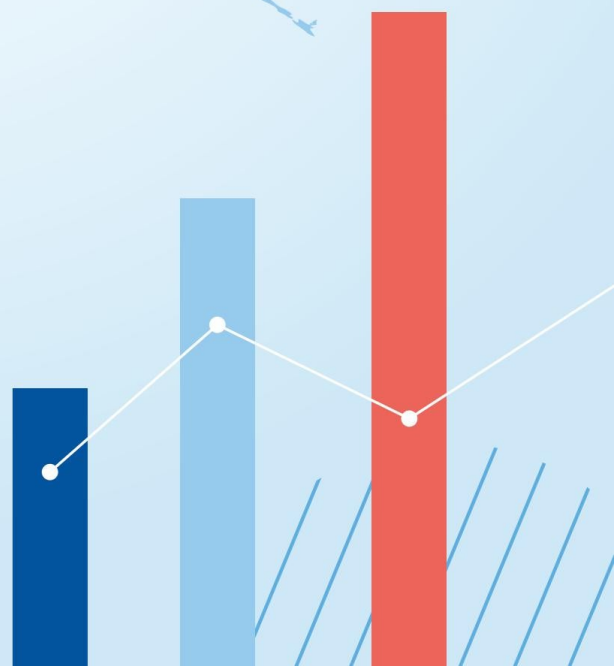
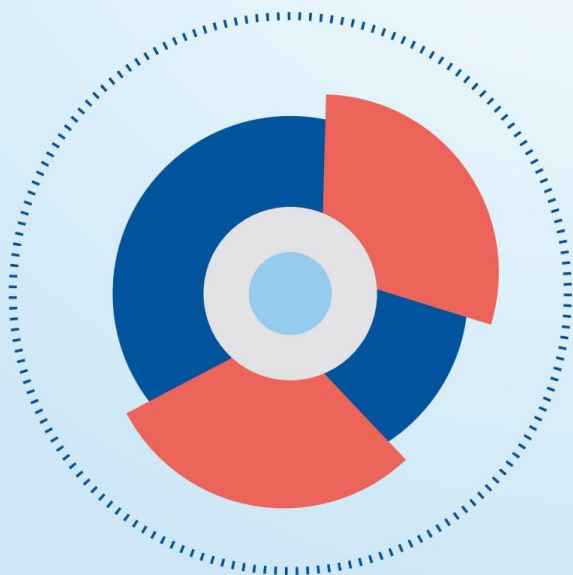


Natural Refrigerants: State of the Industry

Refrigeration in Europe, North America
and Japan, Plus Heat Pumps in Europe



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ATMO Report

OUR SUPPORTERS



2023 EDITION



Natural Refrigerants: State of the Industry

Refrigeration in Europe, North America
and Japan, Plus Heat Pumps in Europe

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About Us

Founded in 2007 as shecco, ATMOsphere is a global, independent market accelerator for clean cooling and heating and natural refrigerant solutions. The company boasts more than 50 years of industry experience throughout its global team located in Europe, Japan and the U.S.

ATMOsphere combines the company's extensive natural refrigerant expertise with the power of its wider network of like-minded experts who share an ambition for scaling up the global clean-cooling economy.

ATMOsphere's business includes product and news marketplaces, events and market research. In addition, in June 2022, ATMOsphere launched its natural refrigerants label as a global gold standard highlighting best-in-class manufacturers – and now contractors – of natural refrigerant systems and components around the world.

Overall, the ATMOsphere platform offers a one-stop solution for – among others – investors, end users, original equipment manufacturers (OEMs), component manufacturers, contractors and others who want to scale up clean cooling.

The ATMOsphere core team includes journalists, analysts, engineers, event organizers, designers and other highly skilled individuals with a diverse background – all working together to gather information and analyze this niche market. As industry experts in this field, the team offers unique insights into trends and market size that cannot be replicated by organizations without the same history and knowledge.

However, the real power of the ATMOsphere brand lies in its network. It spans the whole globe and includes more than 50,000 industry stakeholders – from policymakers and end users to academia, manufacturers and everyone in between.

ATMOsphere is not just a company, but a community of people who believe that the future of cooling is clean and natural.

For more information, visit atmosphere.cool

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A Pivotal Moment for Cooling

We are publishing this annual Market Report on the natural refrigerants industry at a pivotal moment: the launch of the Global Cooling Pledge at the latest United Nations Climate Change Conference, known as COP28, running from November 30 to December 12, 2023, at Expo City, Dubai, United Arab Emirates.

The Global Cooling Pledge aims to reduce the high emissions created by cooling by 68% by 2050 compared to 2022 levels via the adoption of efficient and sustainable cooling technologies in participating countries. The Pledge, for the first time at a COP meeting, recognizes the crucial place of cooling in the overall health of the planet, especially as global temperatures rise.

Our 2023 Market Report will contribute to the conversation in Dubai and worldwide by providing the latest insights and data on natural refrigerant-based commercial and industrial refrigeration systems in several key markets – Europe, the U.S., Canada and Japan. We consider this report to be the world's leading resource for information on the installations and penetration of natural refrigeration in the commercial and industrial sectors.

And the report is better than ever, with new sections on domestic heat pumps and hydrocarbon chillers in the European market – two more exciting and fast-growing opportunities for natural refrigerants. This reflects our strategy of adding new sectors and regions each year to the Market Report, making it the essential resource for understanding the natural refrigerants marketplace.

As the report shows, natural refrigerant installations are experiencing robust growth, thanks to policy developments taking place on both sides of the Atlantic – a more ambitious EU F-gas Regulation and the rollout of the U.S. AIM Act. Natural refrigerants are also benefiting from the growing understanding of the link between the latest f-gases (HFOs and their blends) and PFAS, an environmental and health hazard that we are closely tracking in this report and throughout the year.

In addition to promoting our report at COP28, we will be highlighting it throughout 2024 at our ATMO conferences in Japan, the U.S., Latin America and Europe and at trade shows such as AHR Expo (U.S.), Supermarket Trade Show (Japan), IIAR (U.S.), ARBS (Australia) and Chillventa (Germany). We will also be featuring it in webinars and extensively on social media.

The 2023 Market Report is a gold mine of information and insights on natural refrigerants that will help the countries attending COP28 – and stakeholders worldwide – move faster to clean cooling solutions. Please let us know what else you would like to see covered in the report as we endeavor to improve it every year.

Marc Chasserot
Founder & Publisher
ATMOSphere



ATMOsphere

Natural Refrigerants Label

ATMOsphere launched a label to meet growing market demand for a globally recognized quality label for the natural refrigerant industry that qualifies and celebrates the best natural refrigerant companies and products.

Aimed at natural refrigerant manufacturers (both system and component) and contractors/installers, our custom process considers company vision, customer satisfaction, measurable impact, and investment in training.



atmosphere.cool/natural-refrigerants-label/

Robust Growth, Worldwide

In this 2023 ATMOsphere Market Report, we assess the state of the natural refrigerants marketplace for commercial and industrial refrigeration in Europe, North America and Japan. This year, we have added data on two sectors in Europe: hydrocarbon chillers and domestic heat pumps.

The past year has seen exceptional growth for transcritical CO₂ (R744) installations in both stores and industrial sites throughout the world. In Europe, the leading market, there are now an estimated 68,500 food stores using this technology, accounting for almost one-quarter (22.9%) of all European food stores. The number of stores using CO₂ rack systems grew by 20%, while the number with CO₂ condensing ballooned by 70%. Even on the industrial side, the number of sites with CO₂ systems increased by a whopping 65% to 3,300.

On the other side of the pond, there was comparable growth, albeit from a smaller base. The number of stores in North America using transcritical CO₂ shot up 80% to 2,930, while the number of industrial sites hit 498, a sizeable 71% increase. In Japan, growth was more measured, but still healthy, at 26% for stores (8,385 this year) and 21% for industrial sites (400).

What is driving all this uptake of natural refrigerant-based refrigeration? Clearly, regulatory action has had the most to do with it. In Europe, as explained in the report, the F-gas Regulation, already a major spur to natural refrigerant adoption, has been upgraded this year, making f-gases an even less attractive option. The EU's ongoing consideration of restrictions on PFAS, which is defined to include HFOs, only serves to further accelerate the move toward natural refrigerants.

In the U.S., the rollout of the AIM Act, especially its Technology Transitions piece, has sparked long overdue interest in natural refrigerants by large supermarket chains. The restrictions on 150+ GWP refrigerants in the AIM Act have already led to considerable adoption of CO₂ and hydrocarbon equipment in California, where these limits were enacted in 2020; they are now having a similar effect on a national level. But unlike Europe, the U.S. government has yet to make the connection between PFAS and f-gases.

This report also delves into the many other factors impacting the adoption of natural refrigerants, both on a global and regional level. Worldwide, technological improvements continue to make transcritical CO₂ applicable in all climates and in integrated HVAC&R formats, while lowering the charge levels of ammonia systems and boosting the efficiency of hydrocarbon cases.

In Europe, North America and Japan, changes to the charge limits for hydrocarbons are opening new opportunities for self-contained cases using propane. Europe has many other measures, including its ecodesign and labeling rules, HFC taxes, incentives and RePowerEU heat pump rollout, with the potential to support natural refrigerant adoption.

As this report amply demonstrates, natural refrigerants are a global technology whose time has come.

Michael Garry
Head of Content
ATMOsphere

Methodology

In this 2023 State of the Industry report on natural refrigerants, ATMOsphere investigates the state of the market for key natural refrigeration technologies in commercial and industrial applications in Europe, North America and Japan, the leading and fastest growing markets for natural refrigeration in the world. We also look at the growth of natural refrigerant-based industrial chillers and domestic heat pumps with a rated capacity of less than 12 kW (3.4TR) in Europe.

To fully understand and analyze these markets, ATMOsphere used a combination of qualitative and quantitative research methods, leveraging our expansive knowledge and experience with the subject matter, as well as ATMOsphere's global network of natural refrigerant experts.

The following methods were used:

Desk Research

Desk research was conducted regarding the current state of the commercial and industrial refrigeration and domestic heat pump markets, policy trends and the available natural refrigerant-based options. ATMOsphere leveraged a combination of external reports and academic publications, together with its own articles and reports, to build an understanding of the market.

As the leading market accelerator for natural refrigerants, ATMOsphere is powered by a database of natural refrigerant and clean cooling information, diligently constructed over the years by its analysts and journalists.

Data Collection

The primary source of market data for the European and North American markets was via an industry survey designed by the ATMOsphere team and sent to key European and North American OEMs of natural refrigerant-based CO₂ systems (racks and/or condensing units), low-charge (below 1.3kg/kw or 10.1/lbs/TR) ammonia systems, and hydrocar-

bon-based self-contained retail cabinets and (in Europe) hydrocarbon chillers.

The European market is defined as encompassing the European Union as well as the U.K., Norway, Switzerland, Iceland, non-EU Balkan states, Ukraine, Belarus, Moldova and the European part of Russia.

In all regions, manufacturers of CO₂ racks and condensing units were asked to provide the approximate number of stores (new and existing) and/or industrial facilities (new or existing) that have installed their equipment.

Manufacturers of low-charge ammonia systems (packaged or centralized, including NH₃/CO₂ systems) and hydrocarbon chillers were asked to provide the approximate number of industrial facilities (such as cold storage or food processing, new or existing) that have installed their equipment.

Manufacturers of hydrocarbon-based self-contained refrigerated- and/or frozen-food retail cabinets were asked to provide the approximate number of units (air- and water-cooled) they have sold.

All companies were asked to provide an approximation of their market share of stores and/or industrial facilities using their equipment or their market share for hydrocarbon cabinets.

All companies were guaranteed that their data would be kept in confidence and only used anonymously in combination with data received from other companies to create an aggregate picture at the marketplace.

The survey and interviews received responses from OEMs of transcritical CO₂ equipment, low-charge ammonia equipment, hydrocarbon chillers and hydrocarbon cabinets that together represent a substantial share of the market for natural refrigerant equipment in Europe, North America and Japan.

We also leveraged public data on natural refrigerant system installations from other OEMs available on their websites, provided at conferences, in interviews

with ATMOSphere journalists, or other sources. Additional data was gathered with the help of industry associations.

Our data indicate the number of sites (locations, whether stores or industrial facilities) using CO₂, ammonia equipment or hydrocarbon chillers. An individual site could use more than one system. However, the number of units is indicated for hydrocarbon-based cabinets.

Interviews with Key Industry Stakeholders

ATMOSphere also contacted a number of end users, academics and other experts to improve its understanding of current trends and the state of the market for natural refrigeration installations.

For the Japanese market, in lieu of a survey, in-depth interviews were held with the key suppliers of natural refrigerant-based systems.

For the European heat pump market, outreach was conducted to relevant OEMs and industry stakeholders for primary research. A series of one-on-one interviews was done to gather additional information. Relying on ATMOSphere's database and the European Heat Pump Association's member section, an email outreach and briefing on the objective of this project was sent to manufacturers already producing heat pumps with natural refrigerants or announcing future introductions of this equipment.

A second step of selection identified a target of 29 heat pump OEMs that were invited to take part in a conversation with ATMOSphere experts via a structured interview or alternatively submitting input through a survey. Additional testimonials and information from stakeholders were gathered at conferences and trade fairs, such as ISH 2023 in Frankfurt.

Abbreviations

AIM Act – American Innovation and Manufacturing Act
CARB – California Air Resources Board
CO₂e – CO₂ Equivalent
COP – Coefficient of Performance
CSA – Canadian Standards Association
DOE (U.S.) – Department of Energy
EC – European Commission
ECOS – Environmental Coalition on Standards
ECHA – European Chemical Agency
EIA – Environmental Investigation Agency
EPA (U.S.) – Environmental Protection Agency
EPBR – European Productivity and Benchmarking Research
EPREL – European Product Register for Energy Labelling
ETE – Extreme Temperature Efficiency
EU – European Union
F-Gas – Fluorinated Gas
FMI – The Food Industry Association
FTE – Full Transcritical Efficiency
GCCA – Global Cold Chain Alliance
GHG – Greenhouse Gas
GWP – Global Warming Potential
HCFC – Hydrochlorofluorocarbon
HFC – Hydrofluorocarbon
HFO – Hydrofluoroolefin
HVAC&R – Heating, Ventilation, Air-Conditioning & Refrigeration
ICC – International Code Council
IEA – International Energy Agency
IEC – International Electrotechnical Commission
IIAR – International Institute of Ammonia Refrigeration
IPCC – Intergovernmental Panel on Climate Change
IRA – Inflation Reduction Act
JARW – Japan Association of Refrigerated Warehouses
JIS – Japanese Industrial Standard
JRAIA – Japan Refrigeration and Air Conditioning Industry Association
KHK (Japan) – High Pressure Safety Institute

Executive Summary

LFL – Lower Flammability Limit
MAC – Mobile Air-Conditioning
MFC – Microfulfillment Center
MOE (Japan) Ministry of the Environment
OECD – Organisation for Economic Co-operation and Development
OEM – Original Equipment Manufacturer
OCU – Outdoor Condensing Unit
PEER (U.S.) – Public Employees for Environmental Responsibility
PFAS – Per- and Polyfluoroalkyl Substances
REACH (EU) – Registration, Evaluation, Authorisation and Restriction of Chemicals
RMP (U.S. EPA) – Risk Management Program
SNAP (U.S. EPA) – Significant New Alternatives Policy
TFA – Trifluoroacetic Acid or Trifluoroacetate
UBA – German Environmental Agency
UL – Underwriters Laboratories

Natural Refrigerants

R744 – Carbon Dioxide (CO₂)
R717 – Ammonia (NH₃)
R290 – Propane
R600a – Isobutane
R1270 – Propylene/Propene
R718 – Water
R729 – Air

European Market Data

As of December 2023, there were approximately **68,500** food retail stores in Europe that use transcritical CO₂ systems; of these **60,000** use a centralized system (one or more racks), and **8,500** use condensing units. The number of stores with racks grew by 20% compared to last year, while the number with condensing units grew by 70%. There are an estimated **3,300** industrial sites (+65%) using this technology, for a total of **71,800** transcritical CO₂ sites in Europe.

The market penetration of transcritical CO₂ systems in stores has increased this year to **22.9%** – the percentage of all food retail stores in Europe estimated to feature transcritical CO₂ installations as of December 2023, up from 18.4% last year and 14.1% in 2021. In 2022, we estimated a market size of 299,025 food retail outlets, and in 2023 this has dropped slightly to **298,600**.

ATMOsphere estimated **3.2 million** hydrocarbon-based retail cabinets have been installed in Europe as of December 2023, an increase of **10%** from 2022, when there were an estimated 2.9 million.

As of December 2023, there were an estimated **3,300** industrial sites using transcritical CO₂ refrigeration, accounting for 4.6% of the **71,800** transcritical CO₂ sites in Europe (the rest being food retail stores). These 3,300 sites represent a growth of **65%** from the 2,000 industrial sites using transcritical CO₂ a year ago (3.5% of the total 57,000 transcritical CO₂ sites).

As of December 2023, ATMOsphere estimates there are **3,360** industrial sites using low-charge (below 1.3kg/kW or 10.1lbs/TR) ammonia systems in Europe, based on production numbers from leading OEMs. This represents a growth rate of **18%** over a year ago, when there were an estimated 2,850 such sites.

ATMOsphere estimates there are **5,000** industrial sites with hydrocarbon-based chillers in Europe as of December 2023.

There were approximately 2.1 million new air-to-water heat pumps with natural refrigerants (typically propane) sold in Europe in 2021, according to industry sources. That grew to an estimated 2.5 million in 2022 and **2.8 million** in 2023.

North American Market Data

As of December 2023, there were approximately **2,930** food retail stores in North America using transcritical CO₂ systems, up more than **80%** from 1,605 in 2022 and from 945 in 2020. Of these 2,930 food retail stores, **1,850** are in the U.S. and **1,080** in Canada.

The market penetration of transcritical CO₂ systems in the estimated **71,492** North American supermarket and grocery stores has increased to **4.09%**, up from 2.2% a year ago. When considering convenience stores as well, the market penetration out of **231,443** retail food stores in North America is **1.27%**, up from 0.7% in 2022.

There were **928,000** self-contained hydrocarbon (mostly R290) cases installed in U.S. food stores, an increase of **1%** from the 919,000 cases a year ago. The market is starting to be saturated, and most of the new units are replacement units.

As of December 2023, there were also **498** industrial sites using transcritical CO₂ in North America in 2023, **14.5%** of the total of **3,428** transcritical CO₂ sites. The 498 industrial sites consists of 208 in the U.S. (up from 120 in 2022) and 290 in Canada (up from 170 in 2022).

As of December 2023, ATMOSphere estimates there were **1,045** industrial sites using low-charge (below 1.3kg/kW or 10.1lbs/TR) ammonia systems in North America, an increase of 10% over a year ago, including **110** with packaged units and **935** with central systems. The 1,045 industrial sites equate to **715** sites (**627** with central and **88** with packaged systems) in the U.S. and **330** (**308** central and **22** packaged) in Canada.

Japanese Market Data

As of December 2023, there were **8,385** stores, including **7,800** convenience stores and **585** supermarkets, using transcritical CO₂ systems, mostly outdoor condensing units (OCUs) in Japan's commercial refrigeration sector, up **26%** from 6,630

stores (6,330 convenience/300 supermarkets) reported in December 2022. The 2023 number represents a retail market penetration for transcritical CO₂ of 10.9%

The majority of installations were done by convenience store chain Lawson, which had **5,300** stores using CO₂ OCUs as of February 2023 (more than one-third of its fleet of 14,656 stores).

There were an estimated **55,790** convenience stores in Japan by the end of September 2023, a decline of 0.1% from the previous September (55,872). Also in September 2023, there were an estimated **21,236** supermarkets in Japan, an increase of 0.5% from the previous September (21,131). Combined, this amounted to **77,026** food retail outlets in Japan in 2023, an increase of 0.03% from the prior year (77,003).

As of December 2023, there were an estimated 400 industrial sites (mostly cold storage) using transcritical CO₂ installations in Japan's industrial refrigeration sector, up **21%** from the 330 reported in 2021. With industrial site installations, the total number of transcritical CO₂ installations in Japan was **8,785** sites as of December 2023.

European Trends

On October 5, negotiators from the Council of the EU and the European Parliament reached a provisional political agreement on phasing out substances that cause global warming and deplete the ozone layer, putting into place the final pieces of the revised EU F-gas Regulation and setting the stage for the elimination of f-gases in the EU by 2050.

On August 2, 2023, an updated standard was approved allowing European manufacturers to sell stand-alone commercial cabinets with a flammable refrigerant charge of up to approximately 500g of R290 and up to 1.2kg of flammable A2L refrigerants.

On February 7, 2023, ECHA published a proposed restriction on PFAS (per- and polyfluoroalkyl substances) that would include certain HFCs and HFOs, such as HFC-134a, HFO-1234yf and HFO-1234ze(E) as well as TFA, an atmospheric degradation product of HFO-1234yf (100% conversion) and HFC-134a (up to 20% conversion).

North American Trends

In July the EPA announced its latest action to phase down the use of HFCs, issuing a final rule to implement a 40% reduction below baseline levels from 2024 through 2028. In October, the EPA released a final Technology Transitions rule banning HFCs in certain new equipment and setting a limit on the GWP of the HFCs that can be used in each subsector, with compliance dates ranging from 2025 to 2028.

In 2021, UL's standard 60335-2-89, 2nd Edition raised the charge limit in commercial plug-in display cases to 500g for propane (R290) for open appliances (without doors) and to 300g for closed appliances with doors and/or drawers. In May the U.S. Environmental Protection Agency (EPA) proposed adopting those limits under its Significant New Alternatives Policy (SNAP) 26.

The EPA's Office of Pollution Prevention and Toxics (OPPT) has followed a "working definition" of PFAS that excludes f-gases and TFA. In May, the OPPT said in an email that it is no longer using the working definition of PFAS and would explain the rationale for identifying specific PFAS substances it believes "are appropriate to include within the scope of each individual action." Then in June, the U.S. Senate Environment and Public Works (EPW) Committee released draft PFAS legislation that includes the narrower PFAS definition previously employed by the EPA, but this has not yet been moved to a vote.

Japanese Trends

Japan's Ministry of the Environment (MOE) declared in June that it will continue its natural refrigeration equipment installation subsidy project through fiscal year 2027, with ¥7 billion (US\$48.7 million) allocated for fiscal year 2023, which runs from June 1, 2023, to March 31, 2024.

Of the 3,630 projects subsidized to date, the commercial refrigeration sector has accounted for 2,478; these include supermarkets and convenience stores, with the majority using CO₂ systems, including air-cooled CO₂ condensing units. In addition, Japanese food retail chain Aeon and convenience store chain Lawson have started using hydrocarbon (R290 and R600a) refrigerant showcases.

On the whole, progress toward natural refrigerants is slow. This is because Japan's f-gas laws focus on the life cycle of refrigerants and introduce targeted years and targeted average GWPs for several HVAC&R sectors that are in some cases very unambitious in comparison to the EU F-gas Regulation.

Figure 1: Transcritical CO₂ Installations in Major Regions

(stores and industrial sites, as of December 2023)

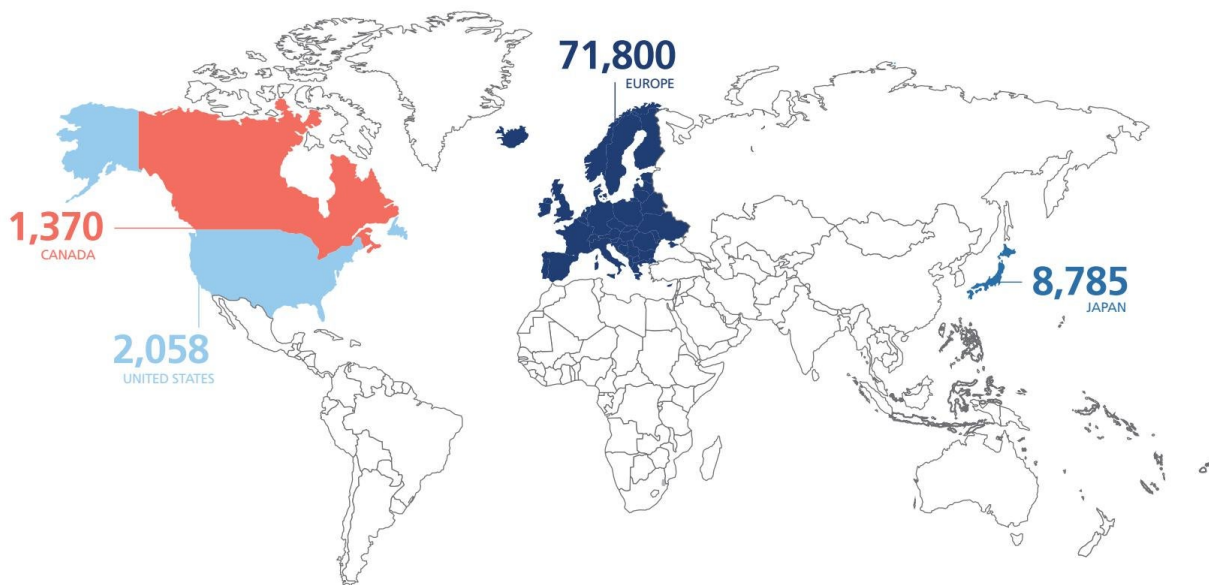


Figure 2: Transcritical CO₂ Market Penetration Growth in Major Regions

(supermarkets, grocery and convenience stores, as of December 2023)

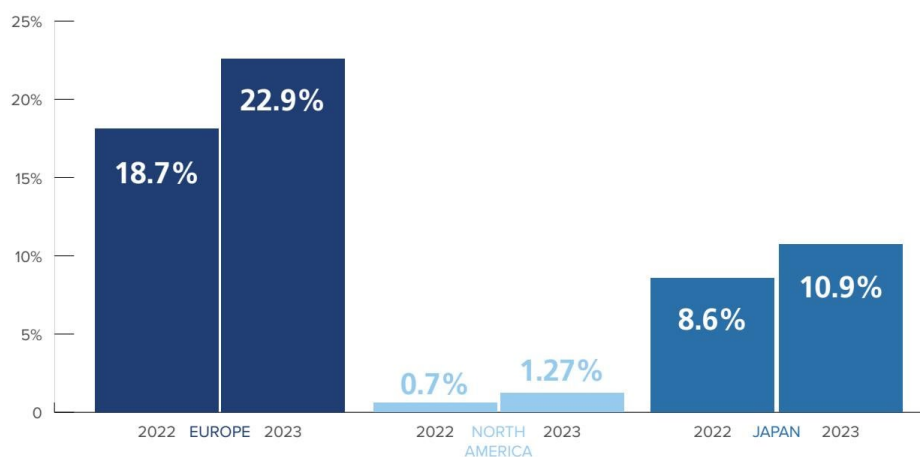
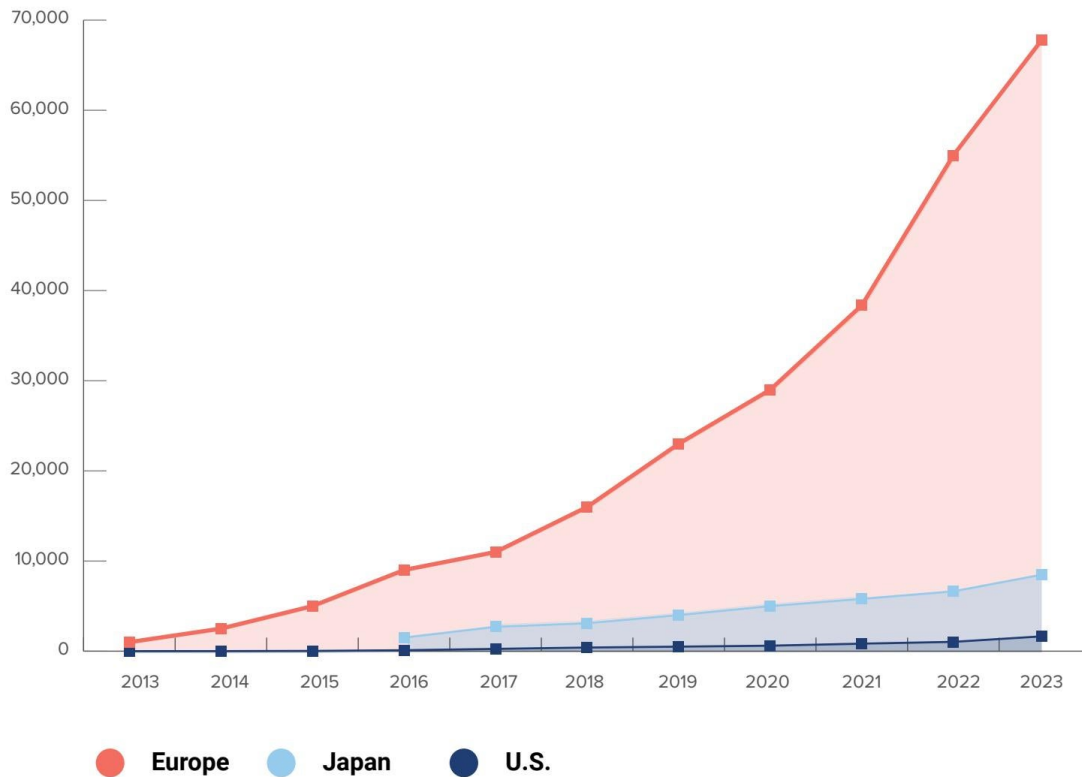


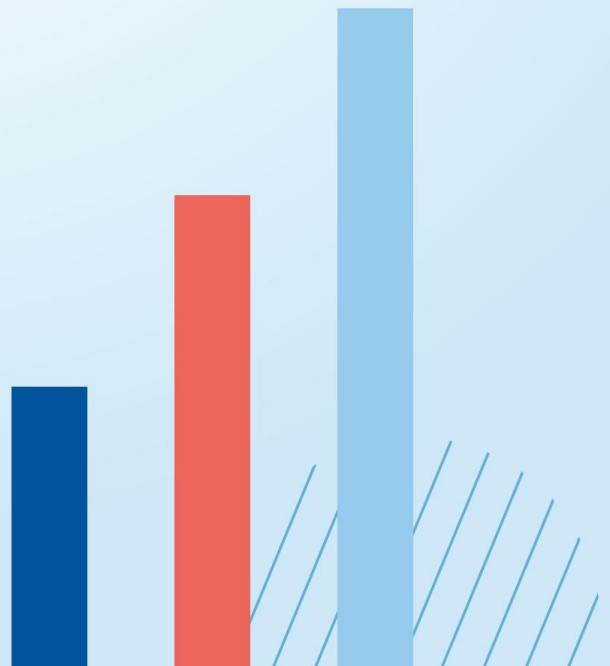
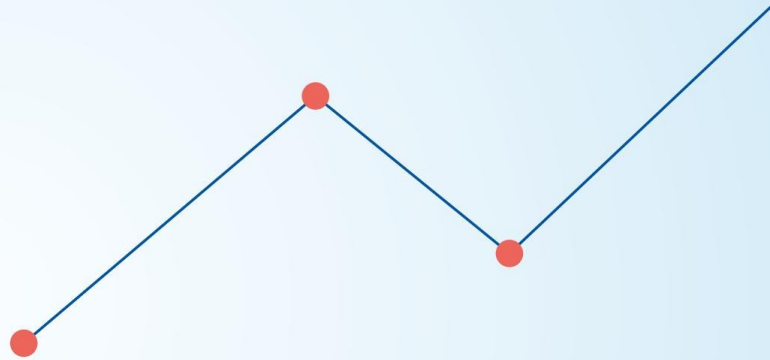
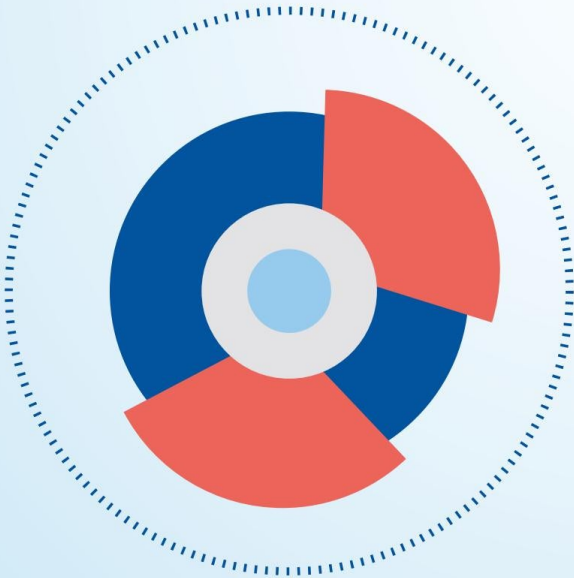
Figure 3: Transcritical CO₂ Installation Growth in Major Regions

(stores)



CHAPTER 1

Global Trends



1.1 The Impact of Market Leaders

In all markets, there have always been a few end users who like to investigate new technologies before their competitors. This has certainly been true for natural refrigerant systems, especially transcritical CO₂ (R744) systems, in the commercial refrigeration and industrial spaces.

