

WORLD GUIDE TO TRANSCRITICAL CO₂ REFRIGERATION

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World Guide to Transcritical CO₂ Refrigeration

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WELCOME MESSAGE BY LEAD AUTHOR

As the use of transcritical CO₂ refrigeration systems increase at an exponential rate around the world, it has become apparent that there is a great need for reliable information from a neutral source. As such, sheccoBase, the “brain” behind shecco, has undertaken an extensive market study to analyze the current state of the global industry and various trends.

When we first started collecting data in 2008, we only counted 140 transcritical CO₂ systems – all of which were in Europe. Today, this number is well beyond 30,000 globally as the accelerated phase down of harmful synthetics drives the search for a more climate-friendly alternative. Most notably we have found that this technology is no longer only used in commercial refrigeration installations. More and more we are seeing success stories in small convenience stores and even larger industrial installations.

The number of transcritical CO₂ installations keeps growing as industry finds innovative ways to realize the potential of CO₂, even in warmer ambient climates previously thought incompatible with transcritical systems. Ice rink applications in particular are also becoming ever-more popular globally.

Thanks to extensive market research and data collection by the inhouse sheccoBase Market Development team, we are proud to present this “World Guide to Transcritical CO₂ Refrigeration.” Our hope is that it will serve as a resource to help drive the accelerated uptake of this highly sustainable and energy efficient HVAC&R technology. That is why it will be freely available, at no cost, as our contribution to help drive “clean cooling.”

The Guide will be published in three separate parts after which the entire combined resource will be

available for download online. Part 1 will look at CO₂ as a refrigerant, covering the history, policy measures and basic technical aspects related to this gas. It will also include a chapter on applications, showing case studies from around the world where transcritical CO₂ has been successfully deployed.

In Part 2, we will specifically look at convenience stores as well as commercial refrigeration installations, sharing market research and data regarding the number of installations worldwide and key market trends. Part 3 will cover industrial applications, as well as barriers and opportunities for the uptake of transcritical CO₂ systems, looking at the future market potential and trends.

Allow me a moment to thank our sponsors who have made this guide possible, many of whom have been key drivers of the uptake of natural refrigerants globally. Some of them will be sharing their expertise and experience by means of partner case studies and interviews, which will feature in Part 2 and 3 of the Guide.

Disclaimer: With technology moving so quickly, the numbers in this Guide might soon be out of date. Make sure to follow us online and on social media to get the latest updates on CO₂ and all other natural refrigerants too.



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ABOUT THIS GUIDE



Introduction

The use of CO₂ as a refrigerant began in early industrial times and has been revived in the past few decades. Just like other natural refrigerants (ammonia, propane, isobutane etc), it neither contributes to ozone depletion nor to global warming, making it a preferred choice in terms of climate friendly cooling technologies.

CO₂ is often preferred over other natural alternatives as it has no flammability risk and no toxicity issues. This has allowed it to thrive without fear of policy or standard interventions that so often stifle the growth of alternatives such as ammonia and/or propane. The only potential concern is the high operating pressures of a CO₂ system, but much research and development has gone into designing the modern systems of today to ensure that this can easily be accommodated.

It's clear that CO₂ is the rising star of the commercial food retail industry – particularly since the refinement of transcritical systems. In Europe especially it's become almost a “no brainer” to select transcritical CO₂ systems for any commercial retail project – new or retrofit. Not only does this ensure the installation is future proof and protected from inevitable synthetic refrigerant phase downs, but it usually also offers impressive energy savings over other refrigerants – curbing indirect greenhouse gas GHG emissions as well as direct ones.

However, CO₂ is no longer confined to just commercial installations. Even smaller convenience store end users are seeing the benefit of going the transcritical CO₂ route and despite a widespread belief that industrial systems are more the domain of ammonia; there is a clear rise in industrial CO₂ applications around the world.

The global HVAC&R market is changing, and it is crucial to keep with the latest industry trends and technologies. As such, this guide will specifically look at the potential of transcritical CO₂ – today and in the future. By sharing case study examples, technical information, policy updates, challenges, opportunities, and even actual figures on the amount of installations completed globally, the aim is to help accelerate the uptake of this climate-neutral, sustainable refrigeration technology around the world.

A SHORT OVERVIEW



CHAPTER 1: **Introduction to CO₂ as a refrigerant**

This chapter takes a look at the history of the use of CO₂ as refrigerant. It describes the key characteristics of CO₂, the types of available systems and the technical function of various components.

READ ON PAGE 10



CHAPTER 3: **Transcritical CO₂ today**

This chapter will give an introduction to our market research results and offer insight into the global transcritical CO₂ market today. It will look at the number of global installations and share general comments from our in-depth industry survey. It will also give an overview of policy and standards affecting the use of CO₂ as a refrigerant.

READ ON PAGE 50



CHAPTER 2: **Applications of transcritical CO₂**

This chapter shows examples of applications of transcritical CO₂ around the world, from its beginnings in commercial supermarkets to new convenience store and industrial applications as well.

READ ON PAGE 30



CHAPTER 4: **Convenience store (small) applications**

This chapter takes a closer look at the market for transcritical CO₂ in convenience stores today, including global market trends, partner case studies, and survey results. What is the potential of this technology for smaller systems?

READ ON PAGE 74



CHAPTER 5: **Commercial/supermarket applications**

What does the market for transcritical CO₂ in supermarkets and commercial installations look like today? We take a look at global market trends, partner case studies and share survey results to get a better picture of this.

READ ON PAGE 100



CHAPTER 6: **Industrial applications**

This chapter investigates the current market for transcritical CO₂ in industrial applications specifically with a look into global market trends, partner case studies and survey results relating to this.

READ ON PAGE 116



CHAPTER 7: **The future of transcritical CO₂ refrigeration**

Based on interviews, market research, and survey results, this chapter anticipates the global market potential for transcritical CO₂ technology, looking at its future uses and projected growth. It will also cover drivers and barriers for the uptake of this technology and include partner interviews on the topic.

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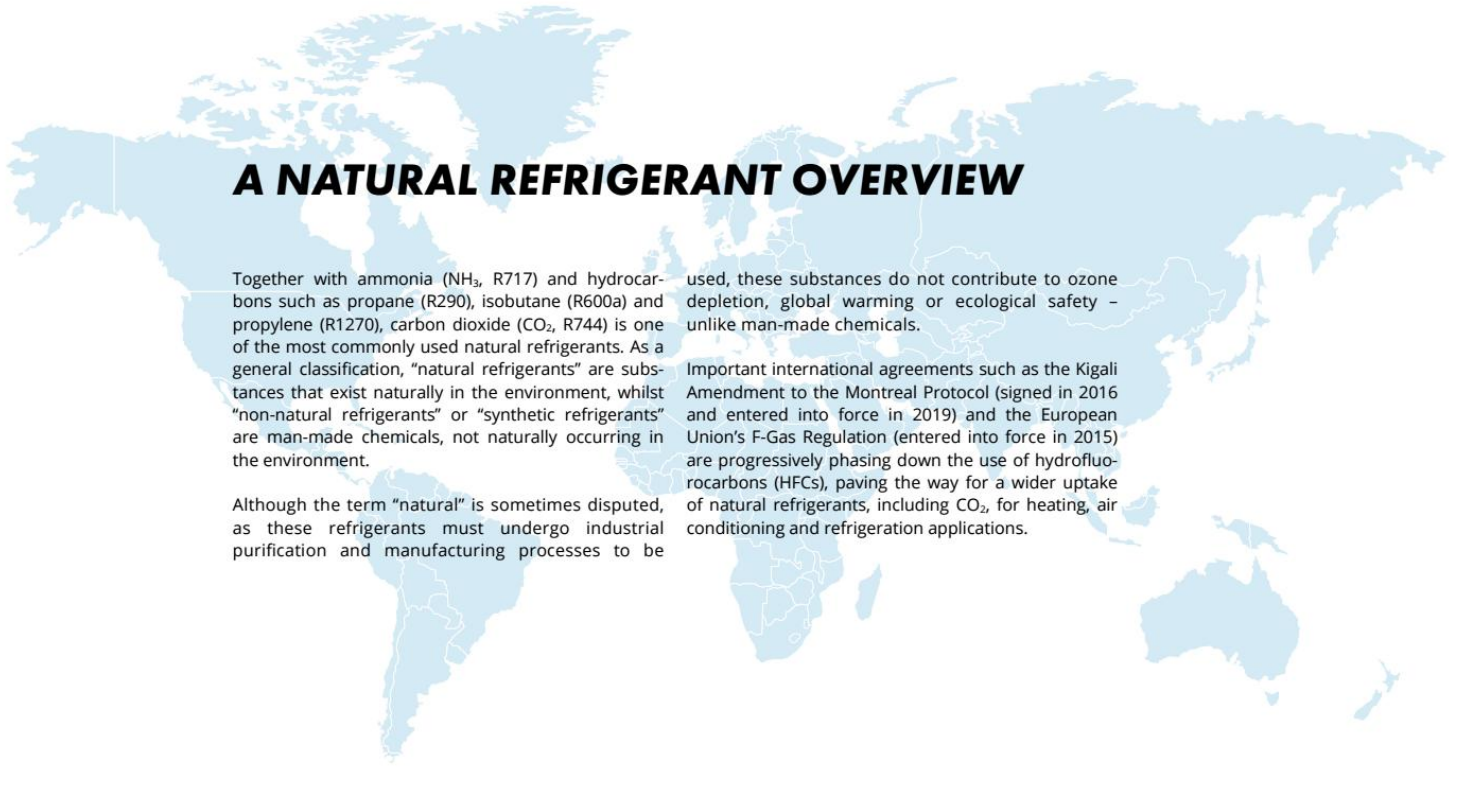
INTRODUCTION TO CO₂ AS REFRIGERANT



