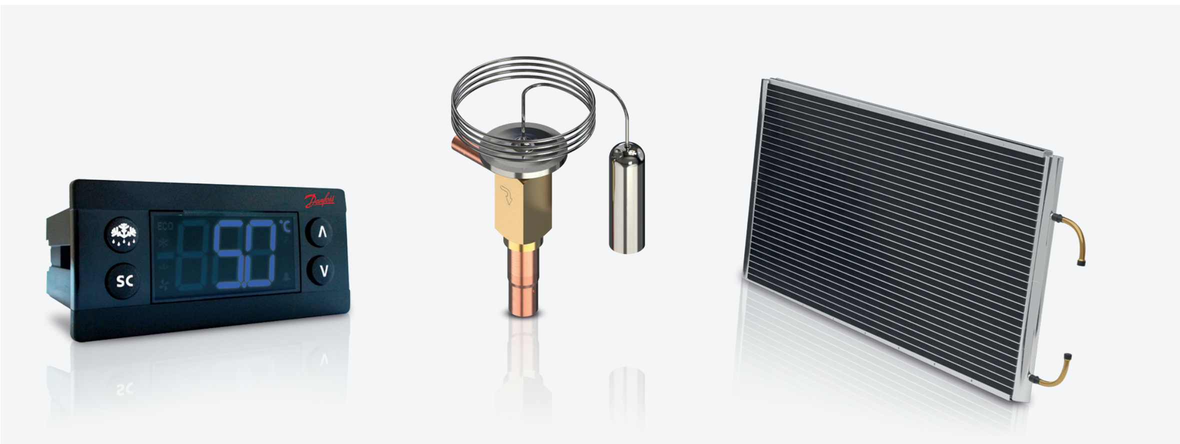
How we helped a **leading Food&Bev manufacturer** reach their **decarbonization number**

A leading food and beverage manufacturer partnered up with Danfoss and designed a next-generation cooler that delivers a 30% energy reduction*.

The Food and Beverage customer's existing fleet of bottle coolers accounts for nearly half its carbon footprint. Danfoss used one of those coolers to create a performance baseline and replaced key components within the cooler to improve its performance and efficiency.

By looking at the entire solution design and how individual components can work together to improve the efficiency, the Danfoss team was able to cut energy consumption by 30% compared to the initial cooler design.

Taking this holistic end-to-end approach to decarbonization together with Danfoss can provide Food & Beverage customers with the needed edge to comply with the latest energy efficiency requirements, while ensuring the best experience to the final end-user customers.



Solution: Danfoss controller, microchannel heat exchanger, and thermostatic expansion valve

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Join us in turning your possibilities into reality – and let's reach your decarbonization number together.

* Tested and proven in Danfoss' Application Development Center.
30% energy reduction was achieved compared to the initial cooler design.

This document was prepared by
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