These end users not only kick off a trend; they drive it over time and can be expected to continue installing new systems and retrofitting existing ones into the future. They also provide legitimacy to the technology, encouraging their competitors and others to eventually follow suit, thereby expanding the market.

In Europe, a number of retailers have launched aggressive transcritical CO₂ installation programs. These include Biedronka, Migros, Albert Heijn, Sainsbury's and the Salling Group.

In other regions, there are far fewer clear leaders, but they have had an outsized impact on the market. In the U.S., the leader is ALDI US, which had installed transcritical CO₂ in more than 600 of its more than 2,000 stores as of September 2023.¹ Also in the US, Target said last year that it has switched to CO₂ refrigeration and will install the technology chainwide by 2040 to reduce its direct operations' emissions by 20%.² In Japan the CO₂ leader is convenience store giant Lawson, which had installed CO₂ condensing units in 5,028 stores as of December 2022.

Other market leaders include the following:

- U.S.-based multinational food processing company Cargill is transitioning from HFC chillers to CO₂-based systems for its industrial applications between 100 and 500kW (28.4 to 142.2TR) in capacity.³ The first CO₂ chiller was installed in Norway in 2022, and the company is evaluating the use of this technology for other projects in Europe. Where ammonia (R717) is in use, Cargill ensures it is confined to machinery rooms by opting for packaged units and cascade systems. This approach has enabled the company to reduce the amount of R717 used, with one instance seeing a decrease from 8 metric tons to under 1.5 metric tons. F-gas regulations and costs associated with HFCs and HFOs are prompting Cargill to shift towards natural refrigerants. For systems with capacities up to 1MW (284.3TR), propane (R290) is also being considered.
- Since beginning work with transcritical CO₂ technology in 2008, German food wholesaler METRO has implemented R744-based systems in 161 stores globally, as of September 2023.⁴ METRO plans to install them in two Ukrainian stores in 2024. This follows an earlier installation in the Kyiv store, which experienced a delay due to the Russian invasion. The company is also upgrading its stores in Moldova, with plans to make them all f-gas-free by next year. As part of METRO's F-gas Exit program, the company aims to eliminate emissions from refrigerant leakages by 2030 and has committed to using natural refrigerant-based equipment for all new HVAC&R systems. However, challenges such as a shortage of maintenance personnel for natural refrigerants hindered the technology's adoption in markets like Turkey and Dubai.
- Major French food retailer Carrefour has committed to reduce greenhouse gas emissions by 30% by 2030, focusing on energy efficiency and transitioning away from HFC refrigerants.⁵ For example, Carrefour's new store in Beringen, Belgium, has incorporated CO₂ refrigerated display units, connected to a centralized CO₂ system. This adaptation is expected to increase the store's energy efficiency by up to 10% due to Belgium's mild climate.
- California-based HVAC&R contractor Coolsys reports that natural refrigerants such as CO₂ and ammonia now constitute at least 65% of its installations.⁶ Over the past 15 years, the company, which oversees 23 other HVAC&R contractor firms in the U.S., has witnessed a growing interest in these refrigerants.

- Seven of the 10 stores operated by DeCicco & Sons, a food retailer based in New York, use transcritical CO₂ refrigeration, with an eighth on the way and the last two slated for conversion to CO₂ in the next three to five years.⁷ This makes DeCicco & Sons one of the leading users of CO₂ refrigeration among small-chain grocery operators in the U.S. The retailer has found that its Larchmont, N.Y., store, the first to use CO₂, consumes between 7 to 37% less electricity monthly compared to a store of similar size using the HFC (R404A) system. Its other CO₂ stores also use less energy than a store with an R404A system.
- Mexican Bakery Giant Grupo Bimbo, which operates over 200 bakery processing plants in 34 countries, says that over 60% of its total refrigerant charge is natural refrigerants.⁸ More than 10% of its facilities entirely use natural refrigerant technologies, with an additional 10% anticipated to transition by the end of 2023. Chillers in its bakeries commonly use CO₂ and propane systems, while the freezing segment incorporates CO₂ and CO₂/ammonia cascade systems.
- Longo Brothers Fruit Markets, located in Vaughan, Ontario (Canada), has adopted transcritical CO₂ systems in 16 of its 36 grocery stores and intends to implement CO₂ refrigeration in all new outlets and significant renovations.⁹ After opening a near net-zero energy supermarket in Stouffville, Ontario, in 2018, the company reported over a 45% reduction in corporate greenhouse gas emissions since 2020, largely due to refrigerant changes. Longo aims to transition all of its stores to natural refrigerants within the next three years, making it a leader among small-chain Canadian retailers.
- In August 2022, the Japanese retail Giant Aeon, which operates a variety of different retail formats, inaugurated its frozen food store, @ Frozen, in Urayasu, which incorporates 55 propane showcases from Daikin's AHT Singapore model line.¹⁰ Spanning 420m² (4,521ft²), the store features plug-in display freezers maintained at approximately -20°C (-4°F). Aeon plans to continue employing these Daikin showcases due to their low-GWP refrigerant, simple plug-in setup, and space-saving design. With recent changes in the Japanese Industrial Standard in 2021 allowing for increased propane charge in refrigeration units, the adoption of such hydrocarbon cases in Japan's commercial sector is projected to rise.

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1.2 Improving CO₂ Efficiency in Warm Climates

Concerns around the efficiency of CO₂ refrigeration systems in warm climates have long been seen as a barrier to CO₂ uptake worldwide, with a so-called “CO₂ equator” dividing viable installations to the north from non-viable ones to the south. However, technology developments such as adiabatic condensing, ejectors and parallel compression have increasingly made CO₂ technology viable in all climates, including regions previously deemed not suitable.

Ejectors and parallel compression make CO₂ systems more efficient while operating in transcritical mode. Parallel compression compresses the excess gas at the highest possible pressure level. This leads to a significant increase of coefficient of performance (COP) in warm climates. Evaporative condensation, mechanical sub-cooling and adiabatic gas cooling decrease the outlet temperature of the gas cooler and force the system to operate longer in subcritical mode, thereby making it more efficient.

Manufacturers are continuing to come up with new ways to improve the efficiency of refrigeration systems, and there are multiple solutions from different companies already available on the market today.

For example, a Carrefour supermarket in Diepenbeek, Belgium, has saved up to 15% in energy use at 25°C (77°F) ambient temperature by using two PX G1300 pressure exchanger devices from U.S. manufacturer Energy Recovery in the store’s transcritical CO₂ system.¹¹ In a Vallarta supermarket in Indio, California, the installation of the device in a transcritical CO₂ system has resulted in up to 30% peak energy savings. The device also replaced several other components, leading to capital investment savings.

Italian OEM Epta has designed its own technologies to improve the efficiency of transcritical CO₂ systems in warm climates, the FTE (Full Transcritical Efficiency) and ETE (Extreme Temperature Efficiency). ETE goes an extra step, enabling efficient operation in temperatures higher than 40°C (104°F), said Epta.

The FTE system, introduced in Europe in 2017 (with version 2 released in 2020), employs a low-pressure liquid receiver to flood medium-temperature evaporators with liquid CO₂. This eliminates superheat and allows the evaporation temperature in the cabinets – and ultimately the efficiency of the system – to increase.

Introduced in Europe in 2020, ETE uses a heat exchanger to subcool a portion of the CO₂ coming out of the gas cooler and delivers the refrigerant – expanded to an intermediate pressure level by the EEV (electronic expansion valve) – to the high-pressure line.

Energy Recovery’s PX G1300 pressure-exchanger device will be a “featured component” of Epta’s next-generation commercial CO₂ refrigeration technology, the XTE (Extra Transcritical Efficiency).¹² An Italian supermarket, the first in Europe to incorporate the PX G1300 device into an Epta CO₂ refrigeration system, saw efficiency improvements of 25-30% at temperatures of 35-40°C (95-104°F), compared to a standard CO₂ booster system.

By removing the barrier that prevents CO₂ systems from operating efficiently in higher ambient climates, these technologies make it possible to install CO₂ systems in stores and warehouses anywhere in the world. This is leading to growth in CO₂ systems in regions previously not considered suitable – such as the southern U.S. – and this positive trend in CO₂ system growth is expected to continue.

Other recently announced ways to improve the efficiency of transcritical CO₂ systems:

- Kyodo Susian Ryutsu, a Japanese food and beverage distributor, transitioned from its dated R22 refrigeration system to transcritical CO₂ condensing units from Nihon Netsugen at its cold chain distribution center near Tokyo in 2021.¹³ The design incorporates a modern defrosting approach that has the potential to cut energy use between 20-30%.
- Professor Mani Sankar Dasgupta from the Birla Institute of Science and Technology (BITS), Pilani, India, introduced a transcritical CO₂ refrigeration system employing multi-ejectors, parallel compression and mechanical sub-cooling.¹⁴ This new system was found to be up to 82.5% more efficient than a conventional transcritical CO₂ booster system in a warm ambient climate and 18.7–46.8% more efficient than a R404A-based DX system.
- Ángel Á. Pardiñas, a researcher at ITG (Galician Institute of Technology), and his team proposed a hybrid ejector that could lift

energy efficiency of transcritical CO₂ systems by between 5% and 42% across all ambient conditions.¹⁵ The proposed hybrid solution encompasses medium- and low-temperature compressor suction groups, non-superheated medium-temperature evaporation with increased evaporation temperature and year-round ejector utilization. During the summer (elevated ambient temperatures), the ejector actively operates as a high-pressure control device. In the winter the ejector remains passive, functioning as a check valve.

- A Norwegian supermarket chain would be able to reduce power usage by 13 to 19% by integrating a CO₂ booster system with a cold thermal energy storage (CTES) medium.¹⁶ Instead of a typical glycol circuit, this system uses water/ice as the storage medium for air-conditioning. (The transcritical system also provides food cooling/freezing and air-conditioning.) Using water/ice for CTES allows cold energy storage during night time that is used during peak hours. CTES technology provides flexibility, adapting to future electricity markets, ensuring savings and promoting sustainability.

1.3 The Growth of Integrated CO₂ Systems

There are at least three regions, Australia, Canada and especially Europe, that are seeing interest in integrated transcritical CO₂ systems, which combine refrigeration, air-conditioning and space/water heating.

In Australia, the large food retailer Woolworths has installed a number of integrated transcritical systems among its CO₂ installations and plans to use this technology where feasible.¹⁷ A remodeled Michael's SUPA IGA store in Keysborough, Victoria, has also installed a fully integrated and highly efficient transcritical CO₂ HVAC&R system.¹⁸

A number of European OEMs offer integrated transcritical CO₂ systems. For example, Danish OEM Advansor presented its new CuBig II, an all-in-one HVAC&R unit that provides refrigeration, air-conditioning, and heating at Chillventa 2022 in Nuremberg, Germany.¹⁹ It is designed for larger commercial and industrial applications. CuBig II has a cooling capacity of up to 450kW (128TR).

In 2022, Swiss cold storage operator Grünenfelder installed an integrated TotalGreEnergy CO₂ refrigeration, heating, and cooling system system from Swiss OEM Biaggini Frigoriferi, in Quartino, Switzerland.²⁰ It has used 30% less energy than the previous systems that employed R507A and R404A for cooling and heating, respectively.

Reversible CO₂ heat pumps, in concert with a transcritical CO₂ booster refrigeration system, are being used in multiple European retail locations for heating and air-conditioning.²¹ For example, at a Migros shopping mall in Lucerne, Switzerland, two reversible CO₂ heat pumps were installed in 2019 to provide heating and air-conditioning. The two air-to-water units replaced the mall's existing oil-fired system and serve 50 shops spread across two 45-year-old buildings. In a shop, a CO₂ booster system with an ejector and parallel compression was installed and linked to the heat pumps. The two heat

pumps offer a cooling capacity of 1.1MW (312.8TR) and a heating capacity of 1.3MW (369.7TR), the latter using heat recovery from the retail booster system.

A supermarket in northern Italy has reduced its energy bills by an estimated €18,000 (US\$19,500) per year by installing a CO₂-based rack from Frigoveneta that integrates the store's refrigeration, HVAC, and hot water production requirements into a single system.²² Previously, the store had a direct expansion R404-based refrigeration system, a methane-fueled boiler for heating and hot water and no air-conditioning. Another supermarket, in Verona, Italy, has cut its HVAC energy use by 40% by integrating its heating and air-conditioning into its CO₂-based refrigeration system from Arneg.²³

Also in Europe, the MultiPACK project, an EU-sponsored initiative, supported the development of integrated transcritical CO₂ systems, particularly in warm climates. Launched in 2016, the project was completed in September 2021.

Examples of integrated CO₂ systems have emerged in Canada. For example, two CO₂ systems from OEM Arneg, coupled on one skid, are providing a 13-story mixed-use building in Montreal, Quebec, with supermarket refrigeration as well as heating, 140°F (60°C) domestic hot water and air-conditioning throughout the structure.²⁴

Integrated transcritical CO₂ systems are expected to be implemented widely in Europe, somewhat in Australia and Canada and eventually in the U.S. and Japan. The biggest driver is the energy savings and emissions reductions that come from leveraging heat reclaim from refrigeration to heat a facility or generate hot water, thereby eliminating fossil-fuel heaters. In addition, by incorporating air-conditioning, the integrated system can reduce overall equipment costs. A caveat is that if an integrated system goes down, all applications would be affected.

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1.4 The Strong Growth of Transcritical CO₂ in Industrial Refrigeration

While transcritical CO₂ refrigeration was first used on a widespread basis in supermarkets, it has gradually become a major option in the industrial space in cold storage, food processing and other applications, competing well with ammonia and other refrigerants in all major markets.

In fact, CO₂ has emerged as a particularly strong refrigerant for low-temperature applications in cold storage and food processing. It is seen as a way of avoiding the safety protocols associated with ammonia refrigeration while still using a natural refrigerant. On the other hand, it represents a new technology for an industry that has long been accustomed to using ammonia.

Transcritical CO₂ systems were originally regarded as most suited to small- and medium-capacity industrial applications, but in the past few years transcritical CO₂ installations have been specified for larger installations as well, with cooling capacities of up to 4MW (1,137TR) being achieved.²⁵ This was helped along by CO₂-specific components, semi-hermetic reciprocating compressors in particular, being scaled to industrial sizes by manufacturers.

For example, Italian compressor manufacturer Dorin's latest range of transcritical CO₂ compressors for industrial applications (CD600) has six cylinders and covers up to 160HP and 100m³/h (3,531.5ft³/h).²⁶ Previous models covered up to 100HP and 98.6m³/h (3,428ft³/h). The latest range of compressors offers a capacity of up to 200kW (56.9TR) with frequency drive capability. With this range of compressors, Dorin sets a new benchmark for industrial CO₂ applications, helping CO₂ to be one of the most cost-effective and efficient solutions. The CD range was originally launched in 2015, and in 2021, Dorin won the 2021 AHR Award in the refrigeration category for the CD600 range.

Meanwhile, German compressor manufacturer BOCK showcased an expanded CO₂ compressor offering at

the 2022 Chillventa trade show, highlighted by the new six-cylinder transcritical HGX56 CO₂ T.²⁷ The compressor is designed for industrial refrigeration and heat pump applications.

U.S. manufacturer Copeland (previously Emerson) has launched its first CO₂ screw compressor for industrial applications.²⁸ It is designed for the high stage of a CO₂ transcritical system and is engineered and rated to withstand CO₂'s high pressures in transcritical mode. It will be available in seven displacements with a power range from 100 to 800HP per compressor, up to 1,600HP in dual configuration and 2,400HP in tri-configuration.

Temprite, a U.S. manufacturer of oil management products for refrigeration systems, in April announced the release of its largest transcritical CO₂ (R744) coalescent oil separator, the Model 439A, designed to meet the growing demand for larger transcritical CO₂ systems.²⁹ "The Model 439A is an ideal fit for commercial cold storage, district heating, and heat pumps," Temprite said in a statement.

OEMs have also joined the industrial CO₂ refrigeration movement. For example, Italian OEM SCM Frigo has added high-capacity industrial transcritical CO₂ racks to its existing condensing units, chillers, and transcritical booster racks for commercial applications.³⁰ The new iBooster is designed for large logistics and processing applications and offers double the capacity of SCM Frigo's existing booster rack. The iBooster can provide up to 1.5MW (427TR) for medium temperature and up to 600kW (171TR) for low temperature.

U.S. manufacturer M&M Carnot started to build transcritical CO₂ industrial systems in April 2023 at its new 25,000ft² (2,323m²) factory space in Federalsburg, Maryland.³¹ In April, M&M Carnot was in the process of assembling a 40ft (12m)-long Aquilon industrial transcritical CO₂ rack with a capacity of 500TR (1,758kW) at -10°F (-23°C) using

large Dorin compressors. Two more similar units were scheduled in the next few months. Also in late April, the company shipped from Canada a 600TR (2,110kW) Aquilon industrial transcritical CO₂ rack, which is one of the largest in North America.

Washington State-based Pro Refrigeration has begun making CO₂ chillers for dairy and distillery applications.³² Southern Distilling Company, located in Statesville, North Carolina, has purchased its third CO₂-based chiller, called PROChiller, from Pro. Late in 2022, South Creek Dairy, a dairy farm based in Earlmart, California, finished commissioning a 100HP CO₂-based PROGreen chiller system from PRO for cooling and heating applications.³³

U.S. contractors have also reported industrial CO₂ refrigeration installations. California-based HVAC&R contractor CoolSys this year gave a presentation about two CO₂-based industrial refrigeration projects.³⁴ At a 330,000ft² (30,660m²) cold storage facility on the East Coast of the U.S., five CO₂ transcritical racks from Zero Zone provide 1329TR (4.6MW) in cooling capacity at various suction temperatures. The other storage facility is on the West Coast with a total of six transcritical CO₂ racks providing 1,129TR (3.9MW) in cooling capacity.

Wisconsin-based contractor Bassett Mechanical simplifies its industrial CO₂ installations by using virtual design and construction for prefabricated production, linking field laser measurements with 3D design and computer numerically controlled (CNC) equipment processing.³⁵ In this way Bassett replaced a paper plant's R22 system with CO₂ chillers using adiabatic condensers, which resulted in an efficient and cost-effective solution.

Last year in Japan, manufacturer Panasonic supplied 10 of its 80HP transcritical CO₂ booster racks and 17 CO₂ outdoor condensing units (OCUs) to the largest CO₂-based cold storage facility, located in Sendai.³⁶ Meanwhile, OEM Nihon Netsugen said in January that it planned to double its production capacity for CO₂ condensing units in 2023 with the construction of a new factory, which opened in March.³⁷ This expansion is designed to meet the demand for industrial transcritical CO₂ refrigeration systems in Japan and Asia Pacific.

Another sign of CO₂'s relevance to the industrial sector is the publication in August 2021 of the International Institute of Ammonia Refrigeration (IIAR)'s ANSI-approved Safety Standard for Closed-Circuit Carbon Dioxide Refrigeration Systems. IIAR has traditionally produced safety standards for industrial ammonia applications, but the trade group has recognized the growing use of transcritical CO₂ by industrial end users and the need for standards to address CO₂.

Robust growth is expected for transcritical CO₂ in cold storage and other industrial applications, especially for low-temperature applications. Its chief competitor will be ammonia, in particular low-charge ammonia and ammonia/CO₂ systems, given ammonia's entrenched dominant position in industrial refrigeration, as well as propane in chillers. It will also compete – but to a lesser degree than in the commercial space – with HFO blends.

1.5 The Myriad Roles of Hydrocarbon Cases

In supermarkets, “remote” refrigerated display cases are typically linked through piping networks to compressor racks or condensing units outside the sales area.

However, another option are so-called plug-in cases with internal condensing units that employ small amounts of hydrocarbon refrigerant, notably propane or, to a lesser degree, isobutane (R600a) or propylene (R1270). These self-contained cases are easier and less expensive to install, maintain and replace than remote systems, allow flexible merchandising and offer low-energy consumption as well as residual heat reuse for the store’s heating and hot water.

Notably, hydrocarbons represent a substantial and growing share of the refrigerants used in the self-contained case marketplace. According to data from Embraco (a brand of Nidec Global Appliance), hydrocarbons accounted for 72% of the refrigerant market share for self-contained cases, with HFCs taking up 18%, in 2021; in 2025, hydrocarbons’ share will grow to 83% and in 2030 to 96%, says Embraco.³⁸

In large stores, air-cooled R290 cases are employed as spot merchandisers – front-end beverage coolers or horizontal bunker cases – supplementing remote cases linked to the central refrigeration system. They can also be used to replace outdated remote HFC cases – which improves the capacity of the HFC rack – as well as old self-contained HFC cases or be installed in an expansion/remodel. Thus, they are seen as an inexpensive way to shift a large store to natural refrigerants without investing in a new rack system.

Most hydrocarbon cases are air-cooled, but a growing number, so-called semi plug-in cases, use a water-loop (glycol) system to remove the heat from lines of contiguous cases. Freor, a Lithuanian manufacturer of propane-based commercial refrigeration equipment, is a leading producer of R290

water-loop (called Hydroloop) systems. For example, Slovakian retailer Fajne Potraviny has recently implemented Freor’s propane Hydroloop system, improving energy efficiency by up to 70%, compared to traditional control systems, Freor said.³⁹ Topten, an online guide for energy-efficient products, has listed Freor’s propane commercial refrigeration cabinets.⁴⁰

In some small-format stores – including grocery, convenience, dollar and even drug stores – hydrocarbon units are being installed throughout the sales floor (and in a growing number of locations, in cold rooms). In Europe, chains like Waitrose in the U.K., Colruyt in Belgium and Germany-based Lidl have installed hydrocarbon units store-wide. In the U.S., Lidl and Wild Fork Foods, a small Florida chain, are examples of retailers that have taken this approach.

The hydrocarbon charge limit of 150g has not prevented the rapid expansion of the R290 display case market. However, the prospects for propane in commercial refrigeration improved when the International Electrotechnical Commission (IEC) increased the amount allowed in self-contained cases to 500g from 150g in 2019; this will potentially lower the cost of R290 equipment, particularly large cases. Regional standards bodies have adopted or are in the process of adopting the IEC model in whole or in part.

In Europe, where many small-format stores have installed hydrocarbon cases throughout the sales floor, and often in the cold rooms, this trend will continue as more small stores are opened in urban areas. Large stores will use R290 cases in more places as a supplement to remote cases. In North America, a small number of small-format stores are installing hydrocarbon cases throughout or in parts of the sales floor, but this will be the exception.

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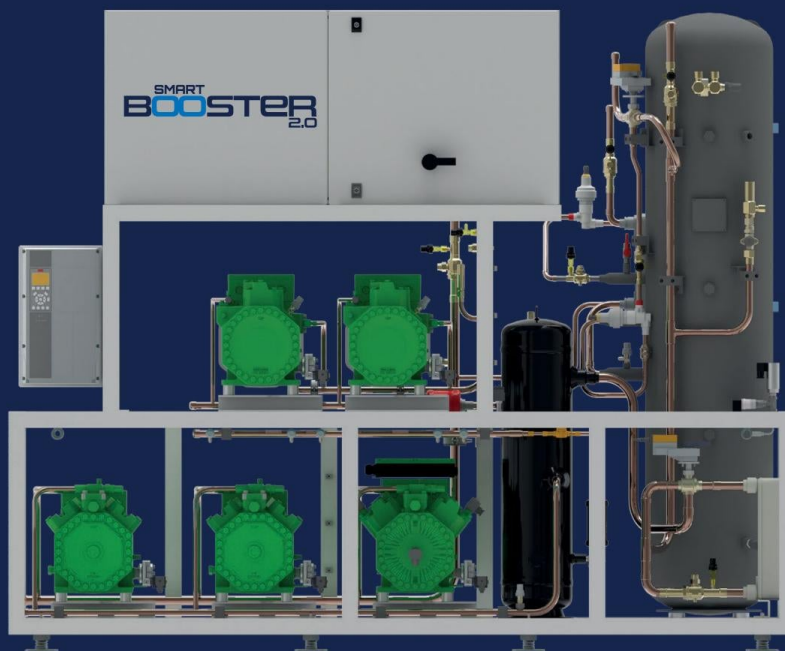
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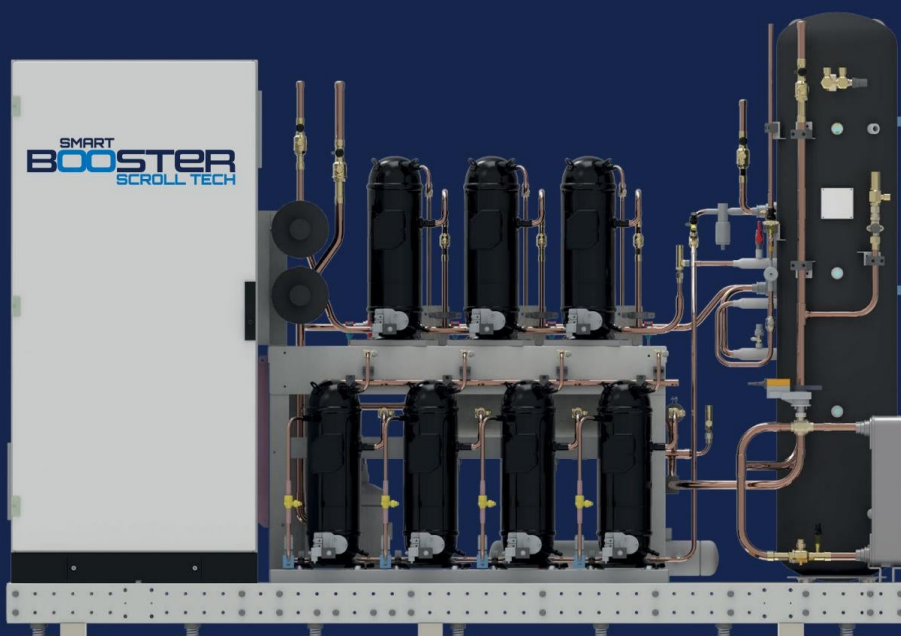
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1.6 Variable-Speed R290 Compressors Meet Efficiency Requirements for Cabinets

Variable-speed compressors for hydrocarbon cases were introduced in 2007. In the last few years, several compressor manufacturers have started expanding their variable-speed portfolios, adding hydrocarbon compressors for both small and larger applications.

In support of this trend, research and testing have found that variable-speed compressors can outperform conventional on-off systems in energy efficiency, temperature recovery time, noise output and operating temperature. Additional advantages of the variable-speed units include the ability to withstand network voltage fluctuations and reduced stress on a compressor's mechanical and electrical parts.

According to compressor manufacturer Embraco, a brand of Nidec Global Appliance, the market share of variable-speed compressors in plug-in hydrocarbon appliances was 18% (the rest being fixed speed) in 2021 and will grow to 30% in 2025 and 50% in 2030.³⁸ Variable-speed compressor adoption is inevitable, says Embraco, in order to meet upcoming efficiency requirements around the world.

Embraco has presented several case studies supporting the benefits of switching to R290 variable speed. For example, using an R134a system with an on/off compressor as a baseline, a 1,120L (39.6ft³) R290 beverage cooler was able to achieve a 35.9% reduction in energy consumption. When adding a variable-speed compressor and R290, it achieved an even higher 53.4% energy reduction in comparison to the baseline.⁴¹

In 2023, AHR Expo attendees got to learn about Embraco's soon-to-be-launched VNEX compressor, which combines its variable-speed technology with propane.⁴² This latest model is designed for large food retail applications in low and medium temperatures.

The manufacturer added that depending on the application, its variable-speed compressors can cut energy use by up to 40% compared to fixed-speed alternatives. Also this year, Embraco launched three of its propane-based variable-speed compressors – VEMT, VEH, and VNEX – in China for the food service and food retail markets.⁴³

German manufacturer Secop has also found cabinet efficiency gains of 20–40% when switching a fixed-speed R290 compressor to a variable-speed model. Variable-speed compressors previously made up 6–7% of Secop's commercial compressor sales, but this share is growing, driven mainly by energy-efficiency regulations.⁴⁴

According to U.S. manufacturer Tecumseh, its propane-based variable-speed compressor meets the requirements of the U.S. Environmental Protection Agency (EPA)'s Energy Star "Emerging Technology" award.⁴⁵

Global beverage producer Red Bull, by installing a variable-speed propane compressor in its refrigerated display cases in 2021, has reduced its energy consumption by 43% compared to its 2007 model and by 8% compared to its 2017 model. The cases, supplied by Italian OEM EPTA Refrigeration, employ a variable-speed compressor with "Smart Drop-In" technology from Embraco.

While there is a cost premium for variable-speed compressors – about double the cost of fixed speed – there can be a quick ROI for the end user (in as little as three months). By improving the efficiency of display cases, variable-speed compressors make hydrocarbon-based units even more attractive and generate a better return on investment and total cost of ownership.



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1.7 Low-Charge Options Boost Ammonia

Over the past five years, low-charge ammonia systems, driven by safety and regulatory considerations, have gained traction in cold-storage and food-processing applications – a trend that is expected to continue throughout the world.⁴⁶ Its growth is being slowed, however, by the increasing uptake of transcritical CO₂ in industrial refrigeration.

The low-charge systems have taken the form of single or multiple packaged units (including chillers), typically installed on or near rooftops, or centralized, machine-room systems. The latter could also include an ammonia/CO₂ cascade or systems that confine the ammonia to the machine room and use a secondary refrigerant for the refrigerated space. All models take advantage of the inherent efficiency of ammonia as a refrigerant.