An overview

The first chapter of the guide seeks to provide the background needed to understand the transcritical CO₂ market today. By looking at natural refrigerants and particularly CO₂ as refrigerant, it is easy to understand what sets this gas apart from all other alternatives.

This chapter also includes a brief history on using CO₂ in HVAC&R, coupled with a rough timeline showing just how quickly this technology has developed over recent years. This section will also delve further into types of CO₂ systems (transcritical systems and others) and the function of key components, giving a basic understanding without getting too technical.



A NATURAL REFRIGERANT OVERVIEW

Together with ammonia (NH₃, R717) and hydrocarbons such as propane (R290), isobutane (R600a) and propylene (R1270), carbon dioxide (CO₂, R744) is one of the most commonly used natural refrigerants. As a general classification, “natural refrigerants” are substances that exist naturally in the environment, whilst “non-natural refrigerants” or “synthetic refrigerants” are man-made chemicals, not naturally occurring in the environment.

Although the term “natural” is sometimes disputed, as these refrigerants must undergo industrial purification and manufacturing processes to be

used, these substances do not contribute to ozone depletion, global warming or ecological safety – unlike man-made chemicals.

Important international agreements such as the Kigali Amendment to the Montreal Protocol (signed in 2016 and entered into force in 2019) and the European Union's F-Gas Regulation (entered into force in 2015) are progressively phasing down the use of hydrofluorocarbons (HFCs), paving the way for a wider uptake of natural refrigerants, including CO₂, for heating, air conditioning and refrigeration applications.

SHORT HISTORY OF CO₂ AS REFRIGERANT

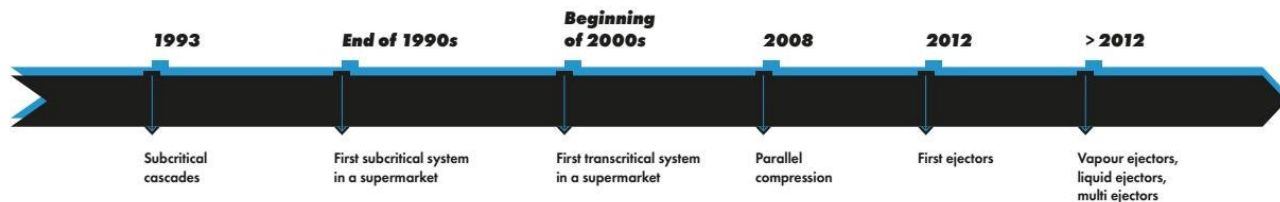
The use of CO₂ as a refrigerant dates back to the early industrial times. In 1850, Alexander Twining obtained a British patent for his "refrigeration machine" and proposed to use CO₂ as a refrigerant.¹ In 1860, S.C. Lowe built a CO₂ refrigeration system. In the years following 1860, CO₂ became more widely used. The peak in the use of CO₂ refrigeration systems occurred in the 1920s. In the 1950s, the last CO₂ systems were installed in marine applications,

before CO₂ was replaced by synthetic refrigerants.² Unlike ammonia, it did not survive the introduction of CFC and HCFC refrigerants³.

With the Montreal Protocol phasing out the use of ozone-depleting substances, CO₂ was rediscovered as an alternative³. The revival of CO₂ refrigeration technology happened in 1993 with the first subcritical systems being installed again.²

At the end of the 1990s, the first subcritical system was installed in a supermarket. At the beginning of the 2000s, it was the first transcritical system in a supermarket. Starting from around 2008, the introduction of parallel compression and subsequently ejectors led to a much higher adaptability of transcritical CO₂ in regions with high ambient temperatures.^{4,5}

INFOGRAPHIC TIMELINE OF KEY MILESTONES IN THE GLOBAL EXPANSION OF CO₂ USE



KEY CHARACTERISTICS OF CO₂ AS REFRIGERANT

Carbon dioxide (CO₂) is naturally occurring; and a colorless gas (or a solid) at atmospheric pressure, which makes up 0.04% of the Earth's atmosphere⁶.

It is a crucial part of life on Earth, as it is the main product of respiration and the main carbon source for plants during photosynthesis. CO₂ is non-flammable and non-toxic. However, a large leak in a confined space can displace available oxygen for breathing⁷.

Emissions of CO₂ from the combustion of fossil fuels lead to the greenhouse effect that is warming up the global climate. However, CO₂ is not the only, and certainly not the most potent, greenhouse gas. Moreover, CO₂ is used as a reference when determining the Global Warming potential (GWP) of other gases. Hence, CO₂ has a GWP of 1.

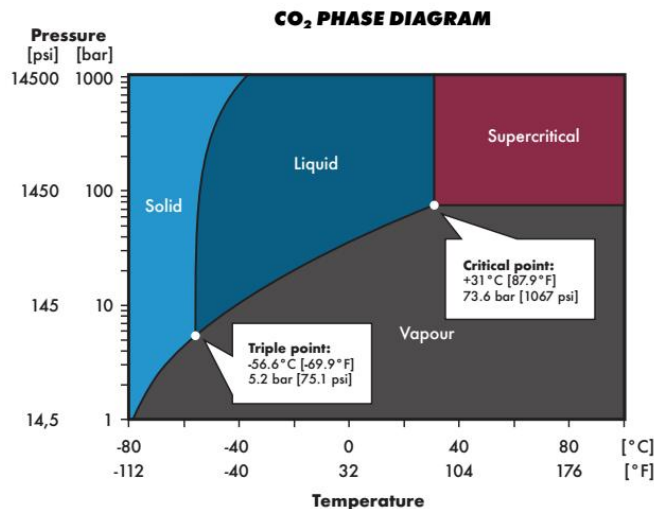
Another measurement of the environmental impact of substances such as refrigerants is the Ozone Depletion Potential (ODP). Synthetic refrigerants with chlorine compounds were found to contribute to the depletion of the ozone layer⁸. CO₂ does not have ozone-depleting characteristics and therefore has an ODP of 0.

CO₂ is classified as an A1 refrigerant, with low toxicity and low flammability⁷.

The phase diagram of CO₂ shows that at atmospheric pressure, CO₂ can only exist as a vapor, or as a solid at extremely low temperatures.

For any type of CO₂ (refrigeration) system, both the triple point and the critical point must be considered. The triple point is at 5.2bar [75.1psi] and at -56.6°C [-69.9°F] and this is where all three phases exist simultaneously in equilibrium. CO₂ can be employed as a refrigerant in a number of different systems including subcritical and trans-critical configurations. A classical refrigeration system is subcritical, meaning between triple point and critical point.⁹

CO₂ reaches its critical point at 73.6bar [1,067psi] and at 31.1°C [88°F], a relatively low temperature compared to other refrigerants. Beyond this point, it is in the "supercritical" phase, meaning that there is no clear distinction between the liquid and the gas phase. In refrigeration systems operating in ambient temperatures higher than 31.1°C [88°F], CO₂ is present as a supercritical fluid and is not able to condense.⁹



Adapted from Danfoss Handbook on Food Retail CO₂ Refrigeration Systems⁹



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The p-h diagram of any substance, such as CO₂, shows the phase of a substance at a specific pressure and enthalpy. Generally speaking, the more to the left in the diagram, the more of the refrigerant is in the liquid state. The isothermals show the corresponding temperature. Typically, enthalpy is in units of kJ/kg or BTU/lb.