These systems have allowed many industrial end users to dramatically cut the amount of ammonia used, compared to traditional liquid-overfeed systems, thereby reducing their safety requirements, while maintaining – or even improving upon – the high efficiencies of traditional ammonia systems.⁴⁷

An example of the growth in low-charge ammonia can be seen in U.S. OEM Evapco, which, since introducing its Evapcold low-charge ammonia packaged units in 2016, has installed more than 150 of the units (including refrigerators and chillers) across more than 30 industrial sites in North America, with each site using between one and 10 units.

Evapco has installed its first low-charge ammonia split refrigeration systems at a cold storage facility in Reno, Nevada with specialist contractor Ti Cold.⁴⁸ The new Tahoe-Reno Industrial Center's five cold rooms and loading dock are cooled by 10 Evapcold low-charge split systems, each connected to two ceiling-mounted evaporators. Previously released Evapcold units include an evaporator. In October, Evapco announced its VersaSplit unit, which supports up to six separate evaporators.⁴⁹

Irish manufacturer Johnson Controls announced its acquisition of U.S. OEM M&M Carnot in June.⁵⁰ Johnson Controls is a major supplier of ammonia-based industrial refrigeration equipment, while M&M Carnot is a leading North American provider of low-charge ammonia units as well as CO₂-based industrial (cold storage and food processing) and commercial (supermarket) refrigeration. In April M&M Carnot announced that, with four orders, it had started building low-charge ammonia packaged refrigeration units for industrial applications under its Pure Refrigeration line at its factory in Federalsburg, Maryland.

Japanese company Mayekawa has started to supply its FUGU mCHILLER water-cooled, low-charge-ammonia chillers to the U.S., following the installation of approximately 40 to 50 units in Europe over the last year.⁵¹ Mayekawa says its air-cooled low-charge-ammonia TAKA mCHILLER, launched last October in Europe, can compete with low-capacity hydrocarbon, HFO and HFC chillers.⁵²

Also in Europe, Italian manufacturer Zudek's air-cooled, low-charge ammonia chiller has improved the energy efficiency ratio (EER) of a cooling system at a pharmaceutical site in Belgium, by 20%, compared to its previous HFC-based unit.⁵³ And OEM Soluzione Termica collaborated with compressor manufacturer Frascold to revamp an Italian dairy's refrigeration system by replacing its f-gas chillers with two low-charge ammonia chillers.⁵⁴

How low is low-charge?

The amount of ammonia in low-charge systems varies. Among the lowest charges was devised by the late Professor Pega Hrnjak of the University of Illinois at Urbana-Champaign and research firm Creative Thermal Solutions (CTS), who developed a system using only 0.1lb/TR (0.01kg/kW) of ammonia with very low-cost components.⁵⁵

In 2016, the International Institute of Ammonia Refrigeration (IIAR) revised its widely respected IIAR-2 safety standard for ammonia, for the first time addressing ammonia equipment outside the machine room such as low-charge ammonia packaged systems, as well as explicitly covering ammonia/CO₂ systems. In November 2018, IIAR released Low Charge Ammonia Refrigeration Management (ARM-LC), its first guidelines for users of low-charge ammonia systems that use a charge of 500lbs (227kg) or less. The guidelines, which cover packaged and centralized low-charge ammonia systems, are designed to help end users of low-charge systems that may not have used ammonia before.

One of the key advantages of low-charge ammonia systems is that they enable end users to avoid demanding federal regulations on ammonia safety. For example, in the U.S., operators of low-charge systems can abide by the General Duty Clause, which is far less restrictive than rules for more than 10,000lbs (4,536kg) of ammonia set by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA).

Low-charge ammonia is bringing ammonia technology into the 21st century, unlocking opportunities for ammonia beyond its traditional market. End users who were previously hesitant to switch to ammonia now have peace of mind thanks to the vastly reduced refrigerant charge and perceived risks. This is expected to lead to the increased uptake of ammonia systems, even in regions where its use has been declining or not popular in the past. Its chief competitor will be transcritical CO₂ systems for those who want to reduce their ammonia charge to zero.



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APPLICA



1.8 Competition from HFOs

As the global shift from high-GWP HFC refrigerants drives the search for low-GWP alternatives, the recent rise of hydrofluoroolefins (HFOs), the latest generation of fluorinated refrigerants, is undeniable. With their sub-10 GWPs, HFOs – and their low-GWP (under 150) blends with HFCs – are the biggest competitor to natural refrigerants.

While pure HFOs like HFO-1234yf are widely used as a substitute for HFC-134a in mobile air-conditioning (MAC), HFO/HFC blends are more commonly employed in commercial and industrial refrigeration.

In the EU as a whole (plus the U.K.) in 2020, HFOs (unsaturated HFCs or HCFCs) represented 22% of the total amount of f-gases in metric tons, according to the European Environment Agency (EEA).⁵⁶

However, in Europe, under the EU F-gas Regulation, as of January 1, 2022, HFC refrigerants of 150 GWP or greater are banned in new refrigerator and freezer cabinets for commercial use. The same ban (for all f-gases) applies to new multipack centralized refrigeration systems for commercial use that have a cooling capacity greater than or equal to 40kW; if these are cascade systems, then the ban applies to f-gases with a GWP of 1,500 or greater.

Under the revised EU F-gas Regulation announced in October, the most commonly used f-gases, representing around 90% of f-gas emissions, will be reduced by 95% by 2030 compared to 2015, going down to zero by 2050 – the world's first total HFC phase out. Refrigerators and freezers for commercial use (self-contained equipment) that contain other fluorinated greenhouse gases (besides HFCs) with a GWP of 150 or more will be banned as of January 1, 2025. For centralized systems under 40kW, the 150-GWP limit takes effect in 2030.

In the U.S., under the AIM Act, the EPA has set a 150 GWP limit on refrigerants in new commercial refrigeration equipment, including self-contained cases and centralized systems as of January 1, 2025, and January 1, 2027, respectively.

This means that for many applications only f-gases with a GWP of under 150, such as extremely low-GWP HFOs R1234yf and R1234ze, and HFO/HFC blends R454C, R455A and R471A, which have a GWP of 148, will, over time, be allowed in new equipment for both low- and medium-temperature applications. Retrofits of commercial equipment would still allow use of refrigerants like R448A and R449A, which have a GWP of 1,379 and 1,390, respectively.

HFO-1234yf is an A2L (slightly flammable) refrigerant and completely oxidizes in the atmosphere to form trifluoroacetic acid (TFA), considered in many quarters a PFAS with potentially harmful human health impacts. R454C and R455A contain between 75–80% HFO-1234yf and are rated A2L.

However, in January 2022, Honeywell announced a new A1 (non-flammable) refrigerant with a GWP of 148 – R471A – for medium-temperature commercial refrigeration applications. It is a blend of HFO-1234ze (78.7%), HFO-1336mzz(E) (17%) and HFC-227ea (4.3%). Still, HFC-227ea, a fire suppressant, converts 100% in the atmosphere to TFA, and HFO-1234ze converts to some degree (less than 10%) to TFA as well.

A study by researchers at the University of New South Wales in Sydney, Australia, suggests that elevated levels of HFC-23 (R23) in the atmosphere could be linked to the commercial uptake of HFO-1234ze, which the study says produces R23 as a significant decomposition product. R23 has a super-high GWP of 18,400. If proven, this would impact the use of R471A.⁵⁷

Nonetheless, R471A is starting to be used in Europe and the U.S. For example, in Lyon, France, a U Express store has installed a central system using R471A, the first such installation in the country.⁵⁸ In the U.S., the EPA, under its Significant New Alternatives Policy (SNAP) program, approved R471A for new commercial and industrial equipment in September.⁵⁹ Food City, owned by K-VA-T Food Stores, has installed two condensing units using R471A for two beverage lineups at a store in Kodak, Tennessee,

according to a presentation made at the FMI (Food Industry Association) Energy & Store Development Conference in October by Charlie Lowe, Director of Refrigeration, K-VA-T Food Stores.

According to industry observers, HFO blends are getting less usage in plug-in cases, which are heavily gravitating to R290 and R600a. In any event, retailers in Europe and elsewhere that opt to retrofit only their refrigerant (typically an HFC) in an existing central system, rather than replace the entire system, are using HFO blends like R449A and R448A; natural refrigerants require an entirely new system and can't be used as drop-ins.

Potential risks of HFOs

Whether or not these HFO solutions represent a bridge to the eventual installation of a natural refrigerant system will depend on many factors, including regulations, equipment cost, total cost of ownership and, most important, the long-term viability of HFOs. Indeed, reputable reports citing the growing health, safety, and environmental risks of HFOs have been surfacing for several years. In a 2021 study of the environmental impact of HFOs, the German Environment Agency (UBA) concludes that HFOs used as refrigerants, foam-blowing agents and aerosol propellants "should be replaced by more sustainable solutions with halogen-free substances" such as natural refrigerants.⁶⁰

The UBA report focuses on the degradation products of HFOs, notably the rapid atmospheric conversion of HFO-1234yf into TFA, which descends to earth in rainfall. Because of the persistence of TFA in the environment and the difficulty of removing it from groundwater and drinking water, the UBA says that the use of HFOs as substitutes for HFCs "must be regarded as problematic."

In sufficient quantities, TFA can be a destructive substance. In pure form, it is harmful when inhaled and causes severe skin burns. But even at extremely small concentrations in drinking water, TFA is potentially harmful to human health. Moreover, it is difficult to remove from the freshwater bodies that supply drinking water using conventional methods.

A new study of households in the U.S. state of Indiana has found TFA in samples of dust, drinking water, human blood serum, and, to a lesser degree, urine.⁶¹ The study says it is the first to report "a

substantial prevalence" of TFA and another similar substance in the U.S. indoor environment and the general population, and it is possibly the first to correlate the presence of TFA in drinking water with TFA in blood samples.

This study concludes that TFA and its chemical ilk are now abundant in the indoor environment and in humans, and this warrants further research on potential adverse health effects.

Meanwhile, new studies around the world continue to detect TFA in the environment. Chinese researchers have projected, for the first time, China's annual and cumulative emissions of HFOs, HFO-1234yf and TFA. European chemical testing agency Eurofins found TFA present in 32 drinking water samples from 31 cities in Sweden and Norway in the 70-720 ng/L range. And in a study of PFAS in marine and terrestrial species in the Norwegian environment, researchers found TFA "a major contributor" to the PFAS burden and "can be important" in the livers of white-tailed eagle, arctic fox and otter.⁶¹

Some aquatic life may already be feeling the effect of TFA, according to a wide-ranging 2017 HFOs/TFA study by the Norwegian Environment Agency. Exposure of freshwater green algae to existing levels of TFA in Malawi, Chile and Germany was found to "equate to there being an environmental risk," the report said.⁶²

In Germany, UBA has set a human health "orientation value" limit of 60 µg/L for TFA in drinking water and a "precautionary measure" of 10 µg/L. The concentration levels of TFA in the environment have begun to approach – or exceed – those levels in some studies.⁵⁷

Long-term exposure to TFA can potentially damage the liver and the thyroid function in humans, according to a report released in 2021 by Refolution Industriekälte, a German consulting and engineering firm focused on sustainable refrigeration.⁶³

Both TFA and HFO-1234yf fall under the definition of PFAS (per- and polyfluoroalkyl substances) established by the OECD (Organisation for Economic Co-operation and Development) and used by scientists around the world.⁵⁷ PFAS encompass a well-known group of chemicals such as PFOA, PFOS and GenX that have been linked to harmful health effects.

Adopting the OECD definition of PFAS, five European countries announced in 2021 their intention to submit a joint proposal to restrict some HFC and HFO refrigerants and TFA as PFAS under the EU's REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation. The European Chemicals Agency (ECHA) is addressing the proposal in 2023.

In the U.S., the Environmental Protection Agency (EPA) uses a different definition of PFAS that does not include f-gases or TFA; however, the agency's narrower definition has come under considerable criticism from U.S. scientists, and a national bill has been put forward to change the EPA's definition to the OECD's. This year, the agency has indicated more flexibility in its definition but in June, a U.S. Senate committee proposed a narrow definition of PFAS that would exclude TFA.

The chemical industry has taken the position that TFA is not a threat to the environment or human health. Mike Sweeney, Global Commercial Refrigeration Platform Lead, Honeywell, made that point recently at the FMI Energy & Store Development Conference, in Baltimore, Maryland, citing United Nations Environment Programme (UNEP) Environmental Effects Assessment Panel reports; the Panel issued an update in 2020, which said that "there is no evidence to date" of adverse effects of TFA in drinking water on human health.⁶⁴ But the Panel's report from 2016 noted that "the formation of TFA from the degradation of HCFCs and HFCs warrants continued attention, in part because of its very long environmental lifetime."⁶⁵

The chemical industry addressed the environmental deposition of TFA in an October 2021 study funded by the Global Forum for Advanced Climate Technologies (globalFACT), which represents f-gas producers Chemours, Honeywell, Arkema and Koura (and equipment manufacturer Daikin). The study concluded that "with the current knowledge of the effects of TFA on humans and ecosystems, the projected emissions through 2040 would not be detrimental." But the study also acknowledged that "the major uncertainty in the knowledge of the TFA concentrations and their spatial distributions is due to uncertainties in the future projected emissions."⁵⁷

With the backing of the major multinational chemical companies, HFOs and HFO blends will continue to be a formidable competitor for natural refrigerants and gain market share in the near term as HFCs are phased down. However, given the growing research into the potential risks and negative impacts of HFOs, it's reasonable to believe that policymakers will become increasingly concerned and eventually enact regulations of HFOs and HFO blends.

If HFOs are restricted, this would leave natural refrigerants as the only viable alternative, creating a massive boost for the natural refrigerant industry. As Europe is the world's leading regulator of refrigerants and home to many of the major studies on the impact of HFOs, we expect this to be where HFOs will be initially regulated, possibly beginning next year.



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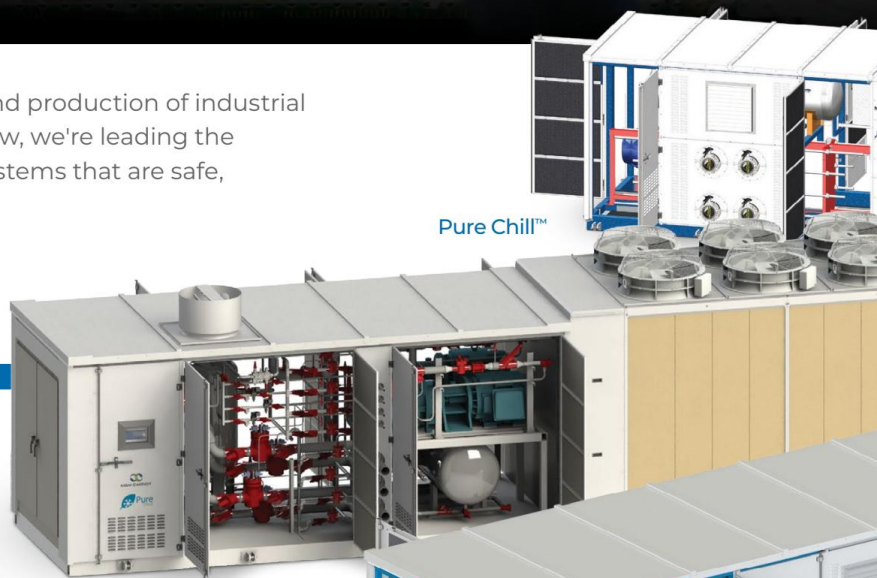
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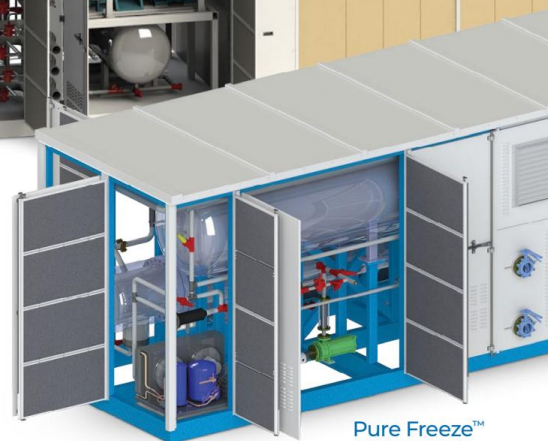
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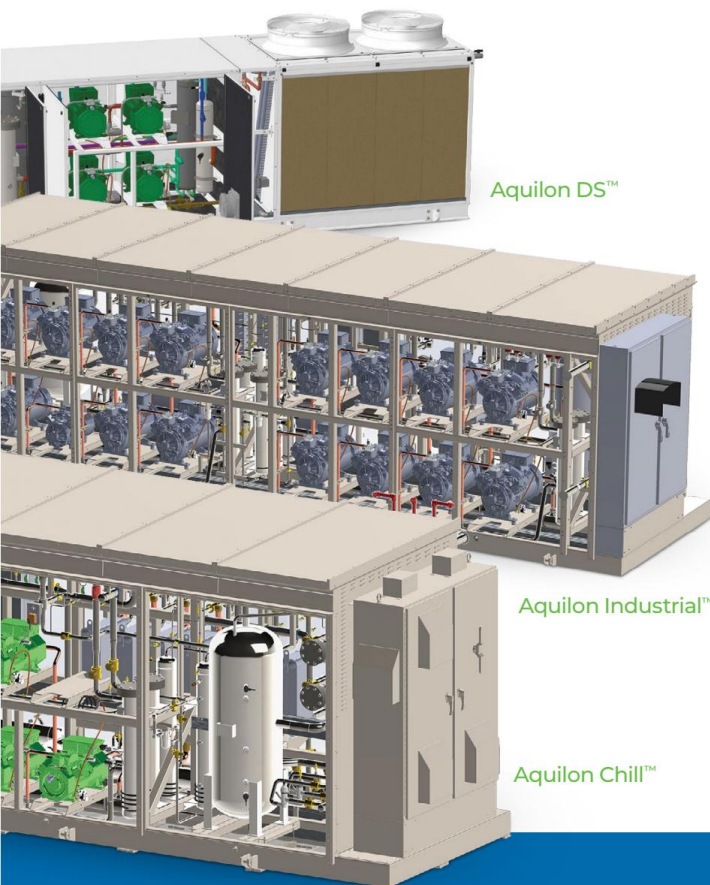


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1.9 COP28 to Launch Global Cooling Pledge

The 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) will be held from November 30 to December 12, 2023, at the Expo City, Dubai, United Arab Emirates. For the first time, COP participants will take into account the detrimental effect of cooling and heating systems on the climate.

The government of the United Arab Emirates, holder of the COP28 Presidency, has been advocating for cooling to become a topic in climate negotiations.⁶⁶ As a result the “Global Cooling Pledge” will be launched at COP28.⁶⁷

This voluntary pledge intends to raise ambition and international cooperation through collective targets on energy efficiency of cooling and climate-friendly approaches, while increasing access to sustainable cooling for the most vulnerable. It is supported by the United Nations Environment Programme (UNEP)-led Cool Coalition and its partners, including Sustainable Energy for All Initiative (SEforALL) and the International Renewable Energy Agency (IRENA).

The Global Cooling Pledge aims to reduce the high emissions created by cooling by 68% by 2050 compared to 2022 levels via the adoption of efficient and sustainable cooling technologies in participating COP countries.

At a time when unprecedented heatwaves are gripping many regions of the world, COP28 highlights how urgent action is needed to deliver sustainable cooling solutions that will protect people without hastening climate change. Several ministers and high-level representatives rallied behind the Global Cooling Pledge, supporting its calls to action on sustainable cooling and the steps the global community must take to achieve a “Cool COP28,” specifically one that sparks commitments towards improving sustainable cooling access.

ATMOsphere has submitted input to the Global Cooling Pledge, raising the fundamental importance of relying on the least climate-detrimental refrigerants, expanding training for all stakeholders, and ensuring sustainable cooling is provided to the most vulnerable people in a fair manner.



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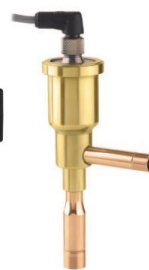
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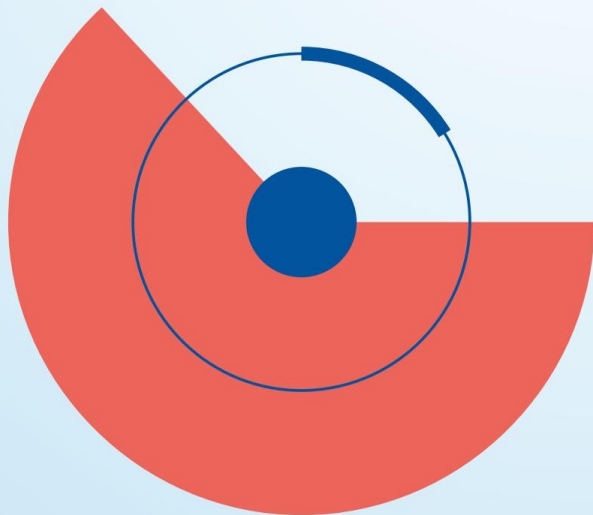
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CHAPTER 2



European Trends



2.1 The European Food Industry: Economic Outlook

In 2022, the European food industry was defined by rising inflation, which was largely driven by the residual impacts of the COVID-19 pandemic and Russia's invasion of Ukraine. Across the European Union, general inflation averaged at 9.2%, up from just 2.9% in 2021, and peaked at 11.5% in October 2022.

The rise in food inflation was even more drastic, with many countries in the EU seeing it reach twice the rate of general inflation. In 2022, food inflation jumped from 4.8% in January to 17.8% in December. Rates continued to increase into 2023, peaking at 19.2% in March, before steadily decreasing.⁶⁸

As 2023 draws to a close, inflation is easing but remains high.⁶⁹

GROCERY RETAIL

In response to economic pressures, consumers have become increasingly price sensitive and are actively looking for ways to save money. Many have turned to discount supermarkets (like ALDI, Lidl and Biedronka), which saw a 1.4% increase in market share across the European sector. The growth of discounters came at the expense of all other channels, with the market share of traditional trade, online grocery, hypermarkets and supermarkets declining by 0.8%, 0.3%, 0.2% and 0.1%, respectively.

In addition to the increased price sensitivity of consumers, the growth in discounters was driven by a significant expansion in their overall retail space over recent years. In 2022, the footprint of discount retailers was 3.6% larger than in 2021 and 9.7% larger than in 2019. By contrast, supermarket space increased by just 1.3% between 2021 and 2022.

According to McKinsey & Company, consumers are unlikely to return to supermarkets from discounters; however, the online grocery market is expected to return to "moderate growth" in the long term.

Tightening margins

Across the major European food retailers, revenue amounted to approximately €3 trillion (US\$3.15 trillion) in 2022.⁷⁰

While overall sales grew by 2.9% between 2021 and 2022, this was predominantly as a result of higher prices, with retail volumes in fact dropping by 3.6%. In real terms, the turnover of European food retailers decreased by 7.1%.

A combination of declining turnover and rising costs has put significant pressure on the margins of many food retailers in Europe and 2022 saw the largest decrease in European grocers' margins in the last five years. Between 2019 and 2022, the average margin dropped by three percentage points.

McKinsey & Company data suggest that the CEOs of Europe's grocers remain cautious but are less pessimistic about the market than in previous years. While the current financial climate will require retailers to tightly manage operational costs, the consultancy believes it also presents grocers with opportunities to "act boldly."

Europe's energy crisis

One of the major elements that drove inflation rates up and retailers' margins down in 2022 was the cost of energy, which surged as Europe shifted away from Russian gas in the wake of Russia's invasion of Ukraine.

According to EuroCommerce, European retailers faced energy bills that were four times higher than in previous years, with energy costs accounting for roughly 40% of their net income.⁷¹

In an effort to reduce energy costs, retailers are implementing a range of programs and initiatives to improve energy efficiency and enhance energy security, such as optimizing lighting, heating and air-conditioning systems.

Investing in the future

Driven by European Green Deal targets, investor expectations and the need to reduce operational costs, an increasing number of food retailers in Europe are investing in sustainability and decarbonization. Such efforts are not only necessarily for reducing greenhouse gas emissions – both Scope 1 (direct) and Scope 2 (indirect) – but also for building resilience and driving long-term growth.

According to a study conducted by McKinsey & Company, 7% of grocery CEOs rank decarbonization targets as a top priority moving forward. Another 26% have ranked it as a predominant trend. As of 2022, 36 food retailers with operations in Europe had established science-based targets for decarbonization, up from 22 in 2021.

The study projects that the investments required to reduce Scope 1 and Scope 2 emissions – which make up just 7% of retailers' carbon footprint – could be as high as €65 billion (US\$68.3 billion) by 2030. Additional investments will be needed to support developments in digitalization, automation and IT improvements.

While Scope 3 (value chain) emissions make up the majority of a grocer's carbon footprint, a greater understanding of options is needed to reduce those emissions.

COLD STORAGE

As of March 2023, Europe's 10 largest refrigerated warehousing and logistics providers operated around 33.2 million m³ (1.2 billion ft³)⁷² across the continent, up from 29 million m³ (1.04 billion ft³) in 2022⁷³. This trend could suggest either increased footprint or market consolidation through mergers and acquisitions.

Like food retailers, European cold storage operators have seen an increase in operating costs, largely from labor and energy. Labor costs are likely to be exacerbated by labor shortages and the need for competitive wages; alternatively, cold storage operators could choose to invest in automation.⁷⁴

Despite rising costs and ongoing economic uncertainty, investment in Europe's cold chain continues with confidence in the rising demand for cold storage facilities and other infrastructure. According to AMA International, a Dutch mergers and acquisition specialist, the revenue of European cold storage facilities will grow from roughly €119 billion (US\$125 billion) in 2022 to €190.5 billion (US\$200 billion) by 2026.

Although the online grocery market segment has stagnated slightly over the last year or two, e-food is likely to become one of the fastest growing revenue streams for food retailers in the next five years.⁷⁵ This will be a major driver in the expansion of refrigerated warehousing in Europe. One challenge here will be ensuring proximity to the consumer – many of whom are in cities, where space is already limited.

The current economic climate is also resulting in changes to consumer behavior, which will have knock-on effects along the supply chain. For example, more consumers are turning to frozen vegetables, meat and other products in an effort to stretch their budgets. In the second quarter of 2023 alone, British consumers bought 1.6% more frozen food than in the previous year, which amounts to 7.6 million tons of products.⁷⁶ Europe's frozen food market is predicted to have a CAGR of 3.03% by 2033, which is likely to drive an increased demand for low-temperature storage facilities and equipment.⁷⁷

Another trend that is likely to affect the European cold chain market is the shift in the production of animal protein from "traditional" countries in Central and Northern Europe to countries in the east and south of the continent. While this will decrease demand for cold chain logistics in countries like Belgium, France, Germany and the Netherlands, it will create a larger market in countries like Italy, Poland and Spain, where production is increasing.⁷⁸

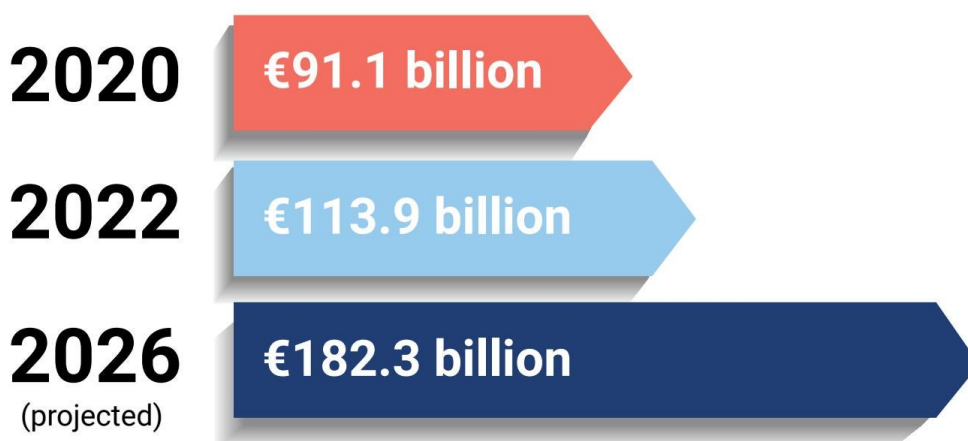
FOOD PROCESSING

The EU food and drink industry is one of the region's largest manufacturing sectors, generating a turnover of €1.1 trillion (US\$1.16 trillion) in 2022.⁷⁹ While the sector is strong, it is not impervious to the impacts of external factors like energy prices and rising inflation, with margins for food processors decreasing by 0.8 percentage points between 2019 and 2022.

According to McKinsey & Company, while energy and other prices peaked toward the end of 2022, "it will take time for these increases to affect food processor prices and ultimately reach consumer prices set by grocery retailers."

Given the volatility of the European food industry over recent years, many food processors are being encouraged to rethink their cold chain strategies to find the right balance between outsourcing and insourcing. From energy and labor costs, to customer demand and sustainability regulations, the Europe's cold chain is becoming increasingly complex.⁸⁰

Figure 4: Revenue of European Cold Storage Facilities



Source: AMA International, July 4, 2022, "Growing Importance of Cold Storage for European Markets," <https://bit.ly/3RAidCe>

Figure 5: Revenue Growth of European Grocery Sector in 2022

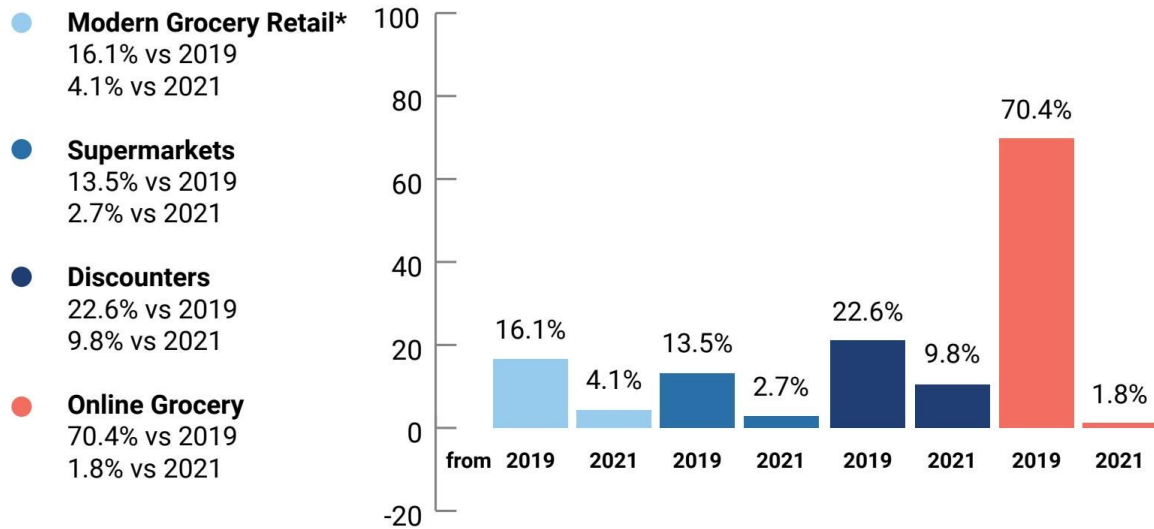
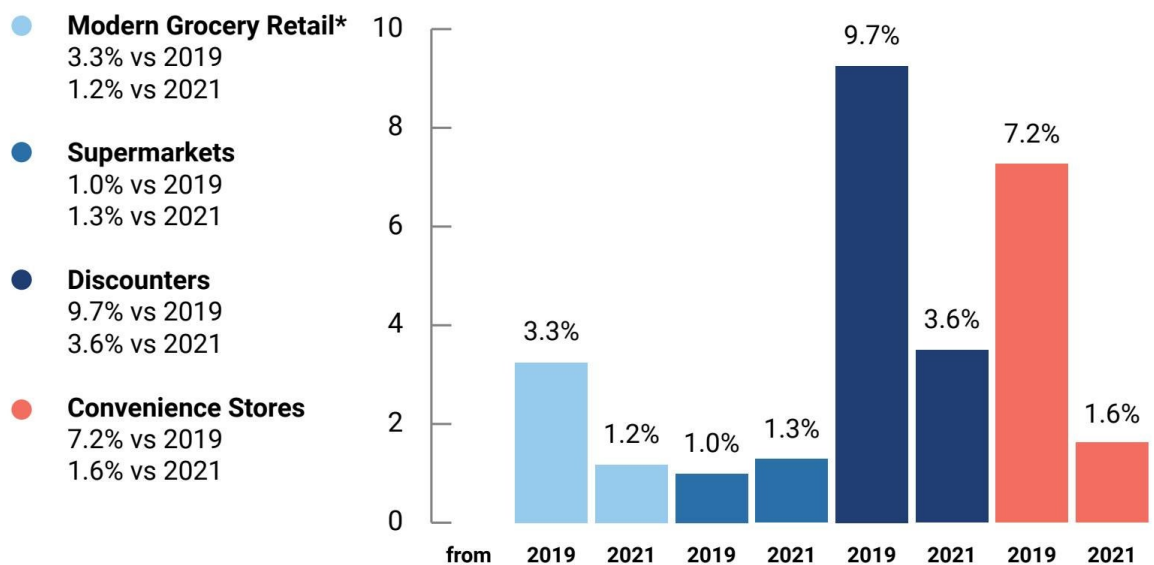


Figure 6: Sales Space Growth of European Grocery Sector in 2022



* Consists of hypermarkets, supermarkets, online grocery and discounters

Source: The State of Grocery Retail 2023 – Europe (2023), McKinsey & Company and EuroCommerce Retail & Wholesale

2.2 The EU's Revised F-gas Regulation

On October 5, negotiators from the Council of the EU and the European Parliament reached a provisional political agreement on phasing out substances that cause global warming and deplete the ozone layer.⁸¹ This put into place the final pieces of the revised EU F-gas Regulation and set the stage for the elimination of f-gases in the EU by 2050.