An example of CO₂ in a subcritical process is shown in the following. In this case, the refrigeration cycle will not take place at temperatures higher than -5.5°C [22°F].

Operating pressures of subcritical systems are between 5.7bar and 73.6bar [82.7psi and 1,067psi], corresponding to a temperature of -55°C to 31.1°C [-67°F to 88°F]

(all in vapor state). A single stage subcritical system has some disadvantages, for example limited temperature range and high pressure.⁹

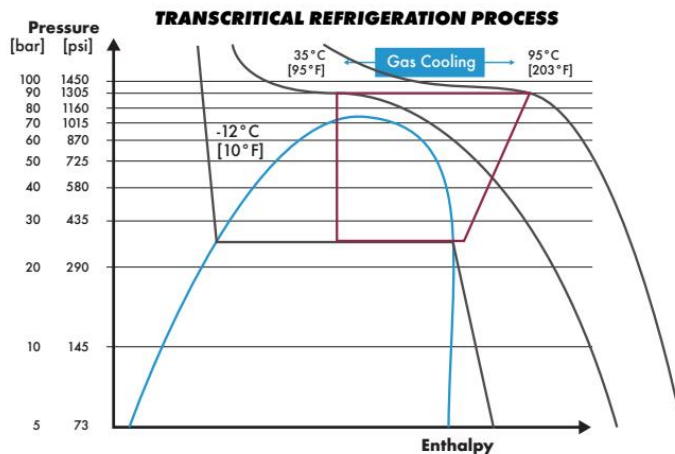
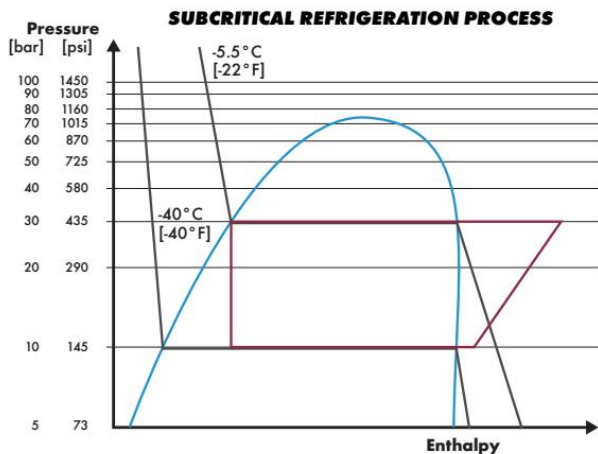
The pressure can be limited to such an extent that commercially available components like valves, compressors and controls can be used.⁹

The p-h diagram of CO₂ in a transcritical system shows that part of the process takes place in the transcritical mode. That is where gas cooling is used.

The process of heat rejection differs between a system that operates in subcritical conditions compared to one in a transcritical condition. In transcritical conditions,

the gas cannot condense, as there is no correlation between pressure and temperature, in contrast to a subcritical system. The function of the gas cooler is to reject heat just like a condenser. But it does so by decreasing the temperature of the gas, and not like in condensation, by phase changing (without changing temperature).¹⁰

Any direct CO₂ system can operate in subcritical and transcritical modes, depending on the ambient temperature. There is the possibility to force a system to operate in transcritical mode by design, but this is only desirable for heating applications, as shown in the following:¹⁰



Adapted from Danfoss Handbook on Food Retail CO₂ Refrigeration Systems



Carbon 4 Retail Refrigeration

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The Life-C4R project has received funding from the European Union under grant agreement n° LIFE17 CCMT/IT/000120. This publication reflects the author's point of view and therefore the Commission is not responsible for any use that may be made of the information contained therein.



It is part of
the **European
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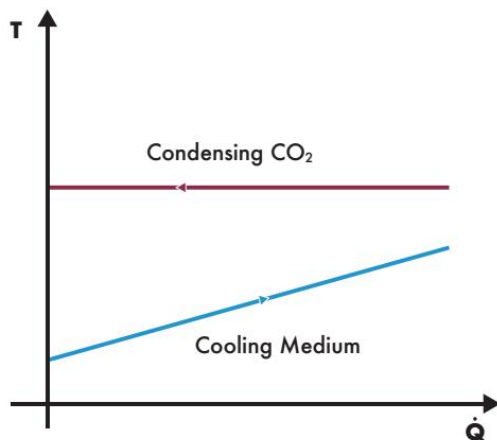
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Using CO₂ is advantageous because of its heat transfer properties.¹¹ In a supercritical fluid, pressure and temperature are no longer dependent on each other during the heat rejection process⁹. During a phase change, such as condensation, the temperature stays constant. In transcritical CO₂ systems, however, the temperature continuously decreases when CO₂ passes through the gas cooler⁹. The heat transfer between CO₂ and the cooling medium (water or air) works differently in subcritical and transcritical systems. In a subcritical system with a counter-flow heat exchanger, the

temperature difference between CO₂ and the cooling medium is the lowest at the outlet of the cooling medium (meaning inlet of CO₂). In a transcritical system, the pinch point, meaning the closest approach in temperatures between CO₂ and the cooling medium, is at the inlet of the cooling medium or between the inlet and outlet of the gas cooler (in the middle of the gas cooler).⁹ Therefore, it is possible to achieve very high temperatures using CO₂ for heating applications, with a cooling medium such as air or more commonly water.¹⁰

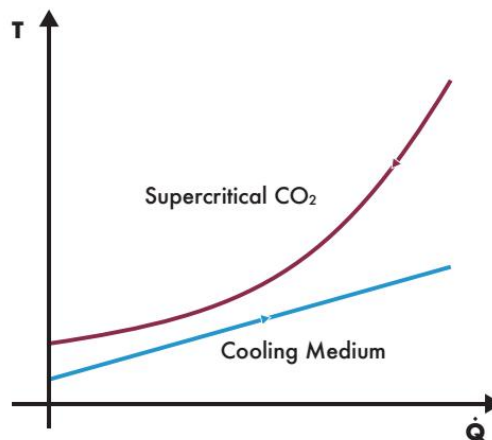
This relationship can be seen in the following figure(s), which shows temperature over heat flow during condensation and during gas cooling. The actual temperatures and pressures are dependent on the specific application. For the transcritical CO₂ curve, they might, for example, be between 35°C and 95°C [95°F and 201°F] (for the transcritical process shown in the p-h diagram).

CONDENSATION



Adapted from Santini, L. et al.¹²

SUPERCritical CO₂



During condensation, the temperature difference between the cooling medium and the condensing steam (here CO₂) is decreasing with increasing heat flow (of the CO₂ and cooling medium). This means that the temperatures approach each other with increasing quantity of heat over time. For transcritical CO₂, this is different – the temperatures approach each other the most between the inlet and the outlet of the gas cooler. With transcritical CO₂, relatively high temperatures can be reached in the refrigeration cycle, which can be used for heating applications, such as heating water or air.

However, the temperature at the gas cooler outlet mainly depends on the ambient temperature. The optimum pressure is not constant but depends on the temperature at the gas outlet.¹³

High ambient temperatures increase the temperature at the gas outlet and increase the pressure ratio to be overcome by the compressor, between suction and discharge pressure. This is the case for any refrigeration system.¹⁰

The additional problem for CO₂ is the flash gas generated. Flash gas is refrigerant in gas form produced spontaneously when liquid is subjected to boiling. Flash gas is generated in any refrigeration system during a pressure drop into the two-phase region. It does not contribute to refrigeration but still needs to be compressed. A pressure drop occurs at the expansion valve into the evaporator; and, in CO₂ systems, at the high-pressure valve into the receiver. However, systems using refrigerants other than CO₂ do not have a high-pressure valve (see Section [“Types of CO₂ systems and function of key components”](#)).¹⁰

Thus, flash gas is generated in CO₂ systems that are running in subcritical mode; but to a higher extent in systems in transcritical mode because of the higher quality of the CO₂ (high percentage of vapor) due to the higher gas cooler outlet temperatures. That is why it is desirable to go more into the liquid phase (“to the left in the p-h diagram”).¹⁰

Yet, there are many solutions available today in order to efficiently use transcritical CO₂ in regions with high ambient temperatures (see Section “Key components in a transcritical CO₂ refrigeration system”).

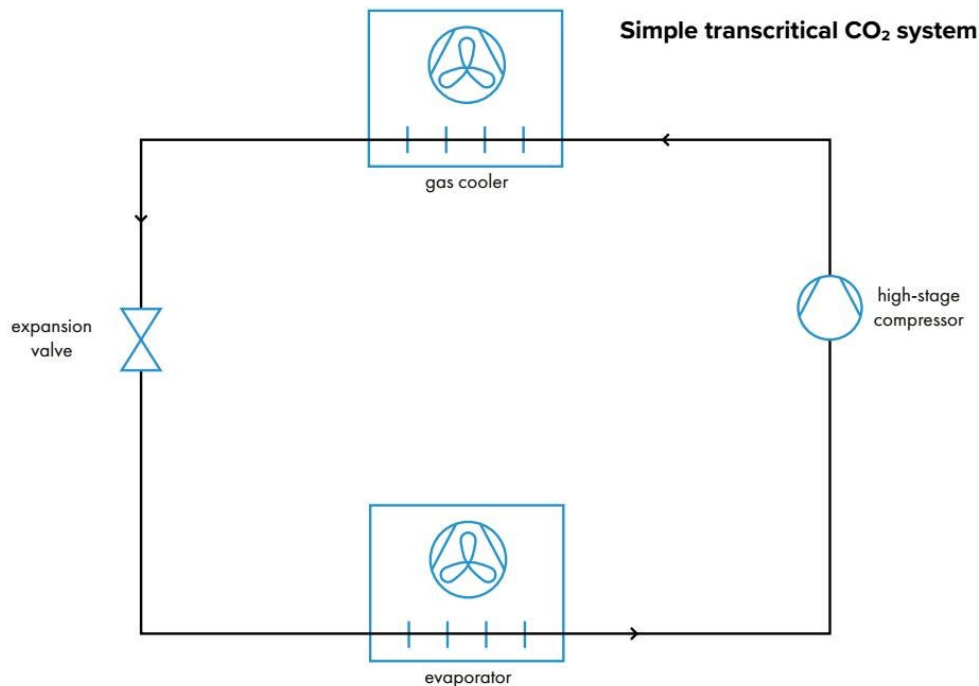
TYPES OF CO₂ SYSTEMS AND FUNCTION OF KEY COMPONENTS

In the following, different types of CO₂ systems are briefly described. They are the simple transcritical CO₂ system, single-stage system, simple booster system, cascade system and secondary/indirect system. The following CO₂ systems are able to operate in transcritical mode: a simple transcritical CO₂ system, a single-stage system, and a simple booster system. The cascade system uses CO₂ in transcritical mode only in rare instances and the secondary/indirect system only uses CO₂ in subcritical mode.

TYPES OF CO₂ SYSTEMS

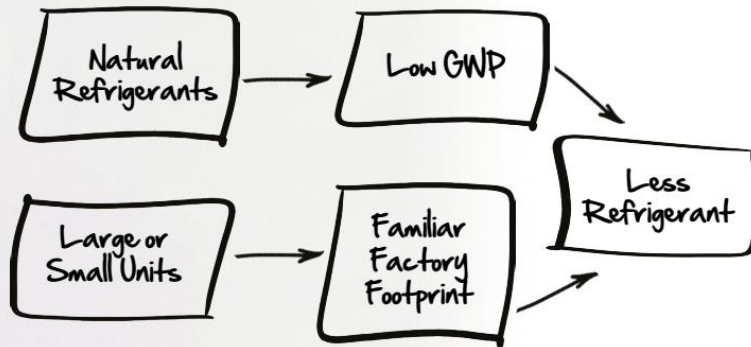
Simple transcritical CO₂ system

A simple transcritical CO₂ system is like a subcritical refrigeration system, only with a gas cooler in the place of a condenser. It is not being used, but for explanation, a schematic sketch is shown in the next figure.



Adapted from Guide by Emerson on Commercial CO₂ Refrigeration Systems¹⁶

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Single stage system

A simple single stage system is shown in the next figure (typically a CO₂ system doing MT refrigeration).¹⁰

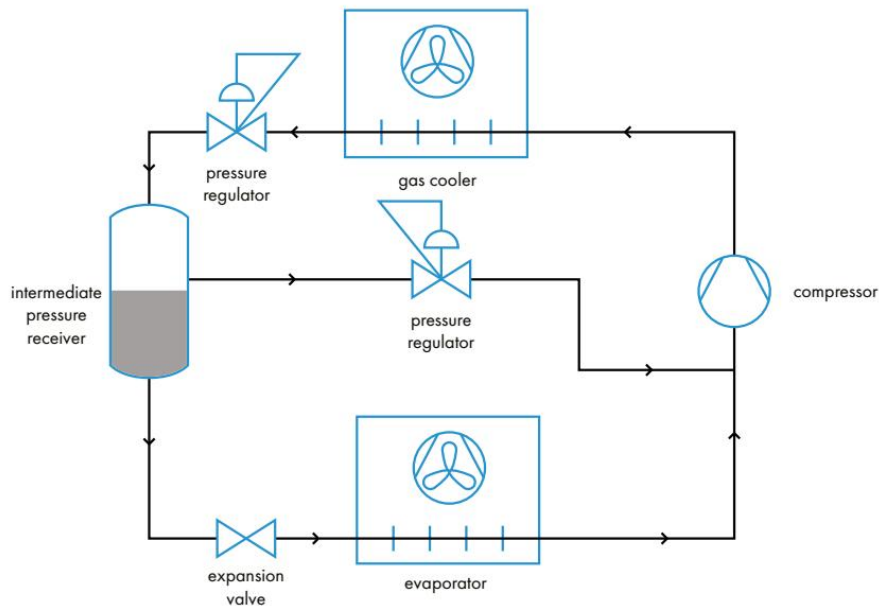
In a single stage transcritical system, the gas cooler pressure is controlled to provide either optimum capacity or optimum efficiency while maintaining the pressure below the maximum allowed at all times. The simple diagram shows how this pressure is controlled in a typical system with single stage compression.¹⁴

In a single stage transcritical system, there are two additional valves compared to a simple system. They control the gas cooler and the intermediate pressure receiver. The gas cooler pressure valve (also called the high-pressure regulating valve) controls the pressure in the gas cooler. It is a pressure-reducing valve, controlled by measuring two parameters — CO₂ pressure in the gas cooler and its exit temperature (exit/outlet of the gas cooler).¹⁴

The receiver pressure valve (also called the medium pressure regulating valve or the **flash gas valve**) controls the pressure of the refrigerant in the receiver and associated liquid distribution pipe work. It is controlled by one parameter, the pressure in the receiver. The receiver is also called a **flash tank**.¹⁴ Flash gas is generated when high pressure CO₂ undergoes a pressure drop into the receiver.¹⁰

The receiver separates the liquid phase from the vapor phase – the liquid is sent back to the evaporator and the vapor is sent back to the compressor.