This provisional agreement, whose legal text is forthcoming, finalizes negotiations on f-gases and confirms an informal agreement reached in June on ozone-depleting substances (ODS).

The agreement will now be submitted to the member states' representatives within the Council and to the Parliament's Environment Committee for endorsement. If approved, the text will then need to be formally adopted by both institutions before it can enter into force.

The agreement follows f-gas proposals by the European Commission⁸² on April 5, 2022, and by the Parliament⁸³ on March 30, 2023, as well as an agreement on a general approach by the Council⁸⁴ on April 5, 2023. Since April, the three bodies have engaged in rounds of negotiations – called a trilogue – to finalize the revised EU F-gas Regulation.⁸⁵

"The agreement introduces new restrictions to make sure that f-gases are only used in new equipment where no suitable alternatives are available or that only the most climate-friendly f-gases are used," said the Commission.⁸⁶ The new restrictions will apply from 2025 to 2035, depending on the readiness to shift to climate-friendly solutions for each type of equipment.

It should further speed the transition to natural refrigerants like CO₂ (R744), hydrocarbons and ammonia (R717) in refrigeration, heat pumps and air conditioners; these refrigerants have all gained world-leading acceptance in the EU since the introduction of the F-gas Regulation in 2006 and its revision in 2014. "The regulation provides incentives to use climate-friendly alternatives, further stimulating the global market and helping other countries to make

the transition as well," said the Commission, adding that it raises ambition "considerably beyond the Kigali amendment to the Montreal Protocol."

The legislation will also improve enforcement and implementation, "making it easier for customs and surveillance authorities to control imports and exports, and to crack down on the illegal trade of gases and related equipment," said the Commission. While existing EU legislation has already limited the use of f-gases significantly, the agreement will prevent almost 500 million metric tons of further emissions by 2050, according to the Commission, which added, "It will contribute to the EU's 2030 climate targets of at least 55% emission reductions, and help make Europe climate-neutral by 2050."

Bans have been significantly updated and strengthened. For instance, for self-contained cases used in store applications, a ban of all f-gas refrigerants over 150 GWP will apply as of 2025.

A 150-GWP limit on chillers will enter into force as of 2027 for systems up to 12 kW (3.4TR), and this capacity segment will need to go f-gas free by 2032. For chillers above 12 kW, the 750-GWP limit will apply as of 2027. Other refrigeration equipment, such as multipack centralized systems with a capacity under 40kW (11.4TR), will have a 150-GWP f-gas limit as of 2030. (Those systems with 40kW or more have had that limit as of 2022.)

Heat pumps too will be subject to bans. Self-contained air-conditioning and heat pump equipment up to 12 kW will need to respect a 150 GWP limit by 2027 and transition to f-gas free by 2032. By 2035, split air-to-air systems up to 12 kW will need to go f-gas free as well.

Other highlights include the following:

- The most commonly used f-gases, representing around 90% of f-gas emissions, will be reduced by 95% by 2030 compared to 2015, going down to zero by 2050 – the world's first total HFC phase out. The production of HFCs, in terms of production rights allocated by the Commission, will be phased down to a minimum (15%) as of 2036. Both production and consumption will be phased down based on a "tight schedule of decreasing quota allocation," the Council said. The agreement introduces a higher quota allocation for the first two periods compared to the Commission's proposal. The feasibility of the phase out of the consumption of HFCs and the need for HFCs in sectors where they are still used will be reviewed in 2040, taking into account technological developments and the availability of alternatives to HFCs for the relevant applications.
- A full market ban will be placed on several categories of products and equipment containing HFCs, including certain domestic refrigerators, foams and aerosols. It brings forward some deadlines for the ban and extends it to products that use f-gases with a lesser GWP. Exemptions from the ban are provided if there are safety concerns.
- A ban is introduced on some equipment needed to repair and service existing equipment. From 2025, servicing equipment for refrigeration equipment that uses f-gases with high global warming potential will be banned unless the gases are reclaimed or recycled, in which case they benefit from an exemption until 2030. A similar ban is introduced for servicing equipment for air-conditioning and heat pump equipment for 2026, with an exemption for reclaimed or recycled gases until 2032. A servicing ban on stationary refrigeration equipment designed to cool products to temperatures below -50°C (-58°F) using f-gases with lower GWP will be applied in 2032, with a permanent exemption where recycled or reclaimed gases are used.
- Starting in 2025, the HFC quota that the Commission allocates every year will be sold for €3 (US\$3.17) per metric ton of CO₂e, adjustable for inflation. Part of the revenue will be used to cover the administrative costs of the implementation of the F-gas Regulation, and the rest will go to the general EU budget.
- EU-member states will set rules on effective, proportionate and dissuasive penalties applicable to infringements. The penalties should at least include fines, confiscation of products, temporary exclusion of products from public procurement and temporary trade bans.
- Member states will need to ensure that natural refrigerants are part of the education of technicians operating in the RACHP market.
- Finally, the provisional agreement explicitly takes into account PFAS-related legislation that is in the making at the EU level.



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2.3 The U.K.'s Approach to F-Gases

Following the U.K.'s departure from the EU via Brexit in 2020, the U.K. Department for Environment, Food and Rural Affairs (DEFRA) started to revise the EU F-gas Regulation to adapt it to the British context.⁸⁷

DEFRA recognizes the positive impact of the current EU F-gas Regulation as it has been successful in cutting 13.6–24.3MtCO₂e of f-gas emissions to date and has generated £1.9–£8.5 billion (US\$2.3–US\$10.3 billion) in total benefits.

DEFRA recognized that the HFC phase down was the driving force behind the majority of these benefits and is currently investigating different measures to tighten the F-gas Regulation further, such as:

1. a more aggressive HFC phase down as the quota price has fallen, and there have not been issues raised with supply;
2. further analysis on the role of, and interactions between, the HFC phase down and bans, in particular the relation to technological innovation and behavioral changes; and
3. ensuring continued reductions in f-gas emissions via stricter containment measures such as leak checks, recovery and destruction.

The U.K. F-gas Regulation aims to ensure U.K. compliance with the Montreal Protocol and the Kigali Amendment, while supporting the U.K. government's net-zero strategy, achieving f-gas emission savings and supporting the roll out of heat pumps.

At the time of writing, DEFRA was consulting interested stakeholders on a variety of data points concerning the cost and energy performances of HVAC&R equipment. A public consultation on a draft text was set to begin after this industry survey was concluded, likely in October–November 2023. The team at DEFRA does not envision the new F-gas Regulation to enter into force before 2025.

More is feasible

In June 2022, the U.K. Climate Change Committee (CCC) – a watchdog of scientists evaluating the British government's climate policies – called for the government to “match or exceed” the level of increased ambition that could be adopted in the revision of the EU F-gas Regulation.

The CCC is an independent, statutory body established under the Climate Change Act of 2008 whose purpose is to advise the U.K. on climate-related and emissions reductions policies, as well as report to Parliament on progress.

Its 2022 report noted that the f-gas sector represented 3% (12MtCO₂e) of total U.K. emissions in 2020. With regard to heat pumps, the scientific body said, “most heat pumps use f-gas refrigerants, which could become a significant source of f-gas emissions as heat pumps get rolled out across the U.K., unless the Government takes action to ensure that they shift to using non-F-gas refrigerants. Potential replacement refrigerants [to fluorinated gases] include propane [R290] and CO₂ [R744].”

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2.4 Hydrocarbon Charge Limits Set for Commercial Cabinets

On August 2, 2023, an updated standard was approved allowing European manufacturers to sell stand-alone commercial cabinets with a flammable refrigerant charge of up to approximately 500g (1.1lbs) of R290 and up to 1.2kg (2.6lbs) of flammable A2L refrigerants.⁸⁸

The updated standard – EN IEC 60335-2-89:2022 “Safety of household and similar electrical appliances - Part 2-89: Particular requirements for commercial refrigerating appliances and ice makers with built-in or remote refrigerating unit or compressor motor” – was published in the Official Journal of the European Union; the Commission Decision (EU) 2023/1586 of 26 July 2023 replaced EN IEC 60335-2-89:2010 and its amendments.

This harmonized European standard covers the safety requirements for commercial refrigeration appliances and ice-makers that have a built-in compressor or are supplied in two units (split system). These are self-contained plug-ins, a large market in the European commercial refrigeration sector. The EN harmonized standard allows manufacturers of this equipment to introduce CE-marked products into the European market with the “presumption of conformity” to the EU Machinery Directive (MD).

With the new harmonized standard, manufacturers will be able to exceed the capacity limit of the previous version when using flammable refrigerants, and potentially reach up to 5–6kW (1.4–1.7TR) of cooling capacity.

On a global basis, the International Electrotechnical Commission (IEC) in 2019 revised its safety standard IEC 60335-2-89, increasing the charge limit for flammable refrigerants in stand-alone commercial refrigeration appliances from 150g (0.3lbs) to 500g, but manufacturers in Europe have not used it due to liability issues with adopting a non-harmonized standard. The IEC standard is a voluntary international recommendation and is not legally binding.

Thanks to the new EN standard, it is not necessary to conduct a separate risk assessment under standard EN 378 when using higher charges of flammable refrigerants.

Heat pumps

Last year the IEC completed the long-awaited approval of higher charge limits for a wide range of flammable refrigerants – A3 (flammable), A2 (low flammable) and A2L (lower flammable) – in household ACs and heat pumps, the culmination of a seven-year process.⁸⁹ The IEC 60335-2-40 ED7 standard is expected to help accelerate the transition from high-GWP HFC refrigerants to flammable refrigerants, notably R290 in this equipment.

As with all IEC standards, it still needs to be adopted by individual countries. The primary method in Europe is for the European Commission to publish the EN 60335-2-40 ED7 as a “harmonized standard,” which would take two to three years. In the meantime, equipment manufacturers could apply the higher charge limits of the new standard by using a “risk assessment” – a simple argument that a new edition of a harmonized standard will be at least as safe as an old (ED6) standard.

Europe has another EN standard, EN 378, that allows up to 1.5kg (3.3lbs) of R290 indoors but is less suitable for factory-built systems – the majority of home ACs and heat pumps – and has stricter room size requirements. EN378 is also in the process of getting updated.

Under the previous IEC iteration, IEC 60335-2-40 (ED6), a 20m² (215ft²) room with a 2.2m (7.2ft) ceiling height could use a wall-mounted AC split system with 334g (0.7lbs) of R290. That is true of the new proposal, except that now additional safety measures allow larger charges to be used.

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2.5 Ecodesign and Energy Labelling

The European Commission's proposed Ecodesign for Sustainable Products Regulation (ESPR) plans to reduce the overall environmental impact of a wide range of products and gradually ease the intricate framework of current Ecodesign and the Energy Labelling legislation while complementing this key pillar of Europe's climate action.⁹⁰

In 2020, the EU Ecodesign and Energy Labelling rules were estimated to have resulted in primary energy savings of 1,039 terawatt hours (TWh) or 89 million metric tons of oil. Ecodesign supports EU energy efficiency goals and makes Europe more resilient against energy shocks. It is estimated to achieve energy savings equivalent to France's annual consumption. Building upon the success of these rules, the European Commission proposed the ESPR in 2021, aiming to expand and strengthen the existing legislation.

The impact of the ESPR is anticipated to surpass that of its original 2009 predecessor, the Ecodesign Directive. To achieve its goals effectively, the ESPR must not only concentrate on individual products, but also emphasize the improvement of collection, sorting, repair and recirculation. The regulation intends to encompass a broader range of products, including textiles and furniture, with the goal of reducing their overall environmental and climate impacts.

The core principles of the ecodesign approach remain unchanged: products falling within the scope of the regulation will be required to meet minimum performance and information (labelling) standards. However, moving forward, these requirements will not focus only on energy use but also encompass aspects such as durability, repairability, reliability, recycled content and substances that may hinder recirculation.

Furthermore, the proposed ESPR introduces digital product passports and mandatory criteria for green public procurement. This demonstrates that the regulation has the potential to significantly influence

the design, manufacturing, and recirculation of products beyond their initial use phase.

The ESPR has the power to create a governing framework and influence other legislation, such as Extended Producer Responsibility (EPR), establishing a minimum standard for product design. Aligning ESPR and EPR legislation creates a strong push for environmental design in the EU.

Ecodesign measures deliver significant savings for consumers, particularly during crises like the Russia-Ukraine war. European households can save €650 (US\$687) per year on energy costs, even more during peak energy prices. Without ecodesign measures, consumers would have spent nearly €1,000 (US\$1,057) more on energy bills during periods of high prices. Ecodesign also leads to substantial cost savings in the purchase and operation of household appliances, with potential savings of up to €620 (US\$655) per year.

Opting for top-class appliances can double annual savings, reducing costs by an average of €950 (US\$1,004). The most significant savings come from energy-intensive appliances like heaters and lighting, but other appliances also contribute to savings. While energy efficiency gains may not always result in significant monetary savings for appliances like TVs and vacuum cleaners, it is still beneficial to choose more efficient models. Switching from a gas boiler to a heat pump can significantly reduce energy bills, with savings of €385 (US\$407) per year despite the higher initial cost of the heat pump.

Meanwhile, the energy label, prominently displayed on products, helps consumers make informed choices about the energy performance of the items they intend to purchase. Although the benefits of ecodesign may not be immediately visible to consumers, the energy label serves as a transparent indicator. Its high visibility encourages manufacturers to continually enhance the energy performance of their products.

Since March 2021, consumers have been benefiting from a simplified, clearer and more accurate “A-to-G” scale label for various household appliances such as washing machines, washer-driers, dishwashers, TVs, monitors, refrigerators and lamps. Additional appliances like tumble dryers and vacuum cleaners will also transition to this new labelling system. This change in labelling was prompted by a 2019 decision by the European Commission to move away from the previous “A+”, “A++” and “A+++” classes that had become increasingly common over the years. The rescaling was necessary because many product models were overcrowding the highest energy efficiency classes, which hindered technological innovation.

Space and water heaters

Heat pumps outperform gas and oil boilers in terms of efficiency. Thus implementing stricter energy-efficiency standards for space and water heaters would enable fossil fuel boilers to gradually be phased out

and lead to a significant reduction in emissions; this reduction would account for two-thirds of the emission cuts in residential and public buildings necessary to achieve carbon neutrality by 2050.

However, these standards have been plagued by unnecessary and persistent delays. Ideally, the revision of the ecodesign and energy labelling regulations for space heaters, which began in 2018, should have been completed within four years. But the current regulations remain outdated and heavily favor gas boilers. These boilers can still be marketed with an A+ rating on the somewhat confusing and misleading scale ranging from A+++ to D. Furthermore, the review process is still in its initial phase, being discussed at the Commission level, a stage that can last up to two years.

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2.6 HFC Taxes and Natural Refrigerant Incentives

A variety of policy measures are in place in Europe to support the uptake of natural refrigerant-based solutions. Generally, these measures can be divided into two categories: measures aimed at making f-gas-based equipment more costly (taxes) and initiatives that support the deployment of non-fluorinated systems (incentives or non-f-gas requirements).

Denmark

Denmark recently renovated its tax scheme for fluorinated substances used as refrigerants.⁹¹ This scheme was passed into law on July 31, 2023. The following are the taxes levied on a variety of key refrigerants, in krone/kg:

- HFC-23: 600
- HFC-32: 101
- HFC-134a: 215
- HFC-404A: 588
- HFC-407C: 266
- HFC-410: 313
- HFC-507: 598
- HFO-1234ze: 1
- HFO-1234yf: 1

France

In France, there are both incentive and disincentive measures. Since January 1, 2019, a law was enacted to apply a tax on HFCs starting in 2025, from which recycled or regenerated refrigerants are excluded. This tax will be applied to HFCs produced in or imported to France, in raw form or pre-charged in appliances. It will be paid to fiscal services by the person who carries out the first delivery of HFCs. The tax amount will increase yearly as follows:

- 2025:** 15€/TCO₂e
- 2026:** 18€/TCO₂e
- 2027:** 22€/TCO₂e
- 2028:** 26€/TCO₂e
- 2029:** 30€/TCO₂e

The intent of the progressive increase in the HFC tax is to encourage users to replace their systems with more environmentally friendly options.

Germany

On January 1, 2023, Germany's new Federal Funding for Efficient Buildings program came into force, providing subsidies for various alternative heating systems, including heat pumps with a COP of at least 2.7 – and a bonus for those charged with natural refrigerants.⁹³

According to Germany's Federal Office of Economics and Export Control, subsidies for heat pumps will cover up to 40% of their cost. This includes a basic subsidy of 25%, a 5% bonus if the refrigerant is natural and a 5% bonus if the heat source is ground, water or wastewater. (The two bonuses are not cumulative, however.)

The minimum eligible investment required for a subsidy is €2,000/US\$2,149 (gross). The eligible costs for energy refurbishment measures in residential buildings are capped at €60,000 (US\$64,466) per residential unit and calendar year, up to a maximum of €600,000 (US\$644,658) per building. "The good news is that the funding environment for heat pumps will remain largely stable in 2023," said Martin Sabel, Managing Director of the German Heat Pump Association, on the Federal Office of Economics and Export Control's website.

In the construction and retrofitting of heat pumps and biomass systems for space heating, at least 65% of the residential units or areas supplied by the systems must be heated by renewable energies.

Starting in 2028, only heat pumps that use natural refrigerants will be funded, according to the Federal Office of Economics and Export Control. However, a new pending regulation, the Energy Buildings Act, could include partially fluorinated hydrocarbons.

Depending on the outcome, there could still be changes in the promotion of heat pumps with propane. Also, the minimum required COP of 2.7 may go up to 3.0 in 2024.

Germany has also released a new version of its world-renowned Blue Angel ecolabel for heat pumps (DE-UZ 230 valid until 2027), which specifies only natural refrigerant-based systems can be granted the ecolabel.⁹⁴

Norway

This average tax in Norway for HFCs in 2023 is 0.952 krone/kg.⁹⁵ It applies to the import and production of:

- pure gas products in bulk and import of all types of combinations of HFCs and PFCs; and
- products in which the gases are integral components, such as air-conditioning and refrigeration units, air-conditioning units in vehicles, expanding foam insulation and aerosol propellants in spray cans.

The rate per kg of gas must be multiplied by the GWP for the relevant taxable gas. The tax obligation does not apply to the recycling of HFC and PFC.

Norway is also actively supporting the uptake of natural refrigerants in systems installed in municipal buildings. In a landmark decision that could set a precedent for cities around the world, Oslo's property administrator, Oslobygg, has updated its guidelines to mandate the use of natural refrigerants in all heat pumps and comfort cooling systems installed in the capital's municipal buildings.⁹⁶

Next year, the average tax rate for HFCs is expected to increase by 23.5% in Norway.⁹⁷

Spain

The new f-gas tax rules came into force on September 1, 2022.⁹⁸ The tax rate is determined by multiplying 0.015 by the GWP of each gas, with a cap of €100/kg.

The rules apply to HFCs, PFCs and SF6 listed in Annex I of the EU F-gas Regulation and to mixtures containing any of these substances.

This tax is levied on the manufacture, import, intra-community acquisition, or unlawful possession of fluorinated greenhouse gases. Notably, however, gases with a GWP of 150 or less are excluded from the tax.

2.7 EU Weighing PFAS Restrictions on F-gases and TFA

On January 13, 2023, a proposal to restrict per- and polyfluoroalkyl substances (PFAS) – known as “forever chemicals” for the durability in the environment – was jointly submitted to the European Chemical Agency (ECHA) by five European countries: Denmark, Germany, the Netherlands, Norway and Sweden. The objective of this proposal was to limit the use of PFAS within the EU.

Notably, the proposed restriction on PFAS focuses on their persistence in nature (“p-sufficient”) and takes a “class-base approach” rather than looking at each PFAS individually.

Over the past three years, EU authorities have collaboratively studied PFAS, their various uses and the risks they pose to humans and the environment. This involved consulting scientific literature and gathering information from relevant businesses, public authorities and organizations.

On February 7, 2023, ECHA published the proposed restriction.⁹⁹ The focus of the proposal is “the Annex XVII entry” outlined on pages 4–8, which provides detailed conditions for the restriction. The adopted working definition of PFAS would include certain HFCs and HFOs, such as HFC-125, HFC-134a, HFC-143a, HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(Z) and HFO-1336mzz(E). The proposal would apply to trifluoroacetic acid (TFA), an atmospheric degradation product of, notably, HFO-1234yf (100% conversion) and HFC-134a (up to 20% conversion).

Condition 1 aims to ban the manufacturing, import and use of PFAS, which would prevent their entry into Europe, export and hoarding. Condition 2 specifies concentration limits for articles containing PFAS, aiming to prohibit intentional use while allowing for trace amounts, considering that PFAS are already pervasive in various products. Condition 3 states that the ban will come into effect 18 months after the restriction is implemented, which is expected in 2025-2026.

The overall goal of the proposal is to reduce the risks associated with PFAS for both humans and

the environment. The proposal contains some time-based refrigerant exemptions:

- Refrigerants in low-temperature refrigeration below -50°C (-58°F) until 6.5 years after entry into force (EiF)
- Refrigerants in laboratory test and measurement equipment until 13.5 years after EiF
- Refrigerants in refrigerated centrifuges until 13.5 years after EiF
- Refrigerants used in maintenance and refilling of existing HVACR equipment for which no drop-in alternative exist until 13.5 years after EiF
- Refrigerants in mobile air-conditioning systems in combustion engine vehicles with mechanical compressors until 6.5 years after EiF
- Refrigerants in transport refrigeration other than in marine applications until 6.5 years after EiF

And one general exemption:

- Refrigerants in HVACR-equipment in buildings where national safety standards and building codes prohibit the use of alternatives

Expected next steps

There are four main stages in ECHA’s process of evaluating the PFAS proposals:¹⁰⁰

- In the first stage, ECHA’s Scientific Committees for Risk Assessment (RAC) and Socio-Economic Analysis (SEAC) discussed at their meetings in March 2023 whether the submitted restriction proposal complies with the legal requirements under REACH. After that, the committees began the scientific examination of the proposal.
- The second stage was a six-month public consultation period that started on March 22, 2023. Anyone could submit information or state

an opinion about the proposal. The deadline to submit comments on this stage of the process was September 25, 2023.

- RAC and SEAC will present their opinions within 12 months.
- The European Commission will draft a definitive proposal for a vote. If approved, the ban would enter into force in 2025 or 2026.

U.K. tags TFA as ‘concern’

In a 2023 report on PFAS, the U.K.’s Health and Safety Executive (HSE) has identified TFA as being “a concern for developmental toxicity” requiring further scrutiny.¹⁰¹

HSE is responsible for the registration, evaluation, authorization and restriction of chemicals (REACH) regulation in the U.K. In the report – titled “Analysis of the most appropriate regulatory management options (RMOA)” – HSE collaborated with the U.K. Environment Agency to examine the risks posed by PFAS and develop potential regulatory solutions.

While its health effect is not yet certain, “TFA has been identified as a concern for developmental toxicity,” says the report, adding that certain HFCs and HFOs, which are “commercially significant in the U.K.,” may “transform to TFA.” As a result, TFA is regarded as needing “further evaluation and investigation.”

The report says that the greatest volume of PFAS potentially available in the British market arises from a limited number of groups, including polyfluoroalkyl substances such as refrigerant gases, fire-fighting foams and cleaning agents.

Monitoring undertaken by the U.K. Environment Agency since 2014 suggests some PFAS are detectable in “most groundwater, surface water bodies and biota” in the U.K., the report says. Of these, short-chain PFAS, which include refrigerants and TFA, “are the most mobile, likely to be present in water compartments and have greater potential to bioaccumulate in air-breathing organisms.” Drinking water can provide a “dominant pathway” for exposure to PFAS.

Assessing the potential impact of PFAS, the report notes that PFAS will persist in the environment for long periods of time “with a potential to cause serious and irreversible damage.” However, it acknowledged that “there remains uncertainty on the human health hazards of the majority of PFAS due to a lack of available data and limited understanding of long-term exposure.”

Thus the agency concludes that “it would be appropriate, considering the Precautionary Principle,” to initiate a series of steps, including:

- Preparation of dossiers to potentially support one or more restrictions of PFAS under U.K. REACH.
- Further evaluation and investigation of substances that have been highlighted to be of concern, including TFA, EEA-NH4, perfluoroalkanes and perfluorocycloalkanes.
- Continued collaborative work across government and with external stakeholders to bring together work on PFAS strategically, including a review of the f-gas regulations to determine whether additional PFAS registered under U.K. REACH should be brought within scope; and the development of statutory standards for PFAS in drinking water in England and Wales.

2.8 RePowerEU's Heat Pump Rollout

The European Commission has developed the REPowerEU program to accelerate the bloc's transition away from fossil fuels toward an electrified future that includes heat pumps. In the coming years, millions of heat pumps are expected to be deployed in Europe to displace the reliance on fossil fuels for heating purposes.

The EU's REPowerEU targets require the amount of newly plugged-in heat pumps to double each year. This would lead to 60 million more heat pumps installed by 2030, compared to the 17 million units installed when REPowerEU was published in 2021.

However this initiative has sparked a debate about whether an ambitious F-gas Regulation would not support an accelerated heat pump rollout.

Much of the incumbent industry pushback to the F-gas Regulation review has been tied to concerns over the availability of refrigerants for the rollout of heat pumps in Europe. However, several industry groups, including the Clean Cooling Coalition, Refrigerants, Naturally!, the Royal Dutch Association of Refrigeration (KNVvK) and STEK (Emission Prevention Refrigeration Technology Foundation), stated, "Our companies' business is aligned with the objectives of REPowerEU and the EU Chemical Strategy for Sustainability," adding, "We support the overall direction of the Commission proposal for the new EU F-gas Regulation, the amendments of the European Parliament and the work related to PFAS."¹⁰²

The statement stressed that "there is no 'conflict' between a phase down of halogenated chemicals and the objectives of REPower EU, in particular those related to heat pumps." It states that manufacturers are already investing "at large scale" in R&D and production capacities for environmentally friendly equipment without f-gases and other halogenated chemicals.

The shift towards natural refrigerant-based heat pumps is evident: at the latest ISH show in March 2023 in Frankfurt, Germany, over 40 different manufacturers from Europe and beyond presented heat pump models to attendees.¹⁰³

To address concerns that an accelerated HFC phase out will jeopardize the rollout of heat pumps under REPowerEU, the European Parliament slightly delayed the EU Commission-proposed bans on new HFC-based heat pumps and increased the HFC quota during the 2027–29 period, with an annual review to ensure compatibility with REPowerEU.

To help reach the REPowerEU's target, the European Commission is planning a Heat Pump Action Plan, to be published by the end of 2023. The call for evidence on the action plan was launched on April 28, 2023. The input provided will be taken into account as the Commission further develops and fine-tunes the initiative.

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2.9 Corporate Sustainability Reporting Directive

The Corporate Sustainability Reporting Directive (CSRD) requires large companies, as well as listed small- and medium-sized enterprises (SMEs), to publish regular reports on the social and environmental risks they face, and on how their activities impact people and the environment.¹⁰⁴

On January 5, 2023, the CSRD entered into force. It modernizes and strengthens the rules concerning the social and environmental information that companies have to report. However, the Directive will need to be transposed into national legislation in the coming years.

Companies subject to the CSRD will have to report according to European Sustainability Reporting Standards (ESRS); in the HVAC&R industry, this includes refrigerants. The standards were developed by the EFRAG (European Financial Reporting Advisory Group), an independent body bringing

together various stakeholders. The European Commission has worked to ensure a very high level of alignment between ESRS and the standards of the International Sustainability Standards Board (ISSB) and the Global Reporting Initiative (GRI).

The following entities will have to start reporting under ESRS according to the timetable below.¹⁰⁵

On June 6, 2023 the European Commission opened a four-week public feedback period on a first set of sustainability reporting standards for companies.¹⁰⁶ Following the feedback period, the Commission adopted the ESRS as a delegated regulation. Currently the Commission is waiting for feedback from the Parliament and the Council; this scrutiny period runs for two months, extendable by two months. The European Parliament or the Council may reject the delegated act, but they may not amend it.

TYPE OF COMPANY	CSRD DEADLINE
Large listed companies, banks and insurance undertakings (more than 500 employees), as well as non-EU listed companies with more than 500 employees	Financial year 2024, with the first sustainability statement published in 2025.
Other large companies, including non-EU listed companies	Financial year 2025, with the first sustainability statement published in 2026.
Listed SMEs, including non-EU listed SMEs*	Financial year 2026, with first sustainability statements published in 2027.
Non-EU companies that generate over €150 million per year in the EU and that have in the EU either a branch with a turnover exceeding €40 million or a subsidiary that is a large company or a listed SME	Sustainability impacts at the group level from financial year 2028, with the first sustainability statement published in 2029.