Simple single stage system

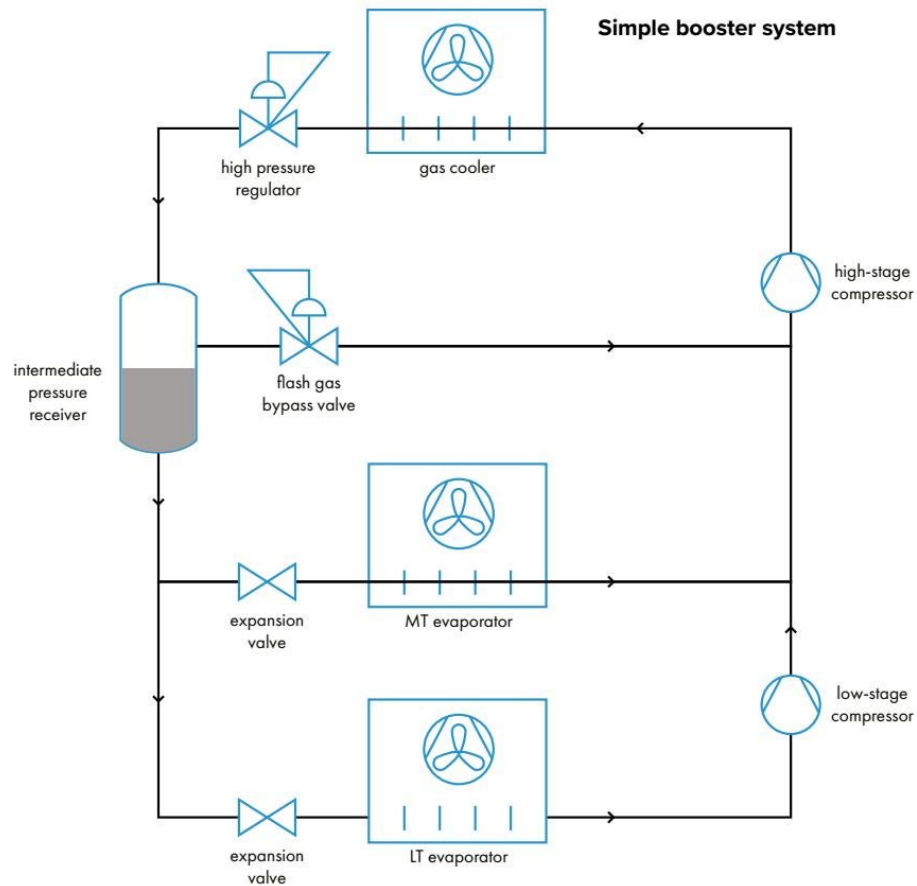


Adapted from Guide by Emerson on Commercial CO₂ Refrigeration Systems¹⁴

Simple booster system

Compared to single-stage retail systems, booster systems are quite commonly used, namely for MT and LT together. A booster system uses two-stage evaporation, for low temperature and medium temperature. Similarly, it uses two-stage compression, with low-stage and medium-stage compressors.^{14 10}

The two pressure regulating valves here are the same as in the simple single stage system; first the high pressure regulating valve ("high pressure regulator") regulating the gas cooler pressure, and then the flash gas bypass valve controlling the receiver pressure (receiver pressure valve).



Adapted from Guide by Emerson on Commercial CO₂ Refrigeration Systems¹⁴

Cascade systems

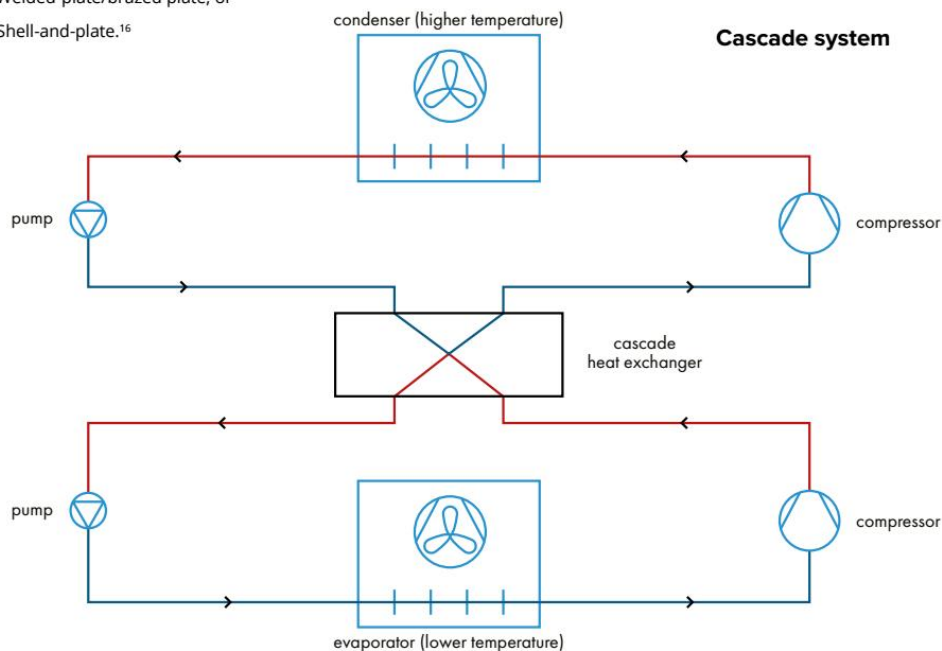
A cascade system uses a combination of two centralized refrigeration systems. The high temperature refrigeration system (ammonia, HFC, HC) cools the lower-temperature refrigeration system (usually subcritical CO_2).^{15 16} This means that the heat rejected by the condensing CO_2 is absorbed by the evaporating high-stage refrigerant¹⁴. The evaporator for the high-stage system is also the condenser for the low-stage system¹⁶. At the low-stage, CO_2 will always be in a subcritical state because the temperature and the pressure of the low-stage is controlled by the high-stage refrigerant¹⁵.

In some cases CO_2 is used in both stages; in low-stage in subcritical mode, in the high-stage it might be transcritical in high ambient temperatures.¹⁴

An advantage of cascade systems is that the pressure is lower compared to a refrigeration system that uses only CO_2 . In refrigeration systems employing only CO_2 , the low critical temperature of CO_2 of 31.1°C [88°F] causes the operating pressures to reach relatively high levels, particularly at high ambient temperatures. In order to limit the pressures, the high-stage refrigeration system provides the condensing for the low-stage CO_2 system and thereby limits the pressure, which would exist if only CO_2 was used in a typical refrigeration cycle.¹⁶

The type of heat exchanger used between the ammonia system and CO_2 system is known as cascade heat exchanger and can be constructed in a number of different ways:

- Shell-and-tube;
- Welded-plate/brazed plate; or
- Shell-and-plate.¹⁶



sheccoBase sketch

Secondary/indirect systems

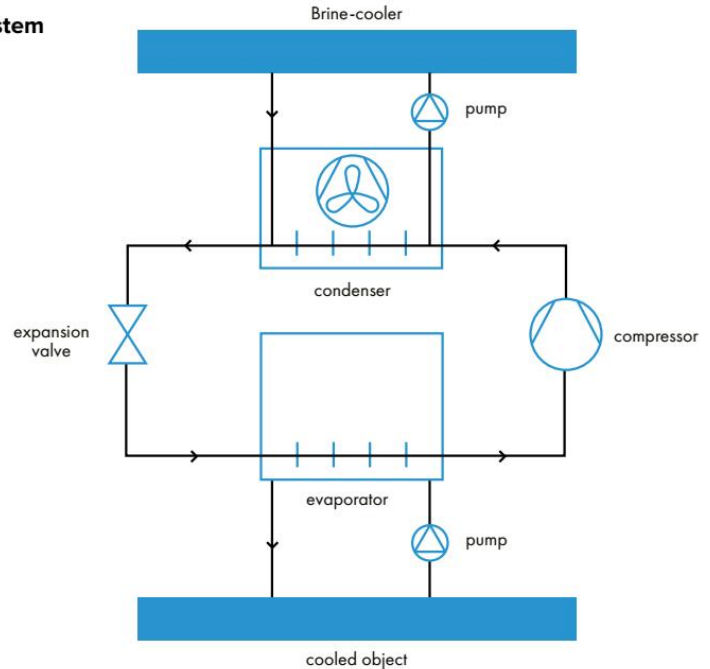
A secondary/indirect refrigerant system uses a centralized system to cool a secondary fluid (e.g. CO₂ in subcritical mode, secondary brine or glycol). The secondary fluid is pumped to each consumer. The consumers can be air coolers, processing equipment or glycol/chilled water heat exchangers. The primary refrigerant is confined to the machine room, so the primary refrigerant inventory is minimized, as are the risks to system personnel.¹⁷

*Principle of an indirect refrigeration system*¹⁸

The primary refrigeration cycle is shown in the center of the image. It contains all the required components – evaporator, compressor, condenser and expansion valve. The secondary refrigerant cycle on the lower side contains a heat exchanger between the refrigerated space and the secondary fluid and a pump to transport the secondary fluid from the refrigerated space to the evaporator.