*However, listed SMEs may decide to opt out of the reporting requirements for two years. The last possible date for a listed SME to start reporting is financial year 2028, with the first sustainability statement published in 2029.

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2.10 European Market Data: Stores Using Natural Refrigerants

TOTAL ADDRESSABLE MARKET

The total addressable market in Europe for food retail outlets, including supermarkets, hypermarkets, grocery, discount and convenience stores, has remained relatively stable over the past year. Some European countries experienced an increase in the number of food retail stores, while others saw a decrease. On average, the number of food retail stores in Europe declined by 0.13%.¹⁰⁷ In 2022, we estimated a market size of 299,025 food retail outlets, and in 2023 we estimate this has dropped slightly to **298,600**.

In this report, Europe is defined as including the EU, U.K., Norway, Switzerland, Iceland, non-EU Balkan states, Ukraine, Belarus, Moldova and the European part of Russia.

Discount retailers in Europe increased their market share by 1.4% compared to 2021. Discounters grew at the expense of all other channels: traditional trade declined by 0.8%, hypermarkets by 0.2%, online by 0.3%, and supermarkets by 0.1%.¹⁰⁸

Based on feedback from a sample of key retail end users, stores are retrofitted on average every 10–20 years, depending on each retailer's individual policies. In Europe, particularly, the retrofit market offers great opportunities to switch to natural refrigerants, with many retailers having done so already.

TRANSCRITICAL CO₂ RACKS AND CONDENSING UNITS

Background

Europe has long been a major source of natural refrigerant innovation in the HVAC&R sector. It is thought that Norwegian scientist Gustav Lorentzen

created the modern age of natural refrigerants in the late 1980s when he developed the modern transcritical cycle for CO₂.

By the 2000s, supermarkets were beginning to use CO₂ refrigeration systems. In 2001, Sergio Giroto, now president of Italian OEM Enx (which he founded in 2004), installed the first transcritical CO₂ multi-compressor system at a Bingo supermarket in Cornuda, Italy. But Europe's natural refrigerant development did not take off until the arrival of the EU's F-gas Regulation, first announced in 2006, revised in 2014, and completing a new revision this year. (Read more about this regulation in chapter 2.1.)

An important trend supporting the growth of transcritical CO₂ in Europe and worldwide is the development of technologies that enable efficient operations of the systems in warm-ambient climates (see chapter 1.2) and make possible an integrated system of refrigeration, air-conditioning and heating (see chapter 1.3).

The market today

According to data collected by ATMosphere, as of December 2023, there are approximately **68,500** food retail stores in Europe that use transcritical CO₂ systems; of these **60,000** use a centralized system (one or more racks) and **8,500** use condensing units. The number of stores with racks grew by 20% compared to last year, while the number with condensing units grew by 70%. There are an estimated **3,300** industrial sites using this technology, for a total of **71,800** transcritical CO₂ sites in Europe.

ATMosphere estimated that there were 55,000 stores in Europe using transcritical CO₂ systems as of December 2022. This includes 50,000 stores with centralized systems and 5,000 stores with condensing units. Additionally, there were 2,000 industrial sites using this technology, bringing the total number of transcritical CO₂ sites to 57,000.

The market penetration of transcritical CO₂ systems in stores has increased this year to **22.9%** – the percentage of all food retail stores in Europe estimated to feature transcritical CO₂ installations as of December 2023, up from 18.4% last year and 14.1% in 2021.

The number of European stores with transcritical CO₂ refrigeration has grown enormously since 2008, when there were an estimated 140 stores using these systems. By 2013, that number had grown to 2,885 and then almost doubled to 5,500 in 2015. In 2017, the number grew to 12,000, and almost doubled again to 23,000 in 2019.

Of the 29,000 transcritical CO₂ installations in Europe as of March 2020, 27,550 (95%) were estimated to be food retail stores. Of these installations, 3.9% (1,074 stores) were using transcritical CO₂ condensing units. The rest employed a centralized system (one or more racks). There were 1,450 industrial sites using transcritical CO₂ systems. As of March 2021, the number of food retail stores using transcritical CO₂ systems in Europe was estimated to be 38,400. There were 1,640 industrial sites using transcritical CO₂ for a total of 40,000 transcritical CO₂ sites in Europe.

HYDROCARBON SELF-CONTAINED CASES

Background

While CO₂ systems represent the largest share of natural refrigerant-based refrigeration in European supermarkets, equipment using hydrocarbons – mostly propane (R290), but also propylene (R1270) and isobutane (R600a) – is another widely employed application. In contrast to CO₂, typically used in racks or condensing units supporting separate display cases, hydrocarbons are mostly used in self-contained plug-in display cases, either air-cooled or water-cooled (via water/glycol loop systems). Hydrocarbons, not CO₂, have become the de facto natural refrigerant for self-contained plug-in units.

In the modern era of refrigeration – post-1990 – hydrocarbons were the first natural refrigerants to gain major traction in the marketplace, but in the domestic, not commercial, sector. In 1992, global NGO Greenpeace spearheaded the development of

the “GreenFreeze” home fridge, which uses no more than 150g of R600a. Initially available in Germany, GreenFreeze gained rapid acceptance in Europe and other locations, and today about 1 billion of the fridges are installed worldwide, according to Greenpeace.

By the 2000s, self-contained plug-in hydrocarbon refrigeration began to catch on in European supermarkets, with R290 the most commonly used refrigerant and R600a in smaller cases. The first air-cooled R290 retail display cases appeared in 2004. Until about 2012, most of the R290 cases were ice cream chest freezers from brands like Unilever and Nestlé.

The first semi-plug-in display cases (with a waterloop system to remove heat) appeared in 2014, followed by the first multi-deck R290 freezers. Today, self-contained propane waterloop systems are enjoying wider uptake in commercial refrigeration applications globally – particularly in Europe, where manufacturers such as Freor have installed numerous waterloop systems.

In Europe, there are more opportunities to install R290 cases than in the U.S. – more stores use them throughout the sales floor, there are more small stores, and there is more conversion to natural refrigerants and more use of horizontal cases. Europe is at least five years ahead of the U.S. in the use of hydrocarbon cases.

The market today

Using data collected from a survey of OEMs, ATMosphere estimated **3.2 million** hydrocarbons-based retail cabinets have been installed in Europe as of December 2023, an increase of **10%** from 2022, when there were an estimated 2.9 million.

As of June 2021, there were an estimated 2.7 million hydrocarbon-based cases in operation in Europe, based on production numbers from leading OEMs. This number also included an estimated 300,000 units beverage coolers.

Figure 7: Transcritical CO₂ Installations in Europe

(as of December 2023)

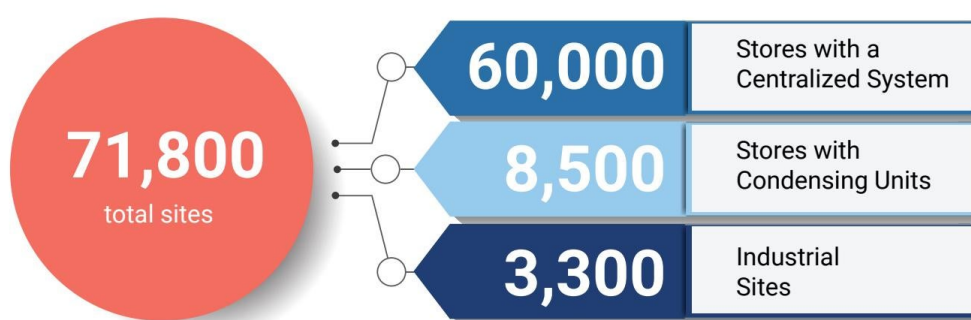
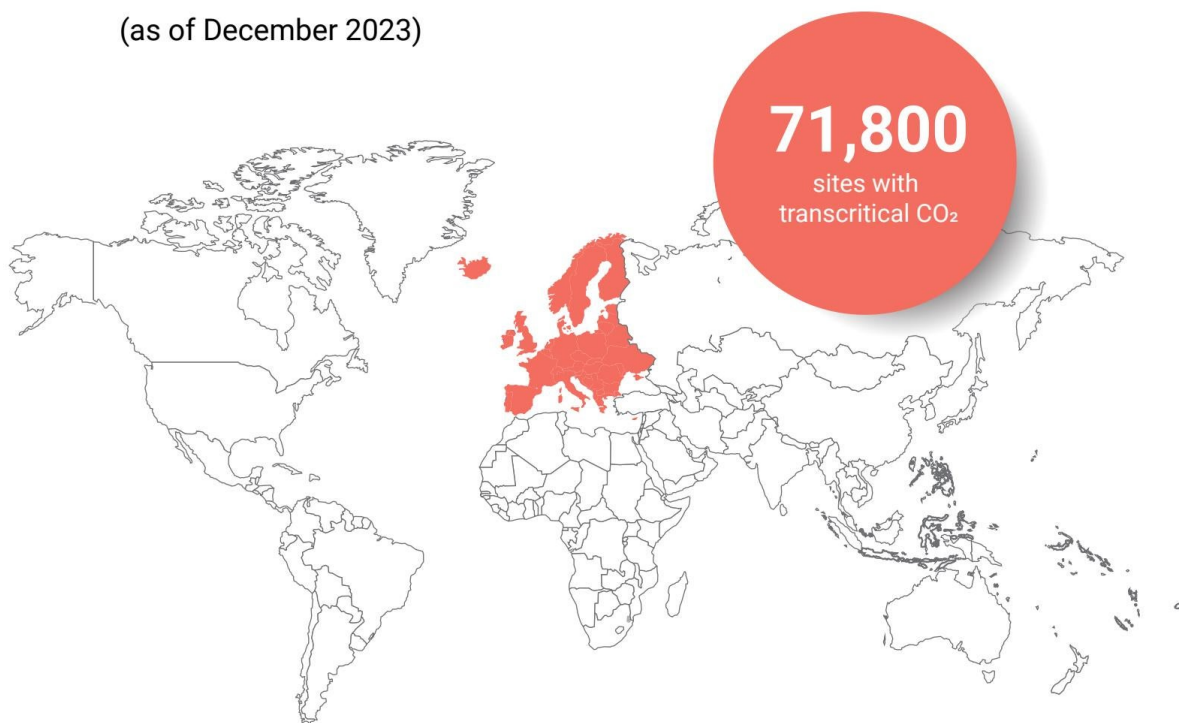
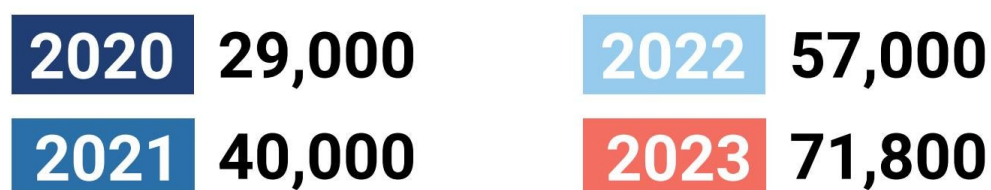


Figure 8: Transcritical CO₂ Commercial Refrigeration Market Penetration in Europe



Figure 9: Transcritical CO₂ Installation Growth in Europe

(stores and industrial facilities)



Percentage growth in 2021 - 2023

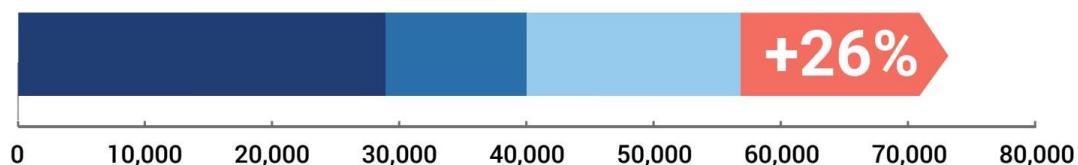
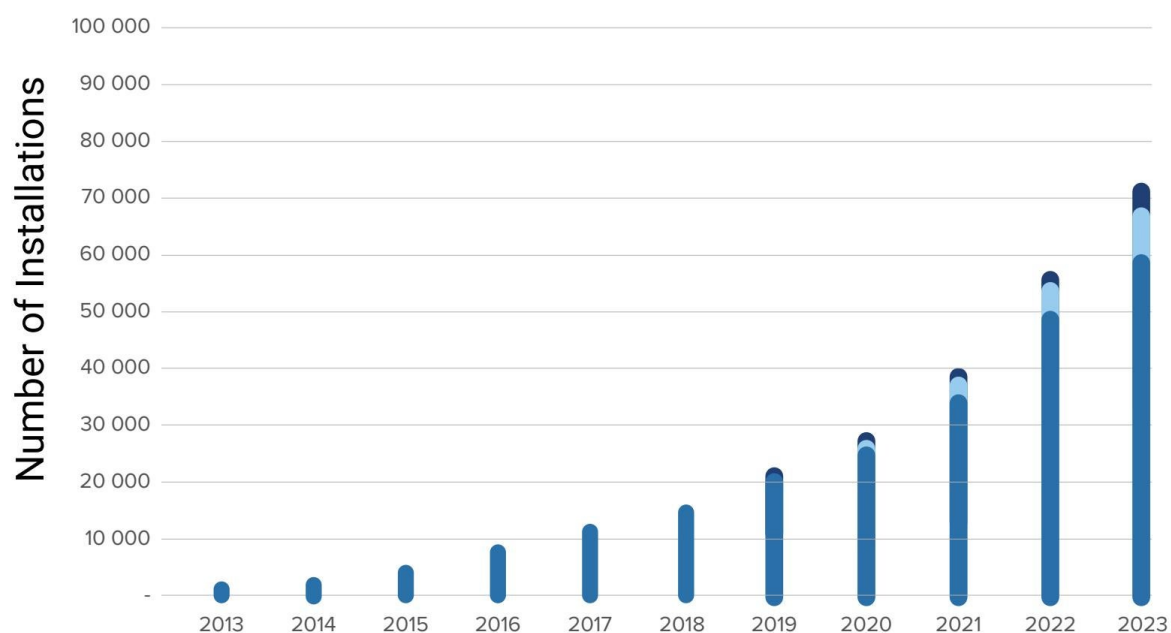


Figure 10: Transcritical CO₂ Historical Installation Growth in Europe

(stores and industrial sites)



Note: Prior to 2020, most installations were at stores.

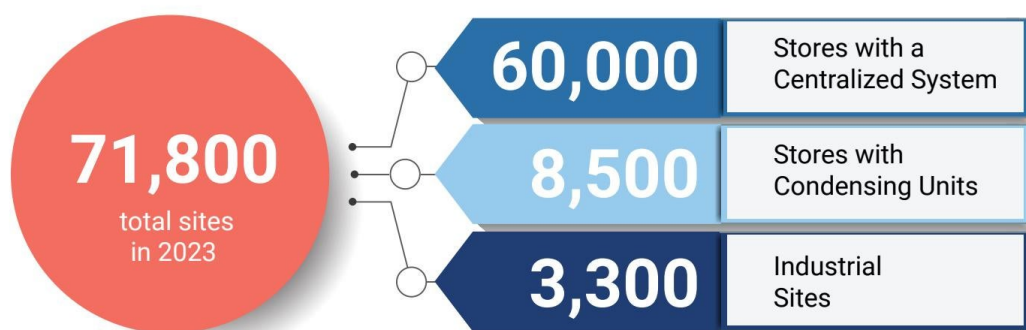


Figure 11: Self-Contained Hydrocarbon Cabinets Installed in Europe

(as of December 2023)

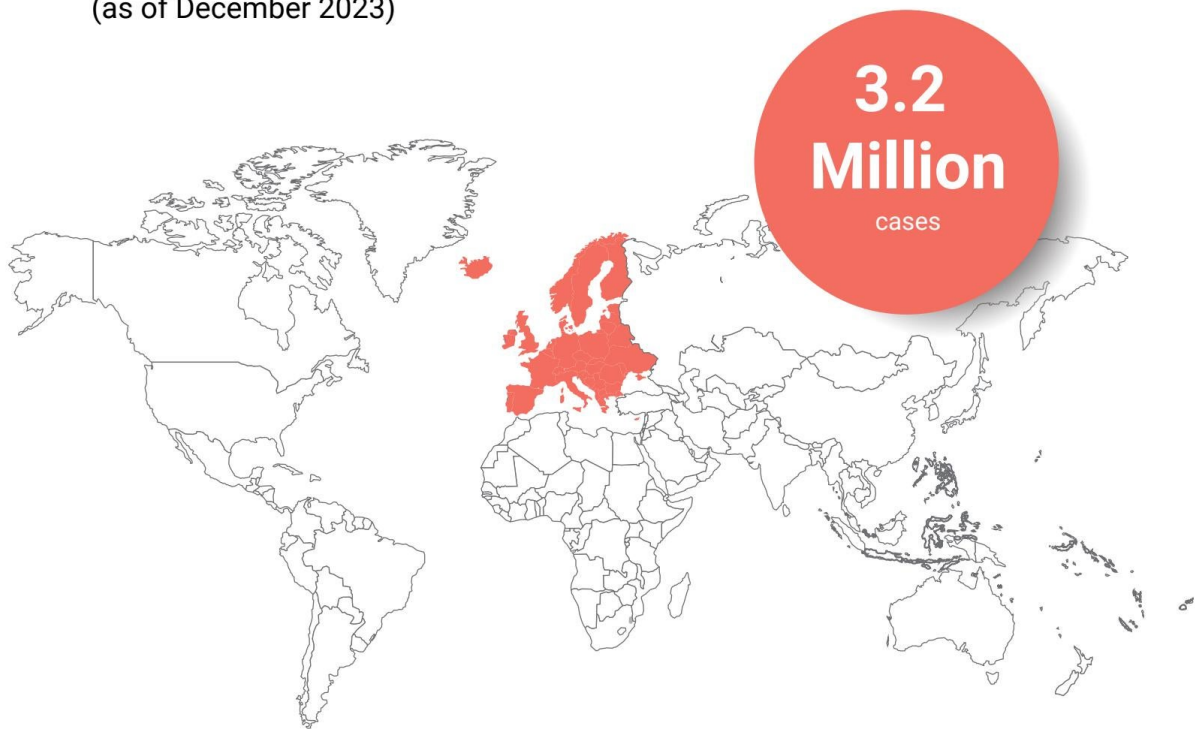
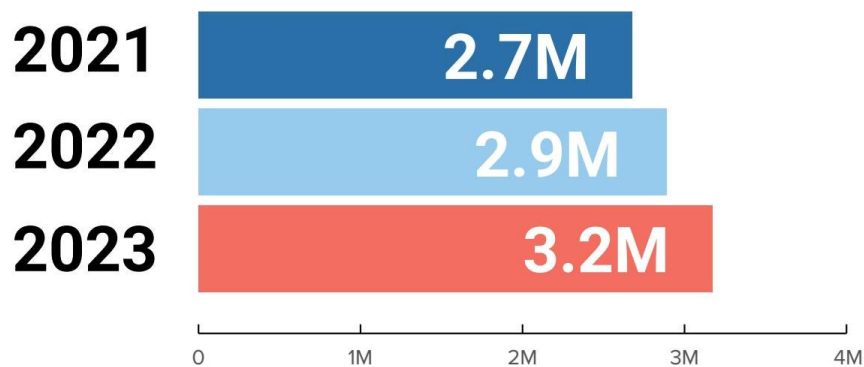


Figure 12: Self-Contained Hydrocarbon Cabinets, Historical Installation Growth in Europe



2.11 European Market Data: Industrial Sites Using Natural Refrigerants

TRANSCRITICAL CO₂

Background

Transcritical CO₂ refrigeration first made its mark in Europe in the supermarket industry, with the first transcritical CO₂ multi-compressor system installed at a Bingo supermarket in Cornuda, Italy, in 2001. With the introduction of the EU F-gas Regulation in 2006, later updated in 2014, and in the final stages of another revision, Europe has become the world's leader in supermarket installations of transcritical CO₂. And in the past three years, larger transcritical CO₂ systems have gained traction in the European industrial refrigeration market as an alternative to ammonia and f-gas refrigerants in cold-storage, food processing, pharmaceutical plants, ice rinks and other facilities; the majority of the installations are in cold-storage facilities.

That transition has been helped by the development of industrial-sized compressors by manufacturers like Dorin. In 2018, Giovanni Dorin, marketing manager at the Italian company, correctly observed that transcritical CO₂ refrigeration technology was poised to takeoff in industrial applications within the next three to five years.¹⁰⁹ (See chapter 1.4 for more on CO₂ refrigeration in industrial facilities.)

The market today

As of December 2023, there were an estimated **3,300** industrial sites using transcritical CO₂ refrigeration, accounting for 4.6% of the **71,800** transcritical CO₂ sites in Europe (the rest being food retail stores). These 3,300 sites also represents a growth of **65%** from the 2,000 industrial sites using transcritical CO₂ a year ago (3.5% of the total 57,000 transcritical CO₂ sites).

Historically, there were an estimated 1,450 industrial sites using transcritical CO₂ systems as of March 2020 (5% of the total), and 1,640 (4.1%) as of March 2021.

LOW-CHARGE AMMONIA

Background

Ammonia was first used as a refrigerant in the 1850s in France. By the early 1900s, the basic design of the vapor compressor refrigeration system, using ammonia as a refrigerant, was established and has served since then as the backbone of the industrial refrigeration industry.

But given its potential toxicity, efforts have been made over the past two decades to reduce the amount of ammonia used. The first concrete prototypes of systems with low and ultra-low charges were realized in the late 1990s, typically as a result of niche-level experiments performed at universities and R&D laboratories.

In 2001, Nestlé, which began using ammonia in place of CFC and HCFC systems in the 1980s, opened the world's first large NH₃/CO₂ cascade system to use compressed CO₂, in Hayes, U.K.¹¹⁰ Beginning in 2015, modern low-charge ammonia systems began to be installed in Europe with the first installation of low-overfeed penthouse package systems. The following year saw the first installation of a low-charge central system.¹¹¹ Since then, companies like Star Refrigeration, GEA, Mayekawa, Zudek and TEKO have been marketing low-charge units of various kinds and dimensions throughout Europe.

The market today

As of December 2022, ATMosphere estimates there were **3,360** industrial sites using low-charge (below 1.3kg/kW or 10.1lbs/TR) ammonia systems in Europe, based on production numbers from leading OEMs. This represents a growth rate of **18%** over a year ago, when there were an estimated 2,850 such sites.

Historically, the number of industrial facilities with low-charge ammonia systems in Europe has been

increasing, from 2,200 in June 2019 to 2,450 in June 2021, a rise of 11%, and 2,850 in December 2022, a gain of 16%.

In May 2022, the European Productivity & Benchmarking Report (EPBR) of the Global Cold Chain Alliance (GCCA), based on data from the 2020 fiscal year, reported that the majority of its third-party cold-storage operators used ammonia for their refrigeration system.¹¹²

HYDROCARBON CHILLERS

Background

In recent years, hydrocarbons, known mainly for their application in commercial display case refrigeration, have found growing employment in industrial chiller applications. Hydrocarbons are considered highly feasible in all temperature ranges except low-temperature applications (-15 to -30°C/5 to -22°F),

Secon, a German manufacturer, was founded in 2010 with the aim of manufacturing chillers solely on the basis of natural refrigerants and became one of the first companies to develop production-ready hydrocarbon chillers.¹¹³ In addition to manufacturing

a range of propane chillers, Secon uses propylene and isobutane refrigerants in its products. Secon's hydrocarbon chiller range in capacity from less than 100kW (28.4TR) to more than 500kW (142TR).

Another major hydrocarbon chiller producer is Spanish manufacturer Intarcon.¹¹⁴ In February 2022, the company announced several new propane-based products in its new industrial product catalog for 2022–2023. Intarcon also produces R290 industrial refrigeration monoblocks for large cold storage facilities and workrooms, such as the Superblock R290. Italian OEM Euroklimat also produces large-capacity R290 chillers.

On the smaller-capacity side, Italian process-cooling and air-conditioning manufacturer MTA released a series of air-cooled industrial chillers using R290 refrigerant in March of 2022. The chillers come in four models, with cooling capacities from 1.7kW (0.48TR) to 4.4kW (1.3TR) and water outlet temperatures ranging from 0°C (32°F) to 30°C (86°F).¹¹⁵

The market today

Based on production numbers from leading OEMs, ATMOSphere estimates there were **5,000** industrial sites with hydrocarbon-based chillers in Europe as of December 2023.

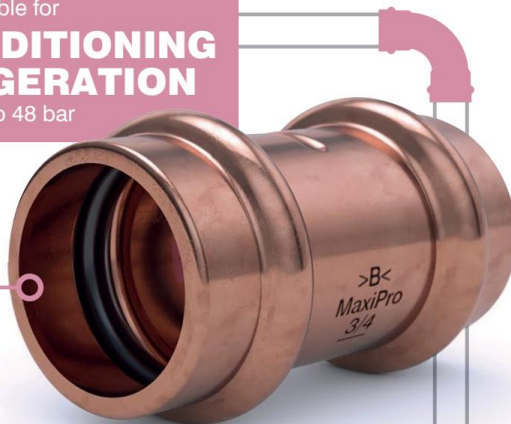
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AIR CONDITIONING & REFRIGERATION
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- Suitable for use with CO2 (R-744)
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Corrosion resistant

an IBP GROUP company

Figure 13: Growth of Transcritical CO₂ Installations in Europe

(industrial sites)

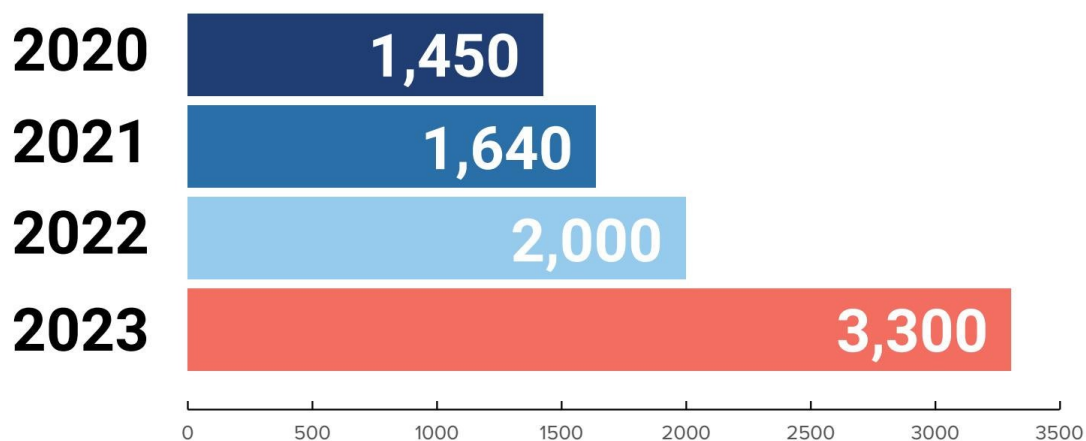


Figure 14: Growth of Low-Charge Ammonia in Europe

(industrial sites)

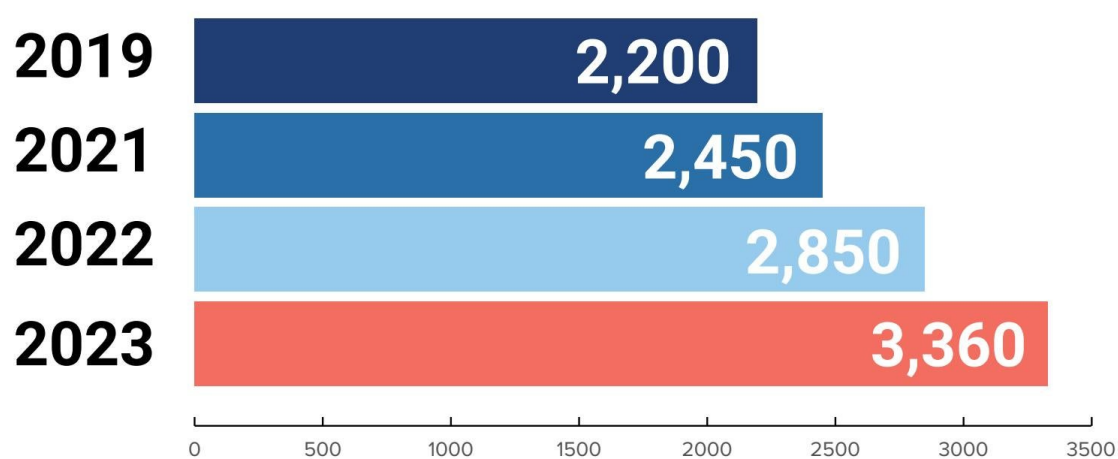
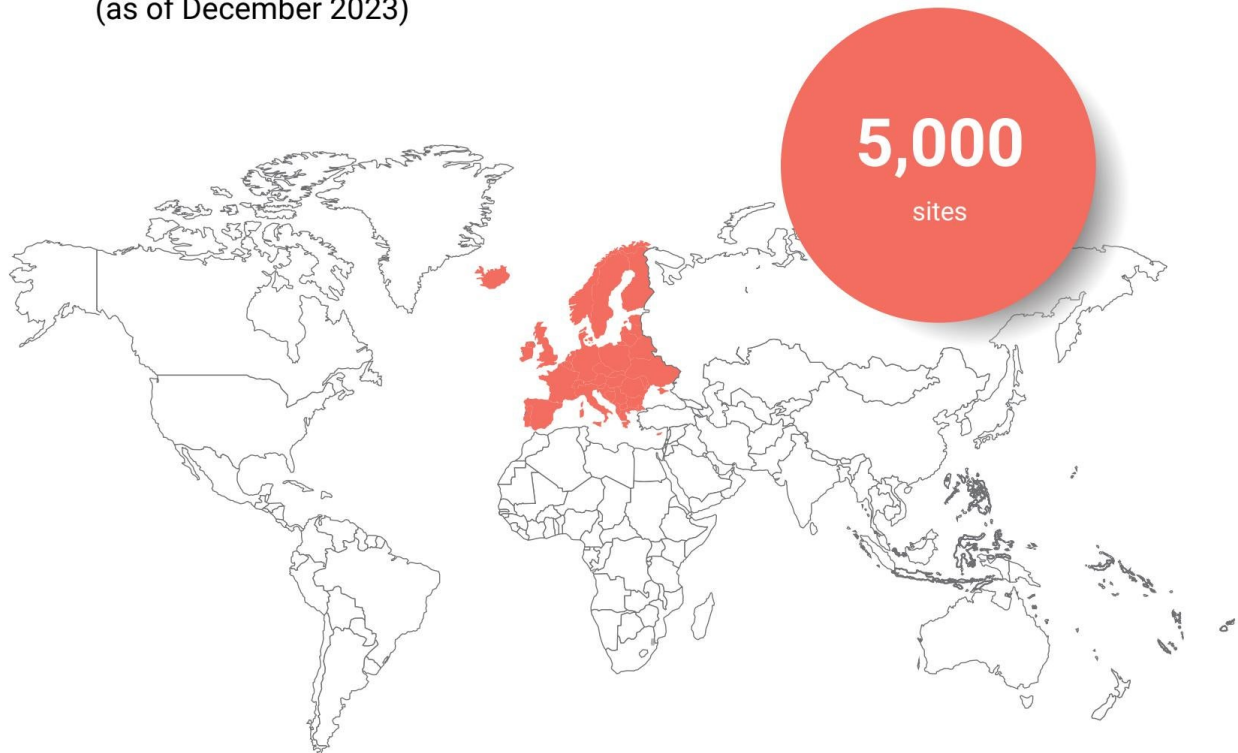


Figure 15: Hydrocarbon Chiller Installations in Europe

(as of December 2023)



130 SERIES

OIL SEPARATORS FOR TRANSCRITICAL CO₂ APPLICATIONS



Temprite's 130 Series addresses the unique and challenging demands of CO₂ systems.