The disadvantage of indirect systems is the additional heat exchange between the primary refrigerant and the secondary refrigerant. It leads to higher temperature differences between evaporation and condensation and thus higher pressure differences to overcome by the compressor; i.e. lower primary evaporating temperatures and higher primary condensing temperatures, or lower secondary condensing temperatures and higher secondary evaporating temperatures, due to losses in the heat exchange process.¹⁰ Furthermore, the pumping power necessary for circulating the secondary fluid reduces the energy efficiency. Using volatile secondary refrigerants such as CO₂ can reduce the pumping power required.¹⁶

Indirect system



sheccoBase sketch

KEY COMPONENTS IN A TRANSCRITICAL CO₂ REFRIGERATION SYSTEM

Valves

To minimize the risk of pressure buildup in the system, measures must be taken in system design to ensure that pressure cannot build up in any portion of the system. All components, valves, piping, fittings, and joining methods must be verified to ensure pressure ratings above the maximum anticipated system pressures.

Pressure relief devices must be located appropriately to allow the system to vent safely in the event of a system shutdown or other event that causes pressure above system ratings. All points within the system must be allowed to vent back to the pressure relief valves without restriction. Check valves are typically utilized to allow portions of the system to vent back to receivers, where pressure relief valves are located. Any portion of the system that cannot vent back to the receiver must have its own pressure relief valve.⁷

Stainless steel is currently the most used and can be adapted for transcritical operation. Only the material thickness has to be adapted in order to resist high pressures. Alternatively, copper-iron alloy piping can be used with an appropriate pressure rating.¹⁰

As the same system can operate in either subcritical or transcritical mode, depending on the conditions, higher quality piping needs to be used for all direct CO₂ systems. Only in cascade systems, lower rated piping can be used because the pressure is controlled there.¹⁰

Apart from the high pressure, a special characteristic of CO₂ systems is that the liquid line is cold (compared to conventional refrigeration systems where operating temperatures are much higher.) Sometimes the temperature on the liquid line goes down to -10°C [14°F] but often it is at around 0°C [32°F].¹⁹

Besides, the liquid lines in conventional systems are at condensing pressure that is higher than ambient temperatures. This means that conventional systems will have a heat loss from the liquid line; while in CO₂ systems, there will be a heat input to the liquid line.¹⁹ Hence, the liquid line of a CO₂ system has insulation whereas conventional systems do not need this.¹⁰ The heat loss in conventional systems will show as additional sub cooling, whereas it will show as **flash gas** in a CO₂ system. The flash gas will reduce the capacity of the expansion valve.¹⁹

However, the high pressure of the CO₂ system results in high-density gas and therefore a reduced capacity drop compared to other refrigerants.¹⁹

Compressors

Compressors need to be specifically developed for the use with CO₂, to withstand high pressures and to be adapted to operating conditions that are sometimes very demanding. There are also adapted lubricants.

Controls

Controls for a transcritical CO₂ system can be divided into four groups: gas cooler controls; receiver pressure controls; compressor capacity controls; and evaporator controls. In applications where heat reclaim is used, a number of control functions around the gas cooler have to be added.²¹

An important aspect in controlling the gas cooler is that in transcritical mode, pressure and temperature are no longer dependent on each other (see section on "[Key characteristics](#)"). Thus, they need to be controlled individually.²¹

Regarding compressor control, the standard settings are not always robust enough to ensure a safe and reliable control. This is because CO₂ is a more dynamic refrigerant than HFCs or others.²¹

Lubricants

Polyester (POE) lubricants have good miscibility with CO₂ and are predominantly used as compressor lubricants in retail CO₂ systems. Because of the high solubility (of CO₂), higher viscosity lubricants are used when compared to those used with HFCs. This reduces the effect of oil dilution by refrigerant and therefore maintains the lubricant properties.¹⁴

POE oils are very hygroscopic (i.e., they readily absorb moisture), so care must be taken to ensure moisture does not enter the system.¹⁴

Technologies to improve efficiency of transcritical CO₂ systems: Ejectors, parallel compression, sub-cooling and adiabatic cooling

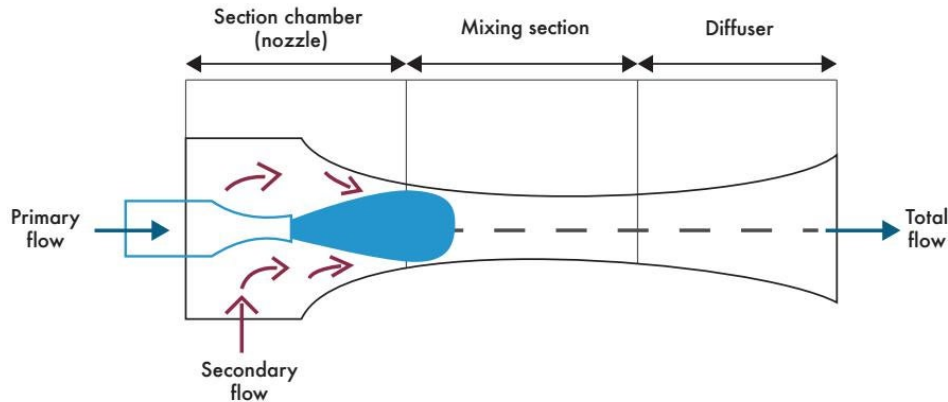
In addition to the different types of transcritical CO₂ systems, additional technologies like ejectors are being used in order to increase the efficiency of the systems. This is where most of the research and development is currently being done.

Today, there are many different types of ejectors, which are often patented by specific manufacturers. The use of ejectors has considerably increased the energy efficiency of transcritical

CO₂ refrigeration systems and made it more efficient to use them in regions with high ambient temperatures. The basic working principle will be explained in the following.

A typical ejector consists of a motive nozzle, a suction chamber, a mixing section, and a diffuser. The working principle of the ejector is based on converting internal energy and pressure related flow work contained in the motive fluid stream into kinetic energy.²²

SCHEMATIC OF A TYPICAL TWO-PHASE EJECTOR DESIGN



Adapted from Elbel, S. & Hrnjak, P. (2008)²²

In basic terms, an ejector is a way to re-use energy in the refrigeration system- by not expanding the refrigerant but keeping the pressure relatively high. The fluid coming out of the gas cooler is not expanded, so that the pressure can be kept high and less work is required for compression. The gas in the suction line of the main compressor (low pressure) and the fluid coming out of the gas cooler (high pressure) are mixed in order to get a mixed refrigerant at medium pressure.²³

More precisely, the primary flow is coming from the gas cooler, with the discharge pressure of the gas cooler, which is dependent on the ambient temperature and can be relatively high. The secondary flow is coming from the suction line of the MT side, with a relatively low pressure (because it has not been compressed). They are mixed to get the total flow. With this method, it is possible to increase the pressure of the total flow by a few bar, compared to the primary flow. Thus, the ejector is doing compressor work and creating a pressure lift.¹⁰

In a concrete example, the evaporation temperature is -5°C [23°F], corresponding to 30bar [435psi]. The discharge pressure is 70bar [1,015psi] and the pressure of the total flow will be 36bar [522psi] or receiver pressure, meaning the ejector causes a pressure lift of 6bar [87psi].¹⁰

Then, the flow goes into the receiver where the liquid is separated from the vapor phase; and the vapor phase will go into the parallel compressor.¹⁰

Other ways to increase the energy efficiency of transcritical CO₂ systems are parallel compression, evaporative condensation, (mechanical) sub-cooling and adiabatic cooling. Ejectors and parallel compression make CO₂ systems more efficient while operating in transcritical mode. Evaporative condensation, (mechanical) sub-cooling and adiabatic gas cooling decrease the outlet temperature of the gas cooler and therefore force the system to operate longer in subcritical mode, thereby making it more efficient.¹⁰

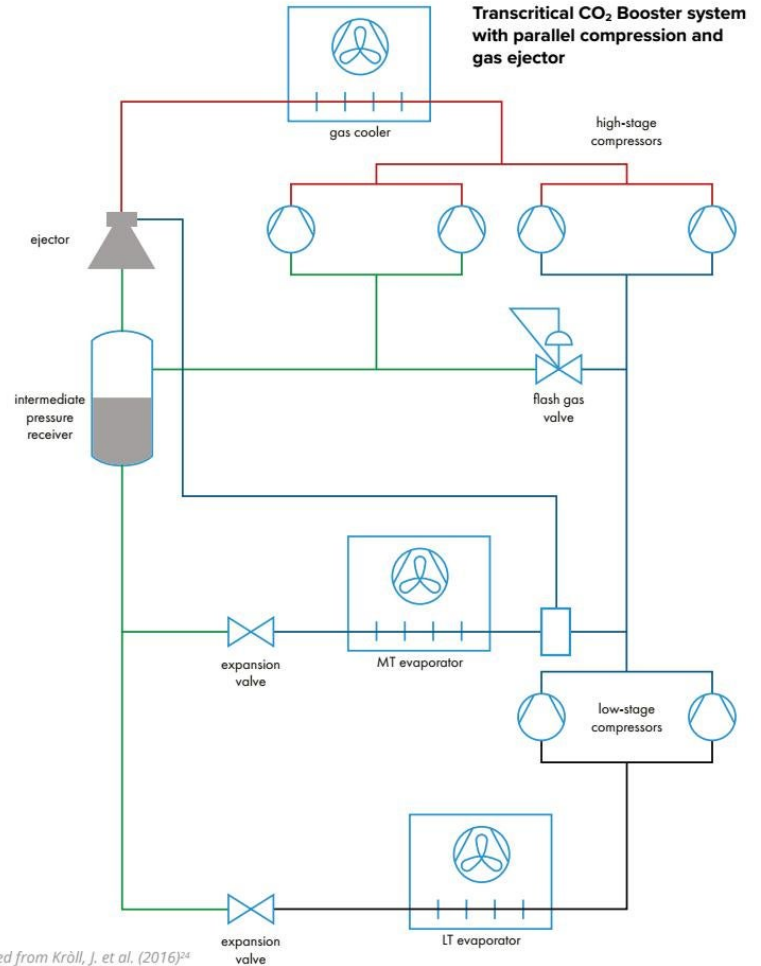
A sketch of a system with ejector and parallel compression is shown in the next figure. Each colored line indicates a different pressure level (from low to high: black, blue, green, and red).

Parallel compression is a solution that compresses the excess gas at the highest possible pressure level. It leads to a significant increase of COP in warm climates.²⁵

To explain it in more detail: Parallel compressors compress the flash gas coming out of the receiver from receiver pressure to discharge pressure, which is higher than the suction pressure. A flash gas valve would have sent the flash gas to the MT suction by dropping the pressure. The parallel compressors make the flash gas valve obsolete for operation in high ambient temperatures. The saving occurs because the flash gas is compressed from a higher pressure than usual when a flash gas valve is used.¹⁰

Evaporative condensation uses water to cool the gas in transcritical CO₂ operation. An adiabatic gas cooler works on a similar principle but allows for the use of less water (only when it is required).¹⁰

Mechanical sub-cooling uses an additional small refrigeration cycle coupled with the main refrigeration cycle in order to provide cooling at high temperatures.²⁵



Adapted from Kröll, J. et al. (2016)²⁴



APPLICATIONS OF TRANSCRITICAL CO₂



An overview

Transcritical CO₂ technology has been deployed in a variety of applications across the world for many years. From traditional supermarket applications to convenience stores and industrial cold storage applications; even on cruise ships and for ice rinks – there are hundreds of examples of successful installations globally.

The following pages showcase examples of a multitude of different transcritical CO₂ installations, varying in size and location, categorized by type of application. Whether in a small, convenience store type of installation, or the more conventional commercial retail one; even industrial projects – transcritical CO₂ is worth considering when designing an HVAC&R installation. Here is how others have done it...

SMALL STORE APPLICATIONS



CONVENIENCE STORES

¹Europe: European retailer Carrefour has installed a full-CO₂ transcritical remote unit at a Carrefour City store in Vannes, Brittany. Opened in October 2017 and located in the city center of Vannes, the store has a commercial surface of 293m² [3154ft²]. To save space for the refrigeration plant, Carrefour installed the refrigeration systems in the store's yard.

The transcritical CO₂ refrigeration system is a two-stage central unit with 22kW [6.3TR] of medium-temperature (MT) cooling and 2.2 kW [0.6TR] of low-temperature (LT) cooling. All refrigerated display cabinets are equipped with doors except the snacking segment. Carrefour has also installed doors on all refrigerated cabinets of the store, as well as LED lighting to increase the energy performance of the store.

²Europe: A Delhaize convenience store in the heart of Belgian capital Brussels uses two CO₂ condensing units. The two new CO₂ condensing units were installed in a franchised Shop & Go store on Boulevard Adolphe Max. The supermarket has a footprint of 250m² [2,691ft²] and opened at the end of June 2018.

One of the units serves the medium-temperature cabinets, and other serves the frozen food cabinets. They were commissioned in late June.

³Japan: In the framework of the convenience store (CVS) concept, Lawson has opened a CVS store that has 263m² [2,831ft²] and provides around 3,000 kinds of products. The CO₂ refrigeration system for this

store helps reduce the energy consumption by 20% in comparison to 2010's standard HFC system.

Half of the 20% energy savings is thanks to the CO₂ system and the other half due to energy saving features of new CO₂ showcases (i.e. sliding glass doors). LED lighting, improved thermal insulation, energy management system and electricity generated with installed solar panels contribute to planned total 50% energy saving of this store opened in February 2014. The system features one 10HP [7.5kW; 2.1TR] unit to provide MT cooling, two 2HP [1.5kW; 0.4TR] units to provide LT cooling and a bottle cooler with built-in CO₂ refrigeration system.

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COMMERCIAL APPLICATIONS



SUPERMARKETS/ RETAIL

U.S.: A 75,000ft² [6,968m²] Seed to Table Market, a refurbished Albertsons store that opened in December 2019 in North Naples, Florida, the most southeastern state in the U.S., has installed a transcritical CO₂ system. The system includes three rooftop adiabatic gas coolers, which helps the system function efficiently in the balmy climes of southwest Florida.

Having recently been installed, the energy usage of the transcritical system has yet to be assessed. But, despite the high ambient of North Naples, the energy consumption of the system as compared to that of a traditional DX system is “parity, probably using a little more.”

U.S.: Weis Markets, a Mid-Atlantic chain of 204 grocery stores, reported dramatic energy savings with transcritical CO₂ in 2019. The chain's first transcritical system consumed less energy than three other store systems during an 8.5-month test.

Weis's first transcritical CO₂ refrigeration system was installed at a 54,000 ft² [5,017 m²] store in Randolph, N.J., in July 2018. Its energy usage during that period was 250,790kWh [71,654RTh], substantially below the energy consumed by the other systems, all based on HFC or HFO refrigerants: 32% less than a 1.5-year-old secondary glycol/DX system, 39% less than a seven-year-old distributed rack system, and 86% below a 23-year-old centralized DX system.

The test period included August and September 2018, when high ambient temperatures, particularly during a two-week period, challenged the efficiency of a transcritical system. Yet Weis's unit consumed less energy during that period than the other systems.

Europe: An Italian supermarket chain is using groundwater as a cooling fluid to condense the CO₂ in a transcritical system in a remodeled store in Milan.

The 400m² [4,306ft²] remodeled store was officially opened in December 2019, after a two-month refurbishment period.

Using groundwater as a cooling fluid allows the system to run subcritically in the warm summer months and reduces the electricity consumption of the compressors. The groundwater used as a cooling fluid in the system is 15 to 20°C [59 to 68°F] warm year-round. This allowed to set a 25°C [77°F] condensing temperature in the system, using a plate heat exchanger. The use of groundwater, instead of air, to condense the CO₂, allows the system to run in subcritical mode even during the hottest summer months when the ambient air temperature is 27 to 28°C [81 to 82°F] or more.