There are seven different sizes of oil separators spanning applications as small as laboratory systems up to the largest industrial applications. The capacities of the 239A and 439A, are ideal for large commercial cold storage, district heating, and heat pump applications. They use the same high-efficiency coalescing filter technology that makes the Temprite 130 series oil separators so consistent, effective, and reliable.

2.12 Domestic Heat Pumps

Background

Europe is embracing the transition towards natural refrigerants where technically possible, especially in domestic systems. This is one of the key takeaways from 2023 from both a regulatory and industry perspective.¹⁰³

According to the provisional agreement reached on October 5 by the Council of the EU and the European Parliament, a full ban was introduced on small (less than 12kW/3.4TR) monobloc heat pumps and air-conditioning that contain f-gases with a GWP of at least 150 starting in 2027 and a complete phase out in 2032.

With regard to split air-conditioning and heat pumps containing f-gases, the co-legislators agreed on a full ban starting in 2035, with earlier deadlines for certain types of split systems with higher GWP gases. Exemptions are provided in cases where this equipment is needed to meet safety requirements. The agreement also includes the possibility to release a limited number of additional quotas for heat pumps if the proposed bans were to endanger the attainment of the heat pump deployment target required under REPowerEU.

Notably, all f-gases will be banned in these subsectors from 2032 and 2035, heralding an end to the use of HFOs in these sectors and paving the way for the adoption of natural refrigerants or not-in-kind technologies. HFOs have been increasingly associated with adverse environmental impacts, including greenhouse gas emissions via industrial production processes and PFAS emissions.

For air-to-water systems, whether monoblocs or split, the evidence from ISH 2023, a trade fair held in spring in Frankfurt, Germany, confirms a wide uptake of natural refrigerants across Europe and the heat pump industry.

A clear example is the number of exhibitors with propane-based heat pumps: 40 companies across five halls, more than 50% of the companies listed on the trade fair website in the air-to-water technology section. This ranged from established players such as LG, Panasonic, Mitsubishi, Viessmann and Vaillant to new small and medium companies operating in the heating and cooling industry. A substantial number of industry stakeholders see natural refrigerants in these systems as the way forward.

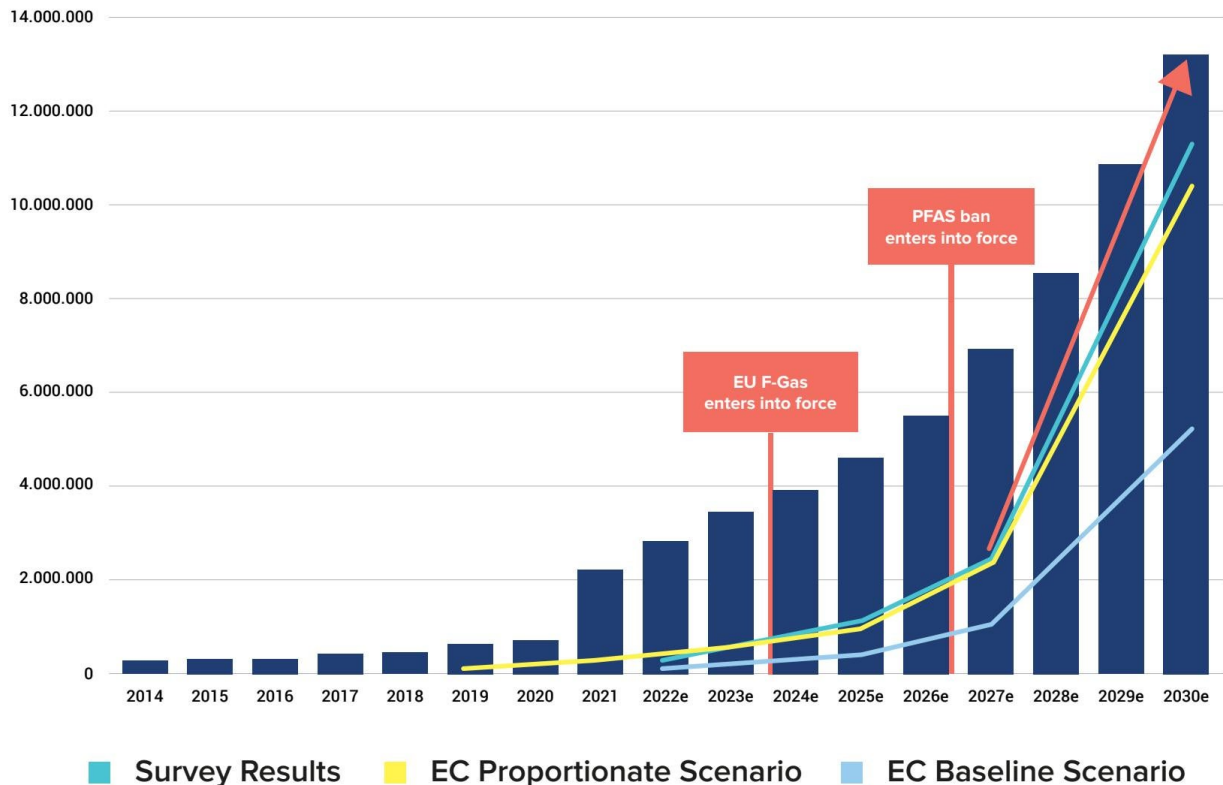
When it comes to air-to-air technology, or direct expansion systems, industry players are also working towards reducing reliance on HFC-32, a medium-GWP fluorinated greenhouse gas, by developing R290-based solutions and marketing them today. Notable examples are Midea, Haier and Clivet, which all have R290 air-to-air systems in their portfolio and are introducing them in Europe following their success in China and India.

The market today

There were approximately 2.1 million new air-to-water heat pumps with natural refrigerants (typically propane) sold in Europe in 2021, according to industry sources. That grew to an estimated 2.5 million in 2022 and **2.8 million** in 2023. EU policy changes, including the revised F-gas Regulation and the possible PFAS ban, will impact the uptake of natural refrigerant heat pumps through 2030.

Figure 16: Air-to-Water Heat Pumps with Natural Refrigerants Sold in Europe

(historical data to 2021 and projections to 2030)



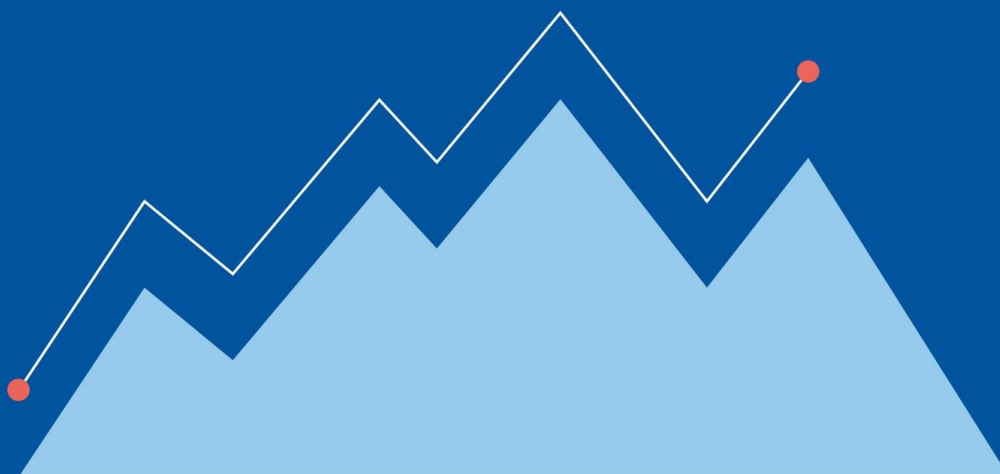
- Yearly sold units assumed to increase at 22% after 2021, calculated as average on data reported by EHPA and based on REPowerEU's plan.
- Estimated entry into force of EU F-gas: January 1, 2024
- Estimated entry into force of PFAS Universal Restriction Intention: January 1, 2027
- The European Commission proportionate action scenario foresees a penetration rate of hydrocarbons in new small heat pumps (<12kW, excluding small reversible air-to-air heat pumps) at 97% in the period 2024-2036, 100% in 2050.
- The European Commission baseline scenario foresees a penetration rate of hydrocarbons in new small heat pumps (<12 kW, excluding small reversible air-to-air heat pumps) at 56.1% in the period 2024-2036, 70% in 2050.
- The ATMosphere survey scenario tends to coincide with the European Commission proportionate action, with respondents reporting market penetration of natural refrigerants in domestic heat pumps at 10% in 2025 and 85% or more in 2030.

Source: ATMosphere's survey, EHPA database and European Commission Impact Assessment modeling.



CHAPTER 3

North American Trends



3.1 The North American Food Industry: Economic Outlook

U.S. supermarkets and grocery stores increased revenue by 0.4% to US\$845.3 billion (€772.8 billion) in 2023.¹¹⁶ In the U.S. convenience store sector, revenues grew by 1.5% to US\$40.0 billion (€36.6 billion).¹¹⁷ Meanwhile, in Canada, supermarket and grocery store sales increased by 1.7% in 2023 to US\$116.1 billion (€106.1 billion),¹¹⁸ while convenience store sales went up by 1.6% to US\$12.6 billion (€11.5 billion).¹¹⁹

The American Frozen Food Institute (AFFI) reported frozen food sales increased 8.6% to reach \$72.2 billion (€66 billion) in 2022, with 29% of consumers indicating they have expanded personal freezer capacity since the onset of the pandemic.¹²⁰ The growing demand for processed frozen food is driving the cold storage construction market. In 2023, refrigerated storage revenues grew by 2.5% to US\$8.4 billion (€7.7 billion).¹²¹

North America accounted for more than 45% of the 2022 global cold storage construction market valued at US\$12.54 billion (€11.5 billion),¹²² with a projected compound annual growth rate of 6.3% from 2022 to 2030.¹²³ Large merchants with growing international trade operations are, in part, creating the growth potential for refrigerated warehouses and transportation to handle perishable food.

Cold storage growth is also being driven by the adoption of advanced technologies in the construction sector and the development of laws regulating food waste. Maximize Market Research forecasts “Mexico to experience exponential [cold-storage] growth in North America” with the country’s economic expansion and modified government rules intended to streamline customs procedures.

The pharmaceutical, biotech and medical sectors also require cold storage, with an increasing demand for preserving vaccines, drugs and other chemicals.

Market Business Insights indicated that cold storage facilities are increasingly using automation and robotics to improve efficiency and streamline operations. Some of the technologies being used include automated doors, pallet conveyors, robotic

palletizing and depalletizing and automated storage and retrieval systems.

In an August Refrigerated and Frozen Foods podcast, Bob Grote, CEO of equipment manufacturer Grote Company, said that food processing and storage companies are looking for partners when it comes to refrigeration equipment to support the entire life cycle from conception to decommission, optimizing and maintaining the system.

The latest United States Department of Agriculture (USDA) figures show that on October 1, 2021, there were 3.03 billion ft³ (0.09 billion m³) of usable refrigerated storage capacity in 904 U.S. warehouses.¹²⁴

As of May 2023, the Global Cold Chain Alliance (GCCA) indicated that the 25 largest GCCA North American warehouse members provide 4.4 billion ft³ (0.12 billion m³) of temperature-controlled refrigerated warehousing and logistics space.¹²⁵

According to Market Business Insights, one of the major market developments in the refrigerated construction industry is the adoption of energy-efficient technologies and eco-friendly refrigerants by leading companies, prompted by environmental regulations and the general shift towards sustainable practices.

Lower prices

The 2023 inflation rate for food in the U.S. remains higher than the 1.6–1.8% rates associated with pre-pandemic levels, but it has dropped from the 10.4% average experienced in 2022.¹²⁶ The average price of food in the United States increased 4.3% in the twelve months that ended in August after posting an increase of 4.9% in July, according to the latest inflation data published September 13, 2023, by the U.S. Labor Department’s Bureau of Labor Statistics (BLS).¹²⁷ The annual increase was greater — 6.5% — for food away from home but less — 3.0% — for food at home (grocery sales).

"Commodity prices are down and mostly flat," said John Anton, Director of Pricing and Purchasing Service at S&P Market Intelligence, adding that he does not expect prices to "fall all the way back to 2019" levels.¹²⁸ He advised buying copper now or in 2024 and trying to "lock prices in until 2030" as there will be a deficit of copper in 2026. He also noted that steel prices are way down, especially stainless steel prices, outside the U.S. He also suggested buying plastics now.

Overall U.S. inflation rates continued to drop in the first half of 2022, reaching 3.0% in June with declining fuel and energy prices.¹²⁹ In 2023, the annual inflation rate in the U.S. accelerated for a second straight month to 3.7% in August from July's 3.2%, with oil prices rising.¹³⁰ The Department of Treasury's July 2023 report indicates that core inflation, not including food and energy prices, is likely to stay above the 2% target throughout 2023.¹³¹

Other economic indicators include a relatively steady consumer confidence index and an unemployment rate that hovers around 3.5%.¹³¹ Bolstered by the Biden administration's economic plan and Secretary Yellen's supply-side economics approach, the U.S. economy remains strong.

The tumultuous supply chain issues of 2022 continued into 2023, according to an S&P Global survey.¹³² But, according to Anton, "The nightmare of 2020 to the first half of 2023 is over. Logistics are clearly better and will stay so." He said that "backlogs are shorter, and delivery and delivery times are better." But supply chain issues will continue to include managing extreme weather events, environmental sustainability issues, uncertainty about consumer behavior, and continued online shopping after the pandemic.

Increased digitization should increase supply chain agility with end-to-end visibility and buyer-seller collaboration.

Consumer trends

One trend for retailers to focus on, according to AFFI, is the continued consumer engagement with frozen foods — a habit from the pandemic that appears to be here to stay, with sales increasing by US\$19.4 billion between 2018 and 2022.

Today's consumer finds grocery shopping a balance between finances, convenience and health. With the higher-than-normal inflation rate, frozen food saves money by reducing food waste. Retail data shows that Gen X, Millennials and Gen Z use frozen foods for all meals and snacks. Frozen food focused on nutrition, freshness and niche markets like gluten-free and high-protein diets has also captured the consumer's eye.

AFFI studies indicate that shoppers take fewer trips to grocery stores but spend more, especially at supercenters and club stores. Frozen food spending at traditional grocery stores accounts for 51.6% of total sales, 26.7% at supercenters and 12.6% at club stores.

In her experience at industry events, Anne-Marie Roerink, President of 210 Analytics, said she frequently hears retailers refer to frozen food as an area of investment in new stores and remodels. Frozen sale merchandisers are popping up in fresh food departments, end caps and checkout.

Meanwhile, rising consumer awareness of sustainability, climate control and PFAS toxicity is driving companies to develop environmental, governance and sustainability (ESG) targets. A McKinsey study looking at purchases from 2017 to 2022 indicates that consumers are, in fact, shifting their spending habits toward products with ESG claims.¹³³ Products making ESG claims averaged 28% growth over the period compared to those without such claims, which averaged 20% growth.

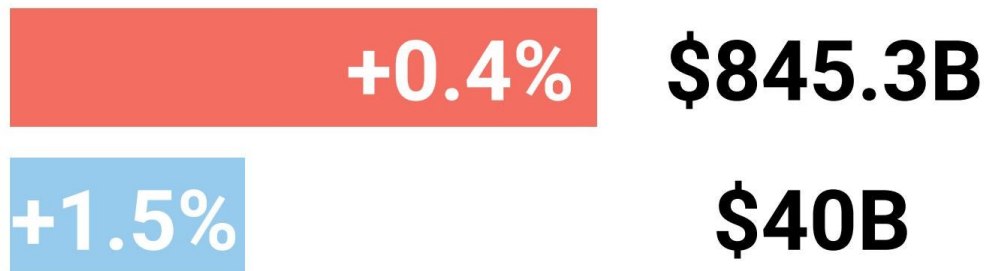
In food retail, the type of equipment used in stores will be a strategic differentiator by 2025, according to Thom Blischok, CEO of the Dialogic Group, who added that 65% of CEOs don't have a strategy to achieve sustainability.¹³⁴

Figure 17: Revenue of North American Stores, 2023

● Supermarkets/Grocery Stores

● Convenience Stores

U.S.



Canada



Source: IBISWorld

3.2 The AIM Act

The American Innovation and Manufacturing (AIM) Act was enacted on December 27, 2020, authorizing the U.S. Environmental Protection Agency (EPA) to address HFCs in three ways:

1. phasing down their production and consumption (import) by 85% compared to baseline by 2036;
2. facilitating the transition to next-generation technologies through sector-based restrictions of certain high-GWP HFCs in new refrigeration, air-conditioning, heat pumps, aerosols and foams products (the Technology Transitions rule); and
3. maximizing reclamation and minimizing leaks from equipment.

The U.S. phase down is consistent with the schedule in the Kigali Amendment to the Montreal Protocol, the global agreement to phase down HFCs that the U.S. joined on October 31, 2022. A global HFC phase down is expected to avoid up to 0.5°C (0.9°F) of global warming by 2100.

In July the EPA announced its latest action to phase down the use of HFCs, issuing a final rule to implement a 40% reduction below baseline levels from 2024 through 2028.¹³⁵ It followed that by issuing new HFC allowances, which allow companies to produce or import bulk HFCs for 2024 per the limits.

In October, the EPA released a final Technology Transitions rule banning HFCs in certain new equipment and setting a limit on the GWP of the HFCs that can be used in each subsector, with compliance dates ranging from 2025 to 2028.¹³⁶ It aligns closely with several petitions to replicate California's HFC restrictions by setting GWP limits of 150 for many refrigeration uses and 700 for air-conditioning and heat pumps. The California regulations have spurred a significant uptick in the use of natural refrigerant-based alternatives like transcritical CO₂ systems and hydrocarbon cabinets in supermarkets in that state.

The rule will restricts the sale, distribution, import, and export of new products containing higher-GWP HFCs three years after the manufacture and import compliance dates to allow for a sell-through period

of previously manufactured or imported products. It also restricts the installation of certain new systems by the designated compliance dates. Thus it distinguishes between "products" and "systems."

This rule does not restrict the continued use of any existing products or RACHP systems.

The following are a sample of some of the self-contained refrigeration, air-conditioning and heat pump product restrictions in the new Technology Transitions rule, with GWP limit and manufacturer and import compliance date.

- Retail food-refrigeration stand-alone units; 150 GWP; January 1, 2025
- Vending machines; 150 GWP, January 1, 2025
- Stationary residential and light-commercial air-conditioning and heat pumps (e.g., window units and portable room air-conditioning); 700 GWP, January 1, 2025

The following are a sample of some of the refrigeration, air-conditioning and heat pump system restrictions in the new Technology Transitions rule, with GWP limit and installation compliance date.

- Retail food supermarkets (with 200lbs/91kg or more of refrigerant charge, excluding high-temperature side of cascade system); 150 GWP; January 1, 2027
- Retail food remote condensing units (with 200lbs/91kg or more of refrigerant charge, excluding high-temperature side of cascade system); 150 GWP; January 1, 2026
- Cold-storage warehouses (with 200lbs/91kg or more of refrigerant charge, excluding high-temperature side of cascade system); 150 GWP; January 1, 2026
- Industrial process refrigeration not using chillers (with 200lbs/91kg or more of refrigerant charge, excluding high-temperature side of cascade system, and with temperature of the refrigerant entering the evaporator above -30°C/-22°F); 150 GWP; January 1, 2026

- Chillers (industrial process refrigeration with exiting fluid above -30°C/-22°F); 700 GWP; January 1, 2026)
- Chillers (comfort cooling); 700 GWP; January 1, 2025)
- Residential and light-commercial air-conditioning and heat pump systems; 700 GWP; January 1, 2025

For refrigerated road transport, systems with the following refrigerants will be banned as of January 1, 2025: R402A, R402B, R404A, R407B, R408A, R410B, R417A, R421A, R421B, R422A, R422B, R422C, R422D, R424A, R428A, R434A, R438A, R507A, R125/290/134a/600a (55/1/42.5/1.5), RS44 (2003 formulation) and GHGX5.

Proposed rule

In October the EPA also announced a proposed rule to better manage and reuse existing HFCs, including by reducing wasteful leaks from equipment and supporting a growing U.S. industry for HFC recycling and reclamation.¹³⁶

The proposed program to manage emissions reduction and reclamation of HFCs and their substitutes would help minimize HFC leaks across the lifespan of existing equipment, such as air conditioners and refrigeration systems, while also maximizing the reuse of existing HFCs. The proposed rule includes requirements for repairing leaky equipment (with no “trigger” leak rates), use of automatic leak detection systems on large refrigeration systems, use of reclaimed HFCs for certain applications, recovery of HFCs from cylinders before their disposal, and a container tracking system.

During the Trump administration, the EPA rescinded a rule applying leak repair requirements to HFCs in addition to those for ozone-depleting substances; the proposed rule restores and expands those requirements, bringing a range of smaller equipment containing more than 15lbs of HFC refrigerants under their purview.

The proposed rule would also require the use of 100% reclaimed refrigerant in most new appliances and systems still containing HFCs beginning in 2028, ranging from new air-conditioners and heat pumps to supermarket cases and other commercial refrigeration equipment.

The following are some of the provisions of the proposed refrigerant management rule under the AIM Act and the proposed effective date.

Leak repair

- For appliances containing 50lbs (23kg) or more of a refrigerant that contains an HFC or a substitute for an HFC with a GWP greater than 53; 60 days after final rule is published.
- For appliances containing between 15lbs (7kg) and 50lbs of a refrigerant that contains an HFC or a substitute for an HFC with a GWP greater than 53; one year after final rule is published.

Installation of automatic-leak-detection (ALD) systems

- For commercial refrigeration and industrial process refrigeration appliances that were installed prior to the effective date of the final rule with a charge size of 1,500lbs (680kg) or more; within one year after the date of final rule publication
- For commercial refrigeration and industrial process refrigeration appliances that were installed on or after the effective date the final rule with a charge size of 1,500lbs or more; within 30 days of appliance installation.

Use of reclaimed HFCs

- For initial charge (installation) of certain equipment: residential and light commercial AC and heat pumps, cold storage warehouses, industrial process refrigeration, stand-alone retail food refrigeration, supermarket systems, refrigerated transport and automatic commercial ice makers; January 1, 2028.
- For servicing and/or repair of certain equipment: stand-alone retail food refrigeration supermarket systems, refrigerated transport and automatic commercial ice makers; January 1, 2028.

3.3 Hydrocarbon Charge Limits

In October, 2021, UL (Underwriters Laboratories) approved UL 60335-2-89, 2nd Edition, including higher charge limits for hydrocarbon and A2L (less flammable) refrigerants in commercial cases.¹³⁷ This followed a vote by the International Electrotechnical Commission (IEC) in 2019 to increase the allowable charge of hydrocarbons like R290 in commercial cases from 150g to 500g, updating its IEC 60335-2-89 standard.

UL 60335-2-89 covers safety requirements for commercial refrigerating appliances and ice makers with an incorporated or remote refrigerant unit or motor-compressor. It incorporates the CSA (Canadian Standards Association) 60335-2-89 standard for the same equipment.

The new UL standard raised the charge limit in commercial plug-in display cases to 13 times the LFL (lower flammability limit) of a refrigerant – or 500g for propane (R290) – but only for open appliances (without doors). It raises the charge limit for closed appliances with doors and/or drawers to eight times the LFL of the flammable refrigerant (300g for R290).

In May the U.S. Environmental Protection Agency (EPA) proposed adopting those limits under its Significant New Alternatives Policy (SNAP) Rule 26.¹³⁸ EPA previously listed R290 acceptable in new self-contained commercial ice machines and stand-alone equipment in SNAP Rules 21 (2016) and 17 (2011), respectively.

The proposed action would follow the UL Standard 60335-2-89, 2nd Edition, in place of UL Standards 563 and 471, and would apply to equipment manufactured after the effective date of a final rule based on this proposal. In addition it proposes listing propane as acceptable as a refrigerant in new refrigerated food processing and dispensing equipment, and exempting it in that use from the venting prohibition under the Clean Air Act section 608.

A number of states, including New York, Washington, California, Colorado, Maine and Texas, have already passed legislation to accept UL Standard 60335-2-89, 2nd Edition once it is approved by the EPA. At least 11 other states have already adopted the updated UL standard into their building codes.¹³⁹ The ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) trade group has also incorporated it in ASHRAE 15, a standard for refrigeration safety.

A higher charge limit for R290 in commercial cases has long been considered necessary for wider adoption of R290 equipment in U.S. supermarkets, though the 150g limit has allowed considerable adoption to date. The higher limit will allow fewer compressors and condensing units to be used in cases, lowering costs and increasing energy efficiency.

The higher UL charge limits are contingent on an appliance being constructed to prevent flammable refrigerant concentration surrounding the appliance in case of a leak (releasable charge) as verified by the “Annex CC” test. Commercial appliances also must employ detection/mitigation controls to limit the releasable charge of the system.

Higher charges for ACs and heat pumps

Higher charge limits for flammable refrigerants were also approved for residential air conditioners, heat pumps and dehumidifiers in May 2022 by the IEC.¹⁴⁰ The IEC 60335-2-40 ED7 global standard allows up to 988g (2.2lb) of R290 in a (fixed) split AC unit and 304g (0.7lbs) in a non-fixed unit, while existing regulation in the U.S. only permits 114g (0.3lb) of propane in fixed or non-fixed units (including outdoors).

The IEC 60335-2-40 ED7 is expected to be harmonized into U.S. standards as soon as possible to allow manufacturers to achieve higher capacities in these systems with low GWP and natural refrigerants. ASHRAE has already proposed an Addendum E amending its 15.2-2022 Safety Standard for Refrigeration Systems in Residential Applications to allow up to 4.9kg (10.9lbs) of flammable (A3) refrigerants like propane in outdoor heat pumps and air conditioners like monobloc units in the U.S.¹⁴¹

ASHRAE's proposal, in an advisory public review draft, completed a 45-day public review period on September 18. If approved by ASHRAE, the charge limit would also need to be endorsed by UL under its 60335-2-40 standard and then by the EPA. Hydrocarbon monoblocs are increasingly popular in Europe.

3.4 The EPA's Risk Management Program

The U.S. Environmental Protection Agency (EPA)'s Risk Management Program (RMP) rule requires facilities that use more than 10,000lbs (4,536kg) of extremely hazardous substances such as ammonia (R717) to develop a Risk Management Plan that:

- identifies the potential effects of a chemical accident;
- identifies steps the facility is taking to prevent an accident; and
- spells out emergency response procedures should an accident occur.¹⁴²

The Occupational Safety and Health Administration (OSHA)'s process safety management (PSM) program, which is under review, also requires strict safety measures for operators using more than 10,000lbs of ammonia.

In August 2022, the EPA announced a proposed update of its RMP rule.¹⁴³ Called the Safer Communities by Chemical Accident Prevention Rule, it is designed "to further protect vulnerable communities from chemical accidents, especially those living near facilities with high accident rates," the EPA said.

Highlights of the proposed rule include:

- providing greater protections for communities living near RMP facilities, many of which are underserved and overburdened by pollution;
- emphasizing the requirement for regulated facilities to evaluate risks of natural hazards and climate change, including any associated loss of power;
- promoting environmental justice through increased availability of information for frontline communities in their requested language; and
- requiring safer technologies and analysis of alternatives for certain facilities with high accident rates.
- Advancing greater employee participation and opportunity for decision-making in facility accident-prevention requirements.

- Requiring third party audits for facilities with a bad track record of accidents.
- Enhancing facility planning and preparedness efforts.

The proposed rule comes in the wake of the checkered history of the RMP, which the EPA introduced in 1996. In January 2017, the "RMP Amendments Final Rule" issued new requirements for prevention, response and public disclosure of information, but key provisions were paused, and most never went into effect. Instead, in 2019, the RMP Reconsideration Final Rule rescinded or modified some of the measures in the 2017 rule.

Five trade groups have co-signed a letter to the EPA objecting to certain provisions of the new RMP proposal: the American Frozen Food Institute, the Global Cold Chain Alliance, the International Institute of Ammonia Refrigeration (IIAR), the North American Meat Institute and the Refrigerating Engineers and Technicians Association (RETA).¹⁴⁴

As they have in the past, the ammonia refrigeration trade groups objected strenuously in their letter to the proposed RMP rules regarding the need for third-party audits to be conducted by independent organizations.

In the U.S., facilities using less than 10,000lbs of ammonia must still follow the less restrictive General Duty Clause (GDC) of the Clean Air Act.¹⁴⁵

Requirements of the GDC include:

- identifying chemical hazards and assessing the impact of possible releases;
- designing and building a safe facility to prevent accidental release of hazardous chemicals; and
- minimizing the consequences of an accidental release.



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3.5 The U.S. Definition of PFAS

In 2021, the OECD (Organisation for Economic Co-operation and Development) proposed a definition of PFAS (per- and polyfluoroalkyl substances) – so-called “forever chemicals,” some of which have been found hazardous to humans – that is based on a molecule having at least one fully fluorinated methyl or methylene carbon atom.¹⁴⁶

Endorsed by a wide range of scientists, this definition not only includes f-gases but also the TFA (trifluoroacetic acid) into which some f-gases, notably HFO-1234yf, decompose in the atmosphere. TFA comes down to Earth in rainwater and has been found to accumulate in water supplies and arctic ice, raising concerns about its ultimate health impact. (See chapter 1.8 on HFOs.)

In addition to the EU, U.S. states such as Arizona, California, Colorado, Connecticut, Hawaii, Illinois, Indiana, Maine, Maryland, Minnesota, Nevada, New Hampshire, New York, Oregon, Rhode Island, Vermont and Washington have adopted legislation targeting PFAS that uses the OECD definition.

However, the Office of Pollution Prevention and Toxics (OPPT) at the U.S. Environmental Protection Agency (EPA) has followed a “working definition” of PFAS that takes a more narrow view, describing the chemicals as containing at least two adjacent carbon atoms, where one carbon is fully fluorinated and the other is at least partially fluorinated. This definition excludes f-gases and TFA.

In May, the OPPT said in an email that it is no longer using the working definition of PFAS and would explain the rationale for identifying specific PFAS substances it believes “are appropriate to include within the scope of each individual action.”¹⁴⁷

This email was shared by Tim Whitehouse, Executive Director, Public Employees for Environmental Responsibility (PEER), in a presentation on the PFAS panel at the ATMOSphere (ATMO) America 2023 conference, held in Washington, D.C., June 12–13. ATMO America was organized by ATMOSphere, publisher of this report.

In June, the U.S. Senate Environment and Public Works (EPW) Committee released draft PFAS legislation that includes the narrower PFAS definition previously employed by the EPA, but this has not yet been brought to a vote.¹⁴⁸

The more restrictive definition of PFAS has prompted widespread criticism, including a 2021 letter from the scientific community to EPA Administrator Michael Regan urging the agency to use the OECD’s definition of PFAS, which it called “scientifically sound and consistent with definitions that have been included in federal and state laws regulating PFAS.”¹⁴⁹ The letter also noted that the EPA’s definition excluded many HFC and HFO refrigerants as well as TFA, which “poses risk to human and ecological receptors.”

In November 2021, U.S. Representatives Deborah Ross (Democrat from North Carolina) and Nancy Mace (Republican from South Carolina) introduced the PFAS Definition Improvement Act (HR 5987), which would adopt the OECD definition of PFAS.

PEER has sued the EPA alleging that the agency was “withholding documents explaining why it has adopted an exceedingly limited definition of [PFAS].” Its legal challenges are ongoing.

Along with a number of scientists, Robert Sussman, former Deputy Administrator of the EPA, believes that PFAS should be treated as a class of chemicals rather than individually, an approach that could facilitate the regulation of f-gases and TFA.¹⁵⁰ He made this point during the PFAS panel at ATMO America.

PFAS includes, by some estimates, up to 9,000 substances that all share common attributes, notably persistence in nature, mobility, accumulation and the potential for the same adverse effects as well-studied PFAS compounds like PFOA and PFOS.

The logo consists of the letters 'HB' in a bold, white, sans-serif font, enclosed within a black rectangular border.The word 'Products' is written in a white, sans-serif font on a solid blue rectangular background.The background of the top section is a photograph of a large, modern industrial warehouse with high ceilings, metal beams, and various equipment. The floor is polished and reflects the overhead lights.

ARE YOU WASTING ENERGY AND MONEY ON UNNECESSARY DEFROSTING?

A blue circular bubble containing a quote. The quote is in white text and is preceded by a large white opening quotation mark.

” Reduce the number of defrosting cycles by 50-70% on a yearly basis. “

Two stylized, light gray snowflake graphics are positioned to the right of the 'REDUCE ENERGY CONSUMPTION' header.

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In cold stores, the HBDF can reduce the number of defrost cycles by 50-70% on a yearly basis, when compared to a traditional timer-based approach. Such a significant reduction can lead to significant energy savings. This means that owners and operators can see a return of investment for the HBDF in as little as 30 days.

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3.6 State F-gas Regulations

California

Some U.S. states have pursued an aggressive course on regulating HFCs independent of the federal government, which only in the last few years has regulated these gases via the U.S. AIM Act. The most active state has been California.

In 2016, California's SB 1383 regulation authorized its Air Resources Board (CARB) to oversee the reduction of state HFC emissions by 40% of 2013 levels by 2030. In 2020, the board voted unanimously to approve a sweeping regulatory proposal putting in place stronger restrictions on the use of refrigerants in HVAC&R applications than current rules. Starting in 2022, new equipment with more than 50lbs (22.7kg) of refrigerant has been required to use refrigerant with a GWP of less than 150.

In addition, food retailers with 20 or more stores would need to comply with one of two options for existing stores: maintaining a weighted average refrigerant GWP below 2,500 by 2026, or reduce GWP potential (charge size times GWP) by at least 25% by 2026. All stores would need to have an average GWP below 1,400 or reduce GWP potential by 55% by 2030.

California's 2020 regulations have already helped drive considerable adoption of natural refrigerants, particularly transcritical CO₂ systems, in supermarkets.¹⁵¹

In October 2022, California built on its 2020 regulation by enacting SB 1206, aimed at the sale or distribution of bulk HFCs or HFC blends, and designed to increase the adoption of natural refrigerants.¹⁵² Under SB 1206, starting in 2025, 2030 and 2033, newly produced HFCs with a GWP greater than 2200, 1500 and 750, respectively, are prohibited.

SB 1206 also requires CARB to publish a refrigerant plan by January 1, 2025. The plan must detail how the state's economy, by sector, will transition from HFCs to ultra-low (under 35 GWP) or no-GWP alternatives – such as natural refrigerants like ammonia, CO₂ and propane – no later than 2035.

New York

Effective January 1, 2021, New York State adopted EPA SNAP Rules 20 and 21 prohibiting certain HFCs in specific stationary refrigeration and air-conditioning end uses. New York, unlike the EPA or other states, uses a 20-year GWP value rather than the traditional 100-year GWP value.

The state has pursued a new rule that proposes GWP thresholds for new and existing facilities. Under consideration are the following limits (all 20-year GWP):¹⁵³

- Under 50lbs of refrigerant: 530 GWP in new equipment as of 2024; 10 GWP in new equipment from 2027 to 2034.
- More than 50lbs of refrigerant: 10 GWP for new facilities as of 2024; 530 GWP in new equipment as of 2024; 10 GWP in new equipment as of 2034; 10 GWP in existing equipment from 2030 to 2035 with a prohibition date that may be determined based on business size (number of stores) and a replacement plan to be approved by the Department of Environmental Conservation.

Washington

Effective January 1, 2020, Washington State adopted EPA SNAP Rules 20 and 21 prohibiting certain HFCs in specific stationary refrigeration and air-conditioning end-uses.

Washington proposed an update in July 2023 establishing GWP thresholds for HFCs used in new equipment and creating a refrigerant management program.¹⁵⁴ The proposed rules would prohibit refrigerants above 150 GWP in new stationary refrigeration equipment containing more than 50lbs of refrigerant and refrigerants above 750 GWP for chillers used for industrial process refrigeration, starting January 1, 2025.



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3.7 Canadian Regulations

Canada ratified the Kigali Amendment in November 2017. This was followed by a phase down of HFC production and consumption that was announced on April 18, 2018. The phase down began in 2019 with a 10% reduction of the baseline, leading up to an 85% reduction in 2036, in alignment with the Kigali Amendment.

The scheduled reduction of HFCs includes bans on refrigerants above a certain GWP in specific appliances. As of 2020, a 2,200 GWP cap was set for centralized refrigeration racks and condensing units, a 1,500 GWP cap for low-temperature stand-alone refrigeration and a 1,400 GWP cap for medium-temperature stand-alone units. In addition, as of 2025, a 2,200 GWP cap is set for mobile refrigeration, a 750 GWP cap for chillers and AC and a 150 GWP cap for domestic refrigeration.

The province of Quebec has stricter GWP limits. Since January 1, 2021, the province has required refrigerants with a GWP under 150 for systems that use more than 50lbs (23kg) of refrigerant and employ more than 50kW of input power. Also as of that date, Quebec has had a GWP limit of 1,500 for systems with less than 50kW of input power.

In Canada, government incentives have supported the uptake of natural refrigerants.¹⁵⁵ In particular Quebec has put in place different public subsidy programs aiming at saving energy and promoting natural refrigerants as a replacement for R22. At the national level, the government started to offer carbon offset credits last year for projects that cut refrigerant emissions.

Canada is also planning action on PFAS while adopting the definition proposed by the Organisation for Economic Co-operation and Development (OECD) in 2021, which includes f-gases and trifluoroacetic acid (TFA). Moreover, Canada is considering addressing PFAS as a class rather than as individual substances or in smaller groups. Addressing PFAS as a class of chemicals would reduce the chance of “regrettable substitution,” support more holistic research and monitoring programs, and provide an opportunity to decrease future environmental and human exposure to PFAS.

3.8 Mexico Implementing Kigali Amendment

Mexico ratified the Kigali Amendment on September 25, 2018, and it took effect on November 30, 2018.

As a developing (Article 5) country, Mexico uses as its HFC baseline the average consumption between 2020 and 2022 plus 65% of its HCFCs baseline. It is required to freeze consumption at that level starting in 2024, then cut consumption by 10% in 2029, 30% in 2035, 50% in 2040 and 80% in 2045.

Natural refrigerant adoption in Mexico has been growing since the installation of a transcritical CO₂ system at a Casa Ley store in 2018.¹⁵⁶ Cold-storage operator Frialsa has installed a number of ammonia/CO₂ cascade refrigeration systems and other stores and industrial facilities are installing CO₂ systems.¹⁵⁷



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3.9 SEC's Proposed Rules on Climate-Related Disclosures

In March 2022, the U.S. Securities and Exchange Commission (SEC) proposed new rules to enhance and standardize climate-related disclosures for investors.¹⁵⁸ The agency hoped to publish the standard by the end of 2023.

The final set of rules will apply to all publicly traded companies in the U.S. and will likely require disclosure of greenhouse gas emissions and risk exposures, among other data. This reporting comes on top of other regulatory obligations, such as those from the U.S. Environmental Protection Agency (EPA).

Greenhouse gas reporting will eventually cover all emissions from a company's operations, facilities and value chain – i.e., scope 1 (direct), scope 2 (indirect from energy) and scope 3 (indirect from upstream and downstream activities). However, compliance requirements will be staggered over the coming years.

Refrigerant leaks would typically fall under scope 1 emissions of companies using heating and cooling applications; yet, they can also be counted as scope 3 emissions in some cases.

Quite a lot of the feedback to the proposed ruling was around the extent of scope 3 reporting, which is “potentially extremely complex,” explained Rob Bradley, Managing Director of Climate Change and Sustainability Services at U.K.-based Ernst & Young (EY).¹⁵⁹

“A lot of the companies we are working with are already thinking about where scope 3 is going to be material to them,” he added.

According to Bradley, there are multiple drivers in why a company may want to take action on climate change and sustainable development, including regulatory compliance and customer or employee expectations. However, the predominant motivator, particularly in the U.S., is what is material to investors, he said.

“These proposals for GHG emissions disclosures would provide investors with decision-useful information to assess a registrant's exposure to, and management of, climate-related risks, and in particular transition risks,” says the SEC.



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3.10 North American Market Data: Stores Using Natural Refrigerants

Total addressable market

In 2023, there were an estimated 63,207 supermarkets and grocery stores¹⁶⁰ and 150,174 convenience stores¹⁶¹ in the U.S. and an estimated 8,285 supermarkets and grocery stores and 9,777 convenience stores in Canada. In total, there were 71,492 supermarkets and grocery stores along with 159,951 convenience stores in North America for a combined **231,443** retail food stores.

The 150,174 convenience stores operating in the U.S. marked a 1.5% increase over 2022, reversing a four-year decline, according to the 2023 NACS/NIQ Convenience Industry Store Count.¹⁶¹ By contrast, U.S. supermarkets and grocery stores showed a decline of 0.2% compared to the previous year. Canada experienced an opposing scenario: supermarkets and grocery stores increasing by 3.6%, convenience stores decreasing by 3%.

In 2022, the number of supermarkets and grocery stores in the U.S. was 63,348, while the number of convenience stores was 148,026. In Canada, there were 8,000 supermarkets and grocery stores and 10,078 convenience stores. Altogether, North America had an estimated 71,348 supermarkets and grocery stores and 158 convenience stores, making a grand total of 229,452 retail food stores.

In 2021, the U.S. had 193,180 food retail stores. These included 40,460 supermarkets and grocery stores and 152,720 convenience stores.

TRANSCRITICAL CO₂ RACK SYSTEMS

Background

Given Europe's lead in the field of natural refrigerant systems, it's no surprise that a transplanted European – Predrag “Pega” Hrnjak, former research professor at the University of Illinois at Urbana-Champaign who died in 2022 – laid the foundation for the technology in North America. Inspired by Norwegian CO₂ visionary Gustav Lorentzen, whom he met in

the early 1980s, Hrnjak and his team wrote research papers on virtually every aspect of CO₂ refrigeration, as well as propane and ammonia systems.

But it was not until 2006 that a U.S. retailer, Food Lion (part of European retail giant Ahold Delhaize), began testing CO₂ as a secondary refrigerant in low-temperature applications at a store in Montpelier, Virginia. Over the next few years, the chain added another secondary CO₂ test store and three stores that employed CO₂ in cascade (subcritical) systems with a primary HFC refrigerant.

In Canada, the Sobeys chain decided in 2008 to install a transcritical CO₂ system supplied by start-up Carnot Refrigeration (now part of M&M Carnot). However, it took longer for transcritical CO₂ refrigeration to reach the U.S. Finally, in July 2013, Hannaford, a Scarborough, Maine-based chain (also owned by Ahold-Delhaize), became the first U.S. supermarket to use the technology at a new store in Turner, Maine. Its supplier: Carnot, whose factory is 240 miles away over the border in Canada.

Over the past few years, the biggest retail food user of transcritical CO₂ systems in the U.S. has been ALDI US, which operates more than 2,000 stores across 37 states. The chain, an independently operated member of the German retailer ALDI Süd, said in October that about 618 of its stores use transcritical CO₂ refrigeration, with 70–100 stores – both new and remodeled – being equipped with the technology each year.¹

With the changing regulatory climate, other big retailers in the U.S. that were previously reluctant to consider transcritical CO₂ systems are now starting to deploy them, including Target, Walmart and Kroger. Last year, at a retrofitted Vista, California, outlet that it is calling its “first net zero energy store,” Target said that it has switched to CO₂ refrigeration, which the company will scale chain-wide by 2040 to reduce its direct operations' emissions by 20%.² The chain is known to have installed transcritical CO₂ in many other stores throughout the U.S.

In Canada, Sobeys uses transcritical CO₂ refrigeration in more than 100 stores, with other major Canadian chains like Loblaw and Metro also employing the technology.

Supermarket are the dominant retail users of transcritical CO₂ systems in North America. However, Hillphoenix, the leading North American producer of CO₂ systems for supermarkets, announced last year its first installation of a transcritical CO₂ system at a convenience store.

In North America, CO₂ systems in stores typically use compressor racks, with one to 2.5 on average installed per store. There is significant interest in CO₂ condensing units among supermarkets in North America, with availability of this equipment increasing. Hillphoenix introduced its first CO₂ condensing unit for store cabinets and cold rooms last year.

The market today

According to data collected by ATMOSphere, as of December 2023, there were approximately **2,930** food retail stores in North America using transcritical CO₂ systems, up more than **80%** from 1,605 in 2022. Of these 2,930 food retail stores, **1,850** are in the U.S. and **1,080** in Canada.

The market penetration of transcritical CO₂ systems in the estimated 71,492 North American supermarket and grocery stores has increased to **4.09%**, up from 2.2% a year ago. When considering convenience stores as well, the market penetration out of 231,443 retail food stores in North America is **1.27%**, up from 0.7% in 2022.

There were also **498** industrial sites using transcritical CO₂ in North America in December 2023, for a total of **3,428** transcritical CO₂ sites. (See chapter 3.11 for more detail on industrial sites.)

Figure 18: Transcritical CO₂ Installations in North America

(as of December 2023)

Canada

1,080 Stores
290 Industrial Sites
1,370 Total Sites

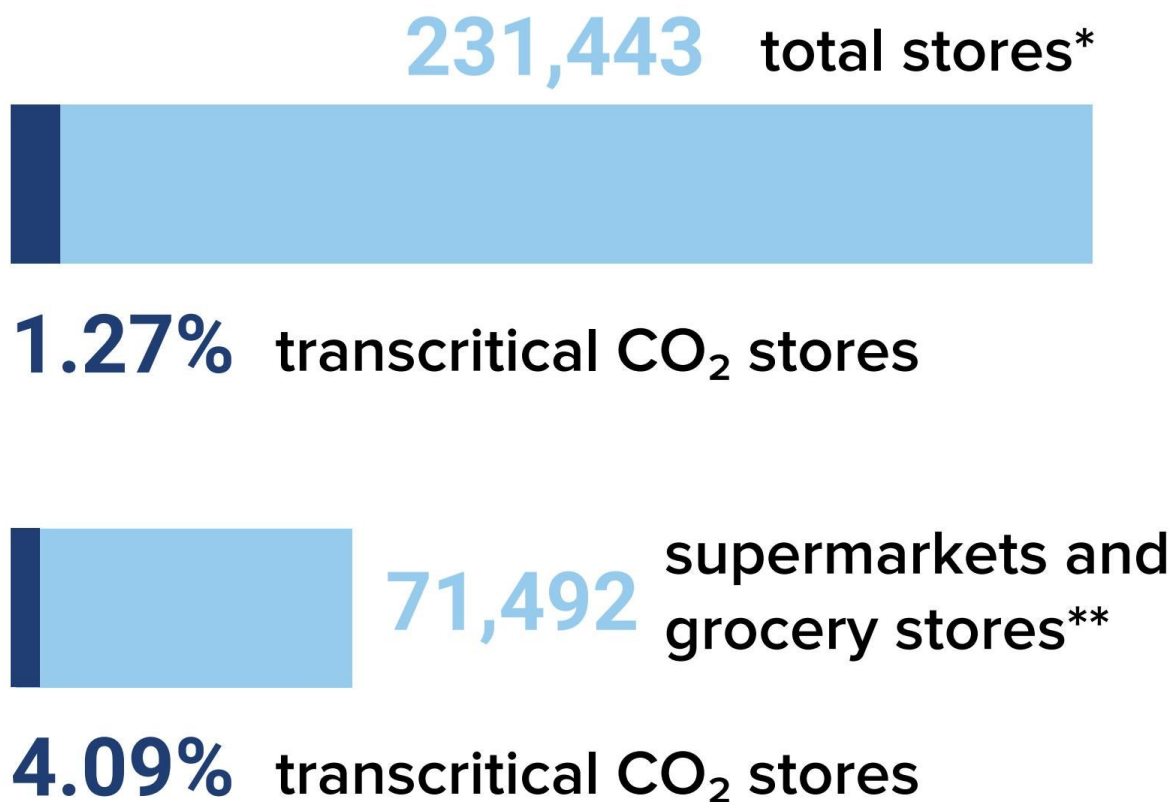
3,428

sites with
transcritical CO₂

U.S.

1,850 Stores
208 Industrial Sites
2,058 Total Sites

Figure 19: Transcritical CO₂ Commercial Refrigeration Market Penetration in North America



*IBISWorld and NACS

**IBISWorld



Figure 20: Transcritical CO₂ Installation Growth in North America

(stores)

2020	945
2022	1,605
2023	2,930

U.S.

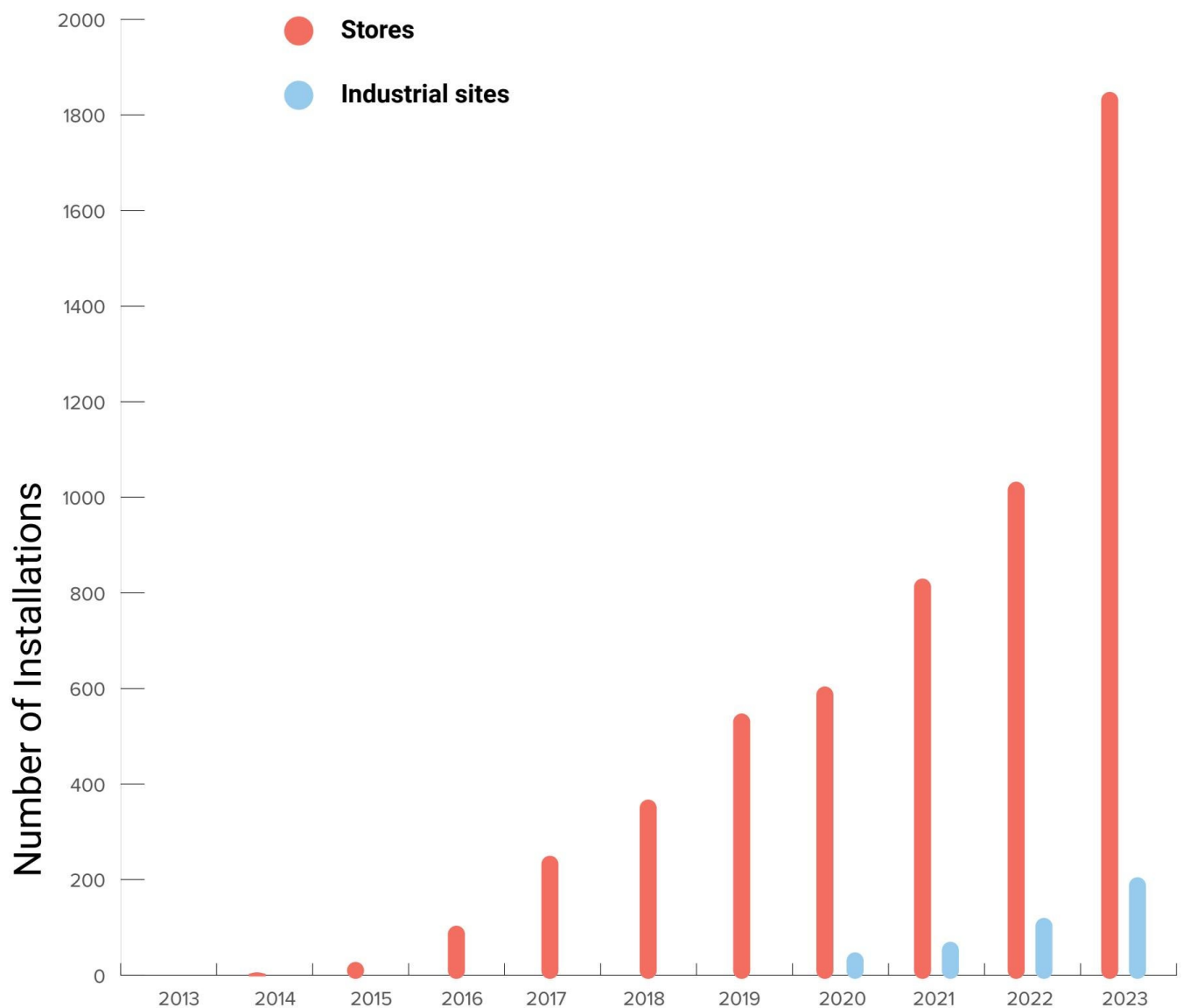
2020	605
2022	1,030
2023	1,850

Canada

2020	340
2022	575
2023	1,080

Figure 21: Transcritical CO₂ Installation Growth in U.S.

(stores and industrial sites)



Note: Prior to 2020, most installations were at stores.

HYDROCARBON SELF-CONTAINED CASES

Background

In addition to CO₂ in transcritical and cascade/secondary systems, the other natural refrigerant used by U.S. grocers in significant numbers is propane (R290), largely in self-contained display cases at the checkout or in spot merchandising locations (with a maximum charge of 150g).

In 2012, Unilever began delivering R290-based ice cream chest freezers to U.S. stores. The big uptick in R290 case adoption in the U.S. began in 2016, in anticipation of the more stringent energy standards released in March 2017 by the U.S. Department of Energy (DOE). The need for better energy efficiency boosted adoption of R290, a highly efficient refrigerant, as well as other technologies such as variable-speed compressors and more efficient fans. Since then, virtually all of the major commercial display case OEMs have transitioned to hydrocarbon refrigerants.

Today, just about every U.S. supermarket deploys at least some hydrocarbon-based beverage coolers at the checkout, and many use them as horizontal ice cream freezers and grab-and-go units at strategic locations. In addition, a small number of stores are using R290 cases throughout the sales area.

For example, more than 150 stores have installed R290 cases from AHT throughout the store, and other stores have deployed R290 cases from Hussmann in large sections or throughout the store. These stores are using semi-plug-in R290 cases attached to waterloop (glycol) systems that remove the heat of condensation. However, the North American market for entire stores using R290 equipment is seen as limited.

One U.S. retailer exploring full-store R290 lineups is ALDI US, which has installed solely R290 self-contained semi-plug-in display cases with a

waterloop in some stores – including a California store that received state incentive funding – and only R290 air-cooled plug-in cases in at least one store. In total, ALDI US has about 10 stores using only R290 cases.¹

In Canada, self-contained hydrocarbon cases have not been as widely adopted as in the U.S., but still represent a sizable market.

Overall, hydrocarbon self-contained case installations in North America represent a minority of the total installed cases in food retail, with the majority being remote cases. Remote cases are typically replaced by new remote cases in retrofits; the exception are horizontal chest “island” freezers that are harder to get to with piping.

But propane-based display cases, both air-cooled and water-cooled, will compete with transcritical CO₂ in complete-store installations in smaller stores, more so when charge-limit increases are approved in North America. (See chapter 3.3.) Propane cases may also take up more center-store space in larger stores that primarily use a transcritical CO₂ system.

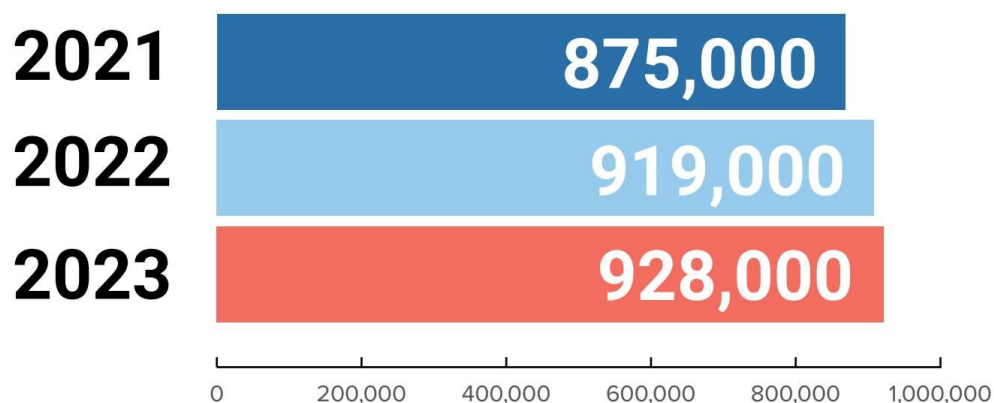
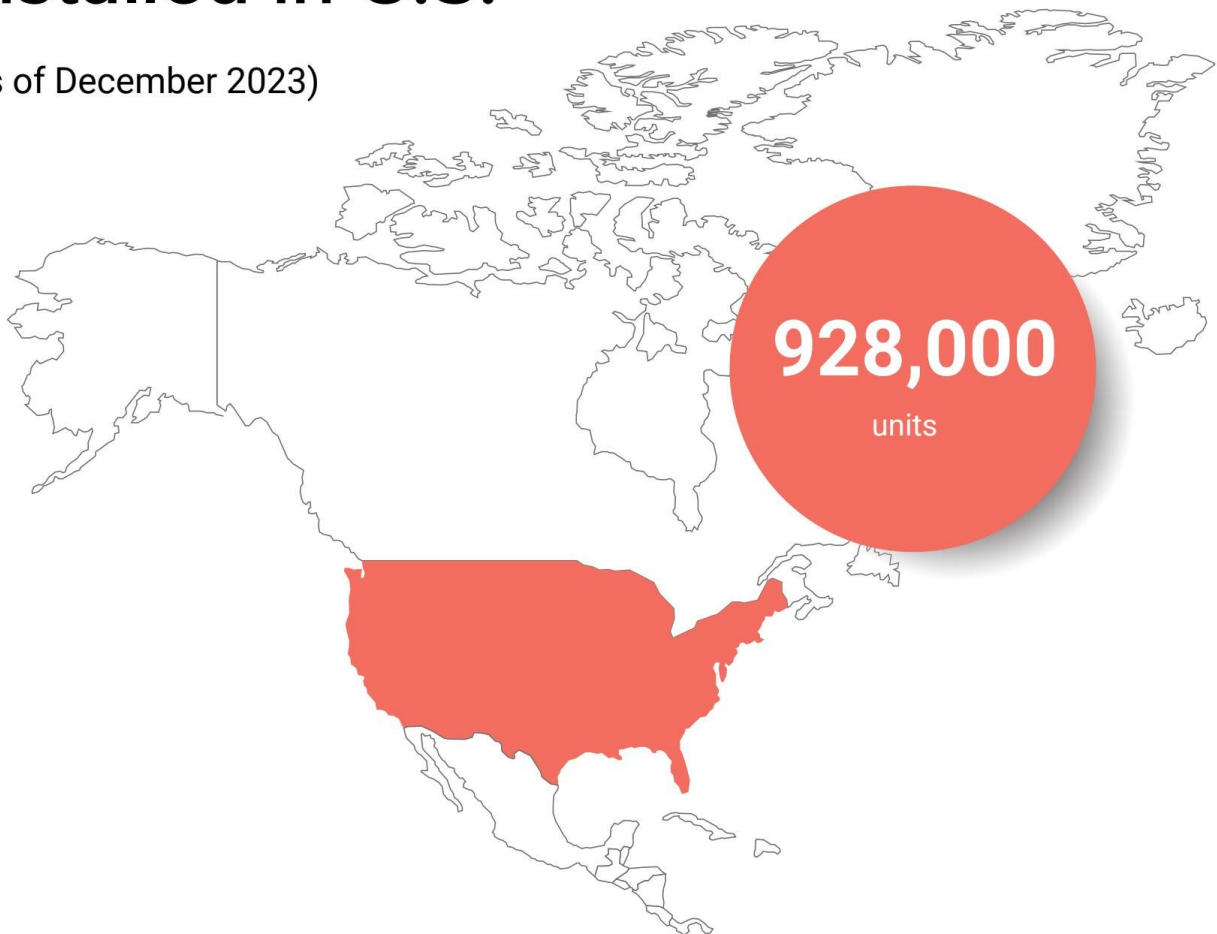
Other opportunities exist for hydrocarbon cases in store expansions, club stores and small stores favoring plug-ins cases, as well as stores seeking a piecemeal approach to transitioning to natural refrigerants. On the other hand, CO₂ condensing units, for which there is growing interest in the U.S., could compete with self-contained R290 cases in smaller stores, and with HFO-blend condensing units in convenience stores.

The market today

As of December 2023, ATMOSphere estimated there were **928,000** self-contained hydrocarbon (mostly R290) cases installed in U.S. food stores, an increase of **1%** from the 919,000 cases a year ago. The market is starting to be saturated and most of the new units are replacement units.

Figure 22: Self-Contained Hydrocarbon Commercial Cabinets Installed in U.S.

(as of December 2023)



3.11 North American Market Data: Industrial Sites Using Natural Refrigerants

TRANSCRITICAL CO₂

Background

One of the first transcritical CO₂ industrial installations in North America came in 2018, when Henningsen Cold Storage (now owned by Lineage Logistics) installed one at its facility in Grandview, Washington.

Over the past few years, industrial installations of transcritical CO₂ in the U.S. have become more widespread, supplied by such OEMs as Hillphoenix, M&M Carnot and Zero Zone. End users include cold storage, food processing, pharmaceutical, manufacturing and ice rinks. At industrial sites, CO₂ systems primarily employ racks (one to 1.5 on average), but some are beginning to use condensing units (one to two per site).

In North America, ammonia has dominated the industrial sector for decades and is expected to continue to do so, particularly for large food processing facilities. However, in smaller food processing and cold storage operations, transcritical CO₂ has been making great progress as end users seek to avoid regulatory pressures that come with ammonia and HFCs.

The market today

As of December 2023, there were also **498** industrial sites using transcritical CO₂ in North America in 2023, **14.5%** of the total of **3,428** transcritical CO₂ sites. (See chapter 3.10 for more detail on store sites.) The 498 industrial sites, which represents a 71% increase from the 290 North American sites in 2022, consists of 208 in the U.S. (up from 120 in 2022) and 290 in Canada (up from 170 in 2022).

LOW-CHARGE AMMONIA

Background

Beginning in the 1980s, companies like Campbell Soup started implementing low-charge ammonia systems. The biggest push to install low-charge ammonia systems in the U.S. began in 2016 when Western Gateway, a cold storage operator in Utah, installed the first Evapco low-charge ammonia packaged unit on its roof.

Another approach is to keep the stick-built, central-engine-room format traditionally used by industrial operators but employ a smaller charge of ammonia.

Ammonia/CO₂ central systems, which confine ammonia to the engine room, are also considered low-charge systems. They began to be installed in the early 2000s and now number well over 100 in North America, supplied by such manufacturers as M&M Carnot and Innovative Refrigeration Systems.

The market today

As of December 2023, ATMosphere estimates there were **1,045** industrial sites using low-charge (below 1.3kg/kW or 10.1lbs/TR) ammonia systems in North America, an increase of 10% over the number a year ago, including **110** with packaged units and **935** with central systems.

The 1,045 industrial sites equates to 715 sites (627 with central and 88 with packaged systems) in the U.S. and 330 (308 central and 22 packaged) in Canada.

As of December 2022, there were 950 industrial sites with installations of low-charge ammonia systems in North America, including 100 with packaged units and 850 with central systems. In the U.S., there were 650 industrial sites (570 with central and 80 with packaged systems) and in Canada, 300 (280 central and 20 packaged).

Figure 23: Growth of Transcritical CO₂ in North America

(industrial sites)

2022	290
2023	498

U.S.

2022	120
2023	208

Canada

2022	170
2023	290



Figure 24: Installations of Low-Charge Ammonia Systems in North America

(industrial sites as of December 2023)

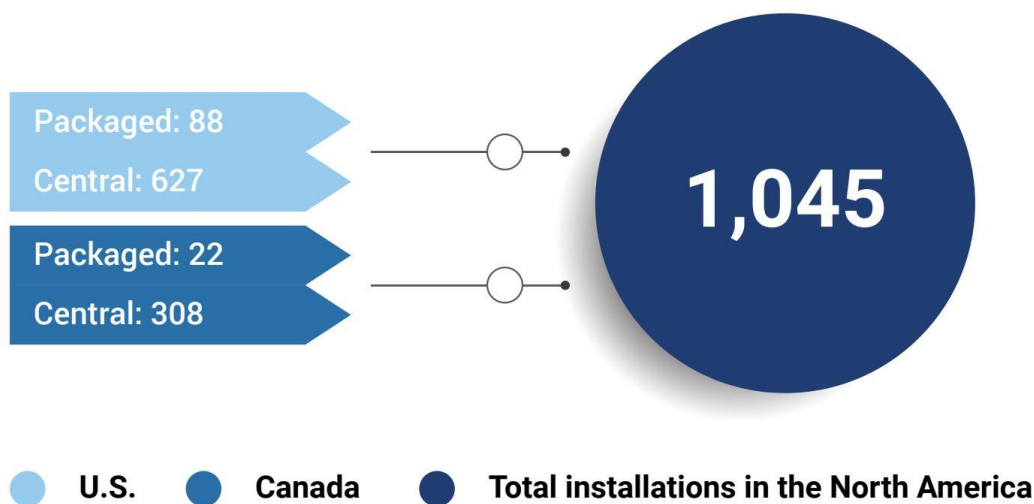
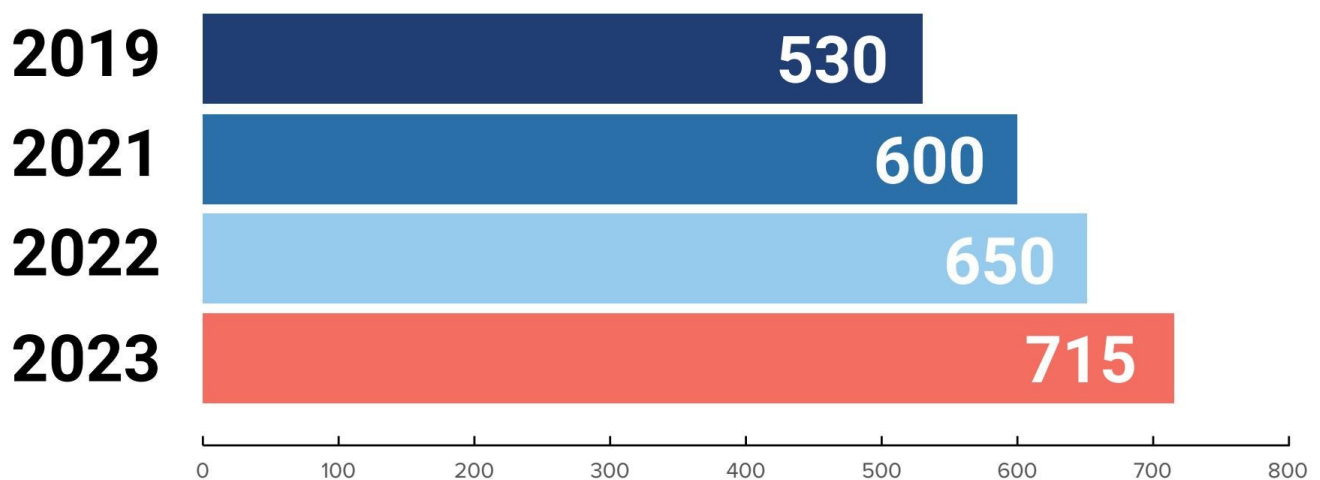


Figure 25: Growth of Low-Charge Ammonia in U.S.

(industrial sites)





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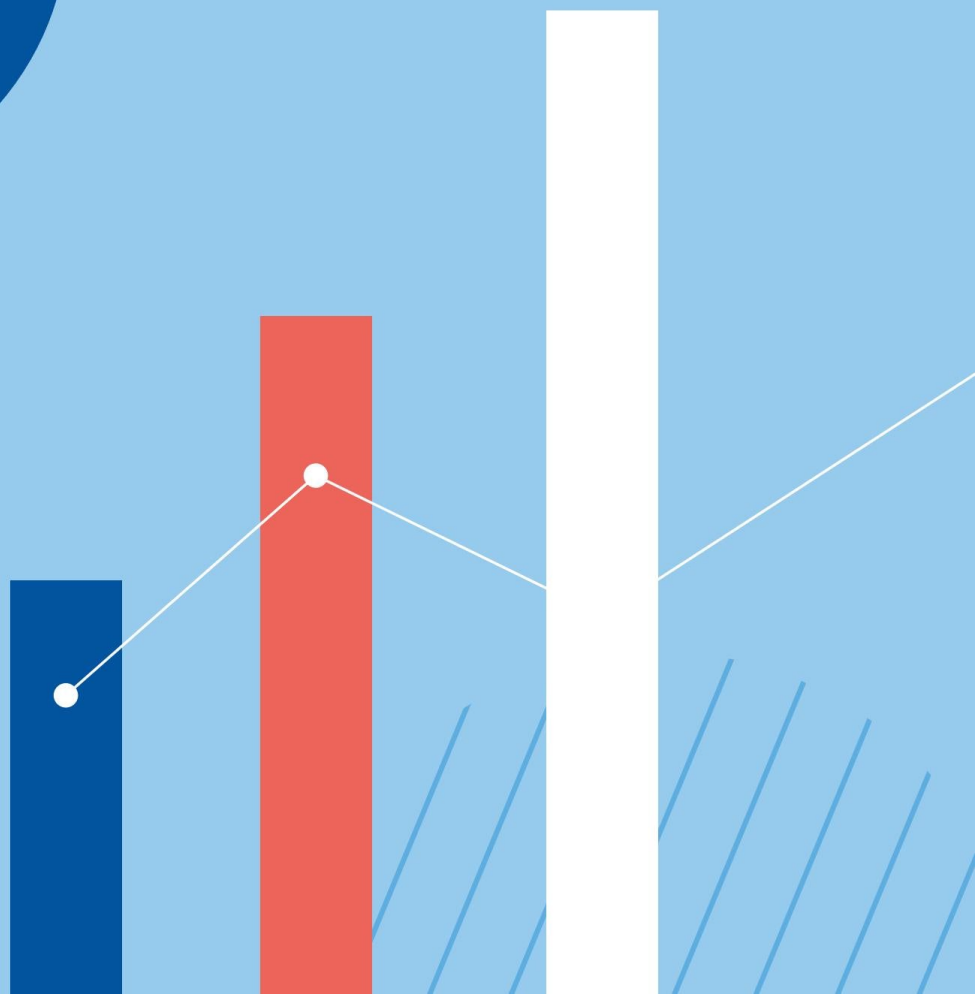
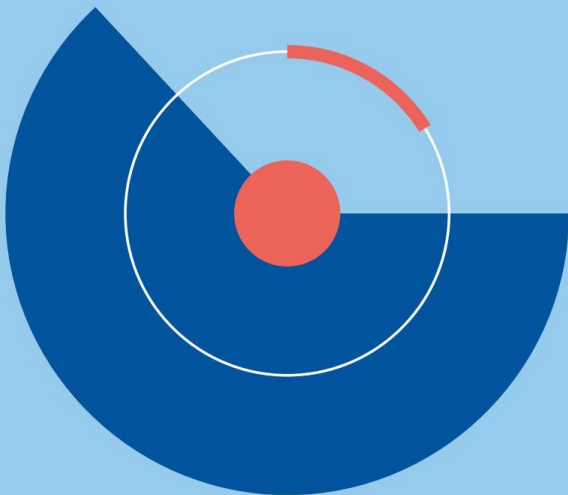
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CHAPTER 4

Japanese Trends



4.1 The Japanese Food Industry: Economic Outlook

Food retail sales in Japan have grown significantly over the past few years, according to the country's Ministry of Economy, Trade and Industry, Statistics Bureau. In supermarkets, sales grew from ¥12.03 trillion (US\$112.68 billion) in 2020 to ¥12.53 trillion (US\$114.14 billion) in 2021 and ¥15.15 trillion (US\$115.28 billion) in 2022. In convenience stores, the growth was from ¥8.96 trillion (US\$83.9 billion) to ¥9.32 trillion (US\$84.85 billion) to ¥11.55 trillion (US\$87.85 billion).¹⁶²

In 2022, supermarkets accounted for 35.30% of food retail sales in Japan, while convenience stores generated 26.90%; the rest came from department stores (12.83%), drug stores (17.96%) and the internet (7.01%). As of September 2023, there were 21,236 supermarkets¹⁶³ and 55,790 convenience stores¹⁶⁴ in Japan.

The demand for chilled/frozen foods in Japan is increasing from the elderly, dual-income households and single people. As a result, frozen food sales have significantly increased in supermarkets, hypermarkets and drugstores.

Frozen food items in Japan have become more diverse due to advances in refrigeration technology and growing demand for eat-at-home products amid the COVID-19 pandemic. Popular frozen food products manufactured in Japan include dumplings (gyoza), croquettes, and wheat-flour noodles (udon).

Ready-made and single-serve meals have also grown in popularity due to their convenience. Meal packs that contain all ingredients needed for a meal are also increasingly used, as they shorten both shopping and food preparation times. "Perfect nutrition food," which consists of high-protein and high-nutrition snacks, is similarly on the rise.¹⁶⁵

In recent years, Japanese food has also exploded worldwide, especially agricultural products.

At the end of 2022, over 20,000 food and beverage products had increased in price, translating to an extra estimated annual household cost of over ¥100,000 (USD\$700).¹⁶⁵

The Japanese cold chain logistics market is expected to grow from ¥2.96 trillion (US\$19.54 billion) in 2023 to ¥3.86 trillion (US\$25.51 billion) by 2028, at a compound annual growth rate (CAGR) of 5%.¹⁶⁶

Most cold storage facilities in Japan are owned and operated by major cold chain corporations, with only a small number available for lease. As older facilities become obsolete and with HCFC (R22) restrictions, some assets will need to be redeveloped over the mid-to-long term.

Cold chain logistics in Japan was initially established for the fresh, refrigerated and frozen food industries. But rapid advancements in biopharmaceuticals and regenerative medicine recently increased the demand for the cold pharmaceutical chain in Japan.

In addition, advances in using e-commerce to sell frozen and chilled goods will accelerate cold storage development. While cold storage facilities have traditionally tended to be constructed in the vicinity of seaports, locations closer to consumers are likely to be increasingly favored for new developments.¹⁶⁷

Figure 26: Japan Food Retail Sales, 2020-2022

(trillion Yen)



Source: Ministry of Economy, Trade and Industry, Statistics Bureau of Japan



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4.2 Natural Refrigerant Subsidy Project

Since 2014, government subsidies have been a major driver of growth for natural refrigerant systems in Japan and has led to an increase in the number of transcritical CO₂ (R744) installations.

The stated goal of the subsidy is to encourage the “shift to natural refrigerants ... and to widely promote the use of energy-efficient equipment,” according to Japan’s Ministry of the Environment (MOE). The subsidy aims to “contribute to driving down the cost of natural refrigerant equipment to achieve cost parity with conventional f-gas equipment, and to accelerate the spread of the technology.” The scheme targets the food retail and food manufacturing sectors as well as cold-storage facilities.

The MOE declared in June that it will continue its natural refrigeration equipment installation subsidy project through fiscal year 2027, with ¥7 billion (US\$48.7 million) allocated for fiscal year 2023, which runs from June 1, 2023, to March 31, 2024.¹⁶⁸ MOE now calls the project “Promotion of HFC-Free and Decarbonization of Refrigeration Equipment Supporting the Cold Chain.”

Of the 3,630 projects subsidized to date, the commercial refrigeration sector has accounted for 2,478; these include supermarkets and convenience stores, with the majority using CO₂ systems, including air-cooled CO₂ condensing units. However, Japanese food retail chain Aeon and convenience store chain Lawson have started using hydrocarbon (propane/R290 and isobutane/R600a) refrigerant showcases.

The remaining 1,152 have been for applications in the industrial refrigeration sector, with the majority of the systems using ammonia (R717)/CO₂ systems like those produced by Japanese manufacturers Mayekawa and Mitsubishi Heavy Industries (MHI).

In an effort to make the subsidy project more accessible, some changes made for the fiscal year 2023 benefit small- and medium-sized enterprises, including making the application easier with a relaxed installation schedule and costs rules and raising the project reimbursement upper limit from one-third to one-half of the construction costs. One rule change affects large corporations, which must announce a target for introducing natural refrigerant equipment.

Since Japan’s initial introduction of subsidies in 2005 for the installation of natural refrigeration equipment, nearly all of the funds allotted by MOE each year have been used.

From fiscal year 2018 to 2022, the subsidy project operated under the name “Project to Accelerate the Introduction of Energy-Saving Natural Refrigerant Equipment for the Early Realization of HFC-Free and Low-Carbon Society,” with an allocated budget for fiscal year 2019 of ¥7.4 billion (US\$51.5 million) and ¥7.3 billion (US\$50.9 million) each fiscal year from 2020 to 2022.

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4.3 Refrigerant Phase Outs and Phase Downs

Japan's revised f-gas laws, which came into effect in April 2015, have created a greater impetus for the uptake of CO₂ systems within the commercial refrigeration sector.

On December 18, 2020, Japan ratified the Kigali Amendment to the Montreal Protocol, joining the global phase down of HFCs. The Amendment requires developed countries to take the lead on phasing down HFCs, with a 40% reduction in 2024 and an 85% cut in 2036 (compared to a 2011–2013 baseline).

As f-gases are still used in many cold storage facilities operated by members of the Japan Association of Refrigerated Warehouses (JARW), there is an urgent need to consider switching to alternative systems, which is driving interest in CO₂. (JARW members represent about 80% of cold-storage capacity in Japan.)

On the whole, progress toward natural refrigerants is slow. This is because Japan's f-gas laws focus on the life cycle of refrigerants and introduce targeted years and targeted average GWPs for several HVAC&R sectors that are in some cases very unambitious in comparison to the EU F-gas Regulation.

For example, condensing units in the commercial refrigeration sector have a targeted weighted average GWP of 1,500 by 2025. Such a high GWP target doesn't incentivize the majority of local manufacturers to invest in natural refrigerants; they instead gradually have shifted to HFO blends like R448A to comply.

On the other hand, the industrial refrigeration sector has a targeted weighted average GWP of 15, so here the move to natural refrigerants (especially NH₃/CO₂ and CO₂) is clear, along with some limited competition from HFOs.

4.4 High Pressure Gas Safety Act

Japan's High Pressure Gas Safety Act restricts the use of CO₂ in large refrigeration systems, subjecting manufacturers to heavy administrative burdens.

However, in July 2017, the High Pressure Safety Institute of Japan (KHK) announced that CO₂ would be reclassified under the Act, moving from the strictest level of Group 3 to the least restricted level of Group 1.

This means that several administrative restrictions such as government notification or permission are no longer required for any manufacturer of CO₂ equipment with a daily refrigeration capacity under 20TR/70.3kW (previously under 3TR/10.6kW).

The regulatory change opened the door to significantly wider adoption of larger CO₂ systems in commercial and industrial applications in Japan.

4.5 Standards for Hydrocarbon Cases

Japan published Japanese Industrial Standard (JIS) C 9335-2-89:2021 in March 2021. The standard, which was developed based on the global IEC 60335-2-89:2019 standard, specifies the increase in the maximum refrigerant charge for commercial refrigeration equipment as 13 times the lower flammability limit (LFL). For R290, this amounts to 494g (17.4oz).

Subsequently, the Japan Refrigeration and Air Conditioning Industry Association (JRAIA) published a new standard (JRA 4078 2021) and new guidelines

(JRA GL-21 2021), which are based on the new JIS standard and specify in more detail safety standards and requirements for hydrocarbons.

The JIS standard, in combination with the JRAIA standards and guidelines, is expected to have a major positive impact on the uptake of hydrocarbon cases in Japan's commercial food retail sector, serving as a clear indication of the direction of the market over the next few years.

4.6 Japanese Market Data: Stores and Industrial Sites Using Transcritical CO₂

Total addressable retail market

There were an estimated 55,790 convenience stores in Japan by the end of September 2023, a decline of 0.1% from the previous September (55,872).¹⁶⁴ Also in September 2023, there were an estimated 21,236 supermarkets in Japan, an increase of 0.5% from the previous September (21,131).¹⁶³ Combined, this amounted to **77,026** food retail outlets in Japan in 2023, an increase of 0.03% from the prior year (77,003).

The floor size for supermarkets in Japan measures around 1,381m² (14,865ft²) on average.

Background on retail sector

While large scale transcritical CO₂ rack systems first started popping up in Europe's commercial refrigeration sector in the early 2000s, Japan began its natural refrigerant commercial refrigeration journey on the smaller end of the CO₂ scale.

The origins of natural refrigerant technologies used in Japan's commercial refrigeration sector can be traced back to the installation of the country's first transcritical CO₂ heat pump systems, called Eco Cute, in the residential hot-water heating sector.

The first Eco Cute CO₂ hot water heat pump was introduced by Denso in Japan in 2001. It was the first CO₂ system to see widespread commercial success in Japan's residential and commercial hot-water markets. As of September 2023, there were an estimated 9,023,305 installed Eco Cute CO₂ hot water heat pumps in Japan's domestic hot water heating market.¹⁶⁹

As CO₂ transcritical technology became proven in the residential heat pump market, similar technologies based on these systems were gradually scaled up in capacity to serve the cooling needs for the country's commercial refrigeration sector.

The majority of CO₂ transcritical systems in Japan's commercial refrigeration sector are now used in convenience stores, which employ air-cooled CO₂ outdoor condensing units (OCU) ranging from 2 to 20HP, rather than CO₂ rack systems. In 2010, major Japanese convenience store operator Lawson

installed its first OCU. Within a few years, the number of installations grew into the thousands, making Lawson the world's leader in the adoption of transcritical CO₂ in commercial food retail. Other convenience store chains using transcritical CO₂ include 7-Eleven, Family Mart and Mini Stop.

The leading provider of OCUs in Japan is Panasonic, with more than 16,000 units for medium- and low-temperature applications installed in Japan as of September 2023.¹⁷⁰

In supermarkets, the uptake of transcritical CO₂ OCUs still remains relatively limited, though a significant increase in adoption is expected over the next few years.

CO₂ technology is relatively mature compared to other natural refrigerants in the commercial refrigeration sector. Due to this technology maturity, the costs of manufacturing the systems are continuing to decrease, and widespread adoption and multiple reference projects and installations have made CO₂ an accepted solution for the food retail market in Japan.

However, the expected increasing market share of HFO blends like R448A for commercial food retail, due to Japan's relatively unambitious f-gas laws, is expected to act as a barrier to maximizing uptake of CO₂ in this sector. Some investments will also be made in hydrocarbon cases, but these are mostly supplemental island freezers.

The retail market today

As of December 2023, there were **8,385** stores, including **7,800** convenience stores and **585** supermarkets, using transcritical CO₂ systems (mostly OCUs) in Japan's commercial refrigeration sector, up **26%** from 6,630 stores (6,330 convenience/300 supermarkets) reported in December 2022. With **400** industrial site installations, the total number of transcritical CO₂ installations in Japan was **8,785** sites as of December 2023.

The majority were installed by convenience store chain Lawson, which had 5,300 stores using CO₂ OCUs as of February 2023 (more than one-third of its fleet of 14,656 stores). 7-Eleven Japan is another significant convenience store user of transcritical

CO₂, with 877 outlets employing the technology as of May 2023. Overall, the convenience store sector's installations of transcritical CO₂ grew by 23% in 2023.

Though uptake of transcritical CO₂ in supermarkets has been relatively limited in Japan so far due to certain cultural and technological preferences, it is expected that this sector will be one of the top candidates for rapid growth of transcritical CO₂ system adoption in the next few years. The number of supermarkets using transcritical CO₂ almost doubled in the past year.

Background on industrial sector

In the past three to five years, Japan has seen a significant uptick in the adoption of CO₂ transcritical systems by end users in the cold storage and food processing industries as companies face increasing pressure to phase out the use of traditional refrigerants such as R22 and increase efficiency.

In 1988, Japan enacted the Act for Protection of the Ozone Layer, which imposed limits on the production and consumption of R22 in Japan. A total ban on production and import of R22 went into force beginning in 2020.

In addition, Japan's subsidy scheme provided by the Ministry of the Environment has been a major driver of natural refrigerant systems in the industrial refrigeration sector.

In July 2017, the High Pressure Safety Institute of Japan (KHK) announced that CO₂ would be reclassified under Japan's High Pressure Gas Safety Act, meaning that several administrative requirements no longer applied to any manufacturer of CO₂ equipment with a daily refrigeration capacity under 20TR (70kW). This change opened the door for significantly wider adoption of larger CO₂ systems in Japanese industrial installations, where capacities are typically under 20TR (70kW).

As in the commercial sector, the CO₂ technology used by the industrial sector is mostly outdoor condensing units (OCUs) up to 100HP. Hot climates have not been a deterrent to CO₂ installations as, for example, Yoshio Ice Manufacturing and Refrigeration, has installed CO₂ in an area that reaches 35°C (95°F) in the summer.

Thus, transcritical CO₂ systems are increasingly seen as climate-friendly and energy-efficient alternative solutions in the Japanese industrial market.

The industrial market today

As of December 2023, there were an estimated **400** industrial sites (mostly cold storage) using transcritical CO₂ installations in Japan's industrial refrigeration sector, up **21%** from the 330 reported in 2021.

Major technology manufacturers such as Nihon Netsugen Systems (NNS), Mitsubishi Heavy Industries and Mayekawa have led this adoption trend in the past few years. For example, NNS reported installing 530 transcritical CO₂ condensing units at 180 projects in Japan as of October 2023. Other suppliers include Panasonic, Shibata, SCM Frigo and Nakayama.

There is increasing competition between transcritical CO₂ technology suppliers in the industrial refrigeration sector, as well as between CO₂ and ammonia/CO₂ secondary technology solutions. End-user case studies showing the costs and benefits compared to ammonia/CO₂ secondary technologies have made transcritical CO₂ increasingly competitive.

But NH₃/CO₂ systems still dominate the market share of natural refrigerant industrial installations. According to data from Japan Association of Refrigerated Warehouses (JARW) members in June 2022, cold storage facilities using CO₂ refrigeration accounted for only 4.2% of cold storage space, while those using NH₃/CO₂ (notably Mayekawa's NewTon ammonia/secondary CO₂ system and Mitsubishi Heavy Industries' system) represented 69.7%, and those employing liquid overfeed ammonia (a declining category) represented 25.6%.¹⁷¹

When it comes to installations of CO₂ systems in the industrial sector, cold-storage dominates with an estimated 90% market share, with the rest in food processing (tunnel freezing, beer brewing, margarine production etc.). However, in the past few years, system installations, such as around four CO₂ tunnel freezer systems provided by Takahashi Manufacturing and Nihon Netsugen Systems, and end-user awareness have begun to point to signs of growth in the food processing sector. Meanwhile, suppliers such as Mayekawa and Mitsubishi Heavy Industries have supplied a number of NH₃/CO₂ systems in this sector as well.

Figure 27: Transcritical CO₂ Installations in Japan

(as of December 2023)

7,800 Convenience Stores
585 Supermarkets
400 Industrial Sites

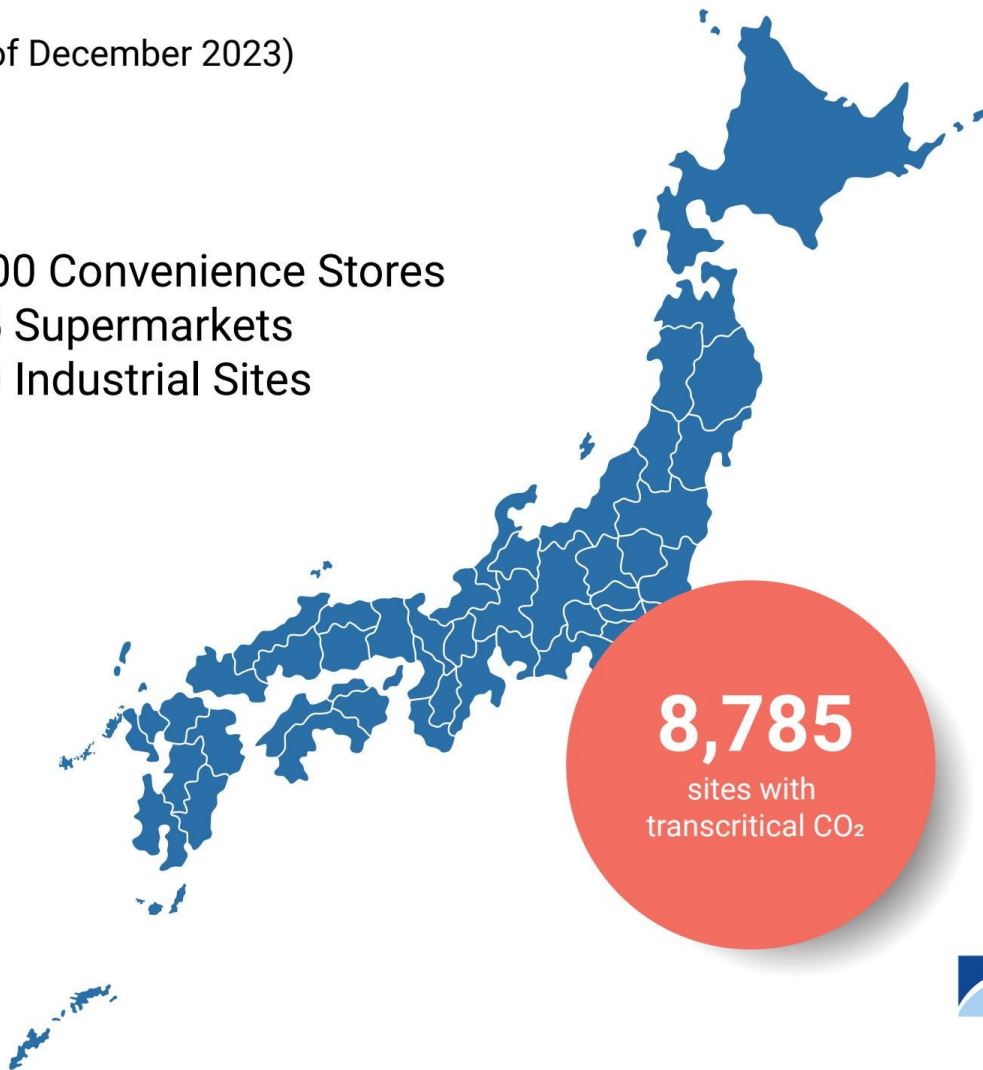


Figure 28: Transcritical CO₂ Commercial Refrigeration Market Penetration in Japan

77,026 food retail stores



10.9% transcritical CO₂ stores (all)

55,790 convenience stores*



14.0% transcritical CO₂ convenience stores

21,236 supermarkets**



2.8% transcritical CO₂ supermarkets

*Japan Franchise Association

**Japan Supermarket Statistics Survey Office

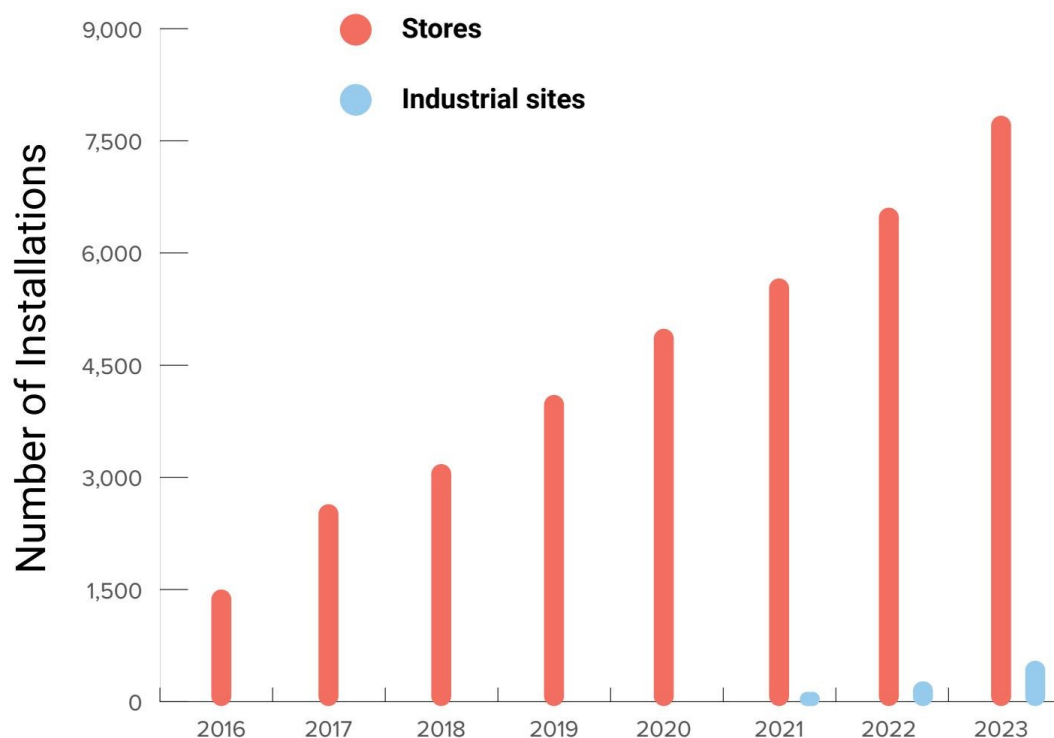
Figure 29: Transcritical CO₂ Installation Growth in Japan

(stores)

2021	5,800	2023	8,385
2022	6,630		

Figure 30: Transcritical CO₂ Historical Installation Growth in Japan

(stores and industrial sites)



Note: Prior to 2020, most installations were at stores.

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