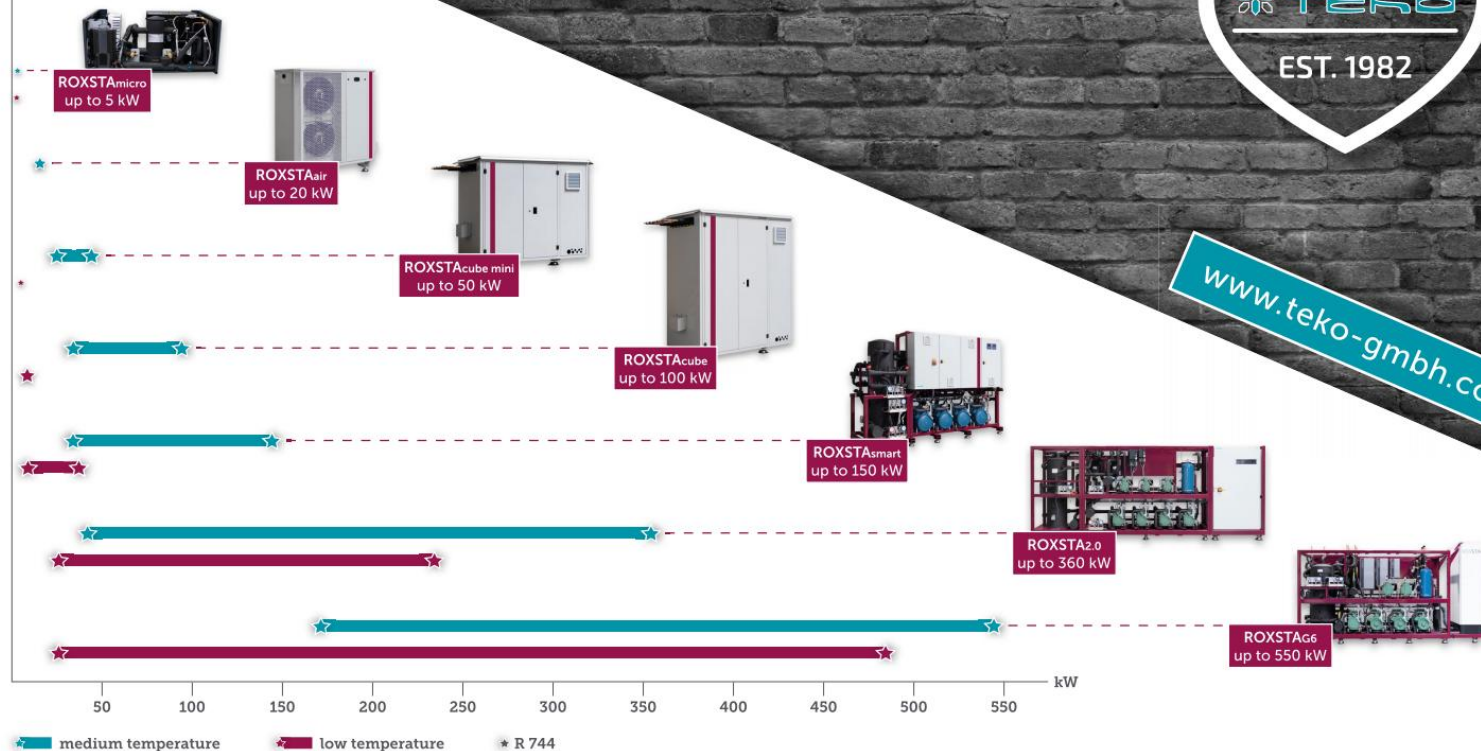
In the winter months the system is designed to run in transcritical mode to satisfy the supermarket's need for hot water. To achieve the needed hot water, the system

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employs heat recovery, which can recover up to 42kW [12.0TR] in winter, equaling "total" heat recovery, and increasing the system's COP to 4.2. The capacity of the Milan system is 30kW [8.5TR] for medium temperature, 6kW [1.7TR] for low temperature and 40kW [11.4TR] for high temperature (air conditioning).

***Europe:** Migros Ticino, a cooperative that is part of Swiss retail giant Migros, installed its first transcritical CO₂ system in 2009 already. Now the company, which operates 33 grocery stores among other businesses, has taken its commitment to natural refrigerants one step further and installed its first fully integrated CO₂ system at a store in Rizzino, Switzerland, in the Italian-speaking section of the country.

The system provides for the store's refrigeration, winter space heating and summer air-conditioning requirements. The transcritical CO₂ compressor rack has subcooling, heat pump and chiller sections, and works with two separate water tanks providing the secondary fluid for the HVAC requirements. The system has been tested down to -5°C [23°F] in winter and up to 42°C [108°F] in late June, meeting the store's needs in all conditions, according to Rossi.

***Europe:** German retail giant Metro recently replaced an inefficient, 20-year-old R404A refrigeration system at an outlet in Ruse, Bulgaria, with a transcritical CO₂ system equipped with ejectors – with zero downtime at the store. This was done in a move towards natural refrigerants and to save electricity. The transcritical CO₂ system is Metro AG's 18th with ejectors.

Metro's 7,000m² [75,347ft²] Ruse store opened in 1999 and was due for an upgrade this year to improve its overall efficiency. In only four months (from May until end August), the entire refrigeration system was replaced, and various other improvements were made, including the addition of glass doors to fridges to minimize openings and thus save energy. The new system will realize a projected electricity saving of a minimum 20% for cooling and more than 35% on heating, explained Schulze.

***South Africa:** Local retail/wholesale outlet Evergreens opted for a transcritical CO₂ refrigeration system in its brand new 22,000m² [236, 806ft²] store in Johannesburg, which opened in August. The new store boasts the largest transcritical CO₂ installation in the South African commercial sector – and one of the largest commercial systems in the world – with a refrigeration capacity of 1.9MW [540TR] serving 167 loads.

The main distribution board manages the racks as well as the evaporator coils. The racks, each with medium-temperature and low-temperature circuits, cool about 167 points, including various cold and freezer rooms, freezer and cold cabinets, and chillers. Loads range in temperature depending on the product, with the freezer rooms being kept at -20°C [-4°F], the citrus at 2°C to 5°C [36°F to 41°F], and the avocados and bananas at 14°C [57°F]. This is because if it is too hot, it will ripen fruit too fast, and if too cold, will make the fruit go black.

The estimated heat rejection is around 384kW [109.7TR], and this is used to heat water from 20°C to 55°C [68°F to 131°F]. Hot gas defrost has been included instead of the normal element heater that uses a lot of electricity.

¹⁰South Africa: In September 2018, food retailer Pick n Pay (PnP) opened its first transcritical CO₂ store, based in Milnerton, Cape Town. Today, it has 16 transcritical stores in South Africa (as per a presentation during ATMOSphere Cape Town 2020) with a projected 32 by end of 2020.

The booster system with parallel compression was manufactured locally and the rack is fitted with 10 compressors, four of which run the medium-temperature side, two doing parallel compression, three running the low temperature, and one satellite low-temperature compressor. The compressors are piped to four circuits: -36°C [-32.8°F] to the fish island freezer; -28°C [-18.4°F] to freezer cabinets and freezer store; and -8°C [17.6°F] to the medium-temperature cabinets. Two compressors are piped to provide parallel compression of flash gas. Included in the rack is a plate heat exchanger to reclaim heat for heating of hot water to 55°C [131°F], which is used for washing and cleaning in the bakery, butchery, food preparation areas, and for staff ablation.

¹¹Australia: Thanks to its natural refrigeration system, a significant reduction in carbon footprint is projected for the new IGA Supa retail and liquor store, which opened in Creswick, Australia in August

2019. “We will have a 47% reduction in our carbon footprint because we chose natural refrigerants over high-GWP refrigerants, and our emissions will be 6,209 CO₂e tons less per year,” said the owner. They also heat the store and produce hot water from the excess heat generated by the CO₂ system, further reducing costs and emissions.”

Other considerations that motivated the business case for a CO₂ system were cost savings, energy efficiency and future-proofing the store.

¹²Australia: A recently opened Woolworths Supermarket in Burwood, a suburb of Melbourne, Australia, is the first supermarket in the world to become associated with certification from the stringent Living Building Challenge (LBC) performance standard, in part by employing two transcritical CO₂ refrigeration systems and doors on all meat and dairy cases.

Three transcritical CO₂ refrigeration racks are being used by Woolworths in the shopping center, two for the supermarket's chillers and freezers, and one for the Dan Murphy's liquor store (part of the Woolworths group) located inside the center. Both systems include parallel compression. Doors have also been included on all meat and dairy cases, which will reduce the energy consumption by around 30%, by preventing cold air from spilling from the cases, noted Woolworths. Energy is also further reduced by use of waste heat from refrigeration to heat the store and switching off lights after hours.

¹³New Zealand: The Fresh Choice Papamoa and Countdown Hāwera food retail stores both opened in 2019, each with an energy efficient transcritical CO₂ system. With regards to energy efficiency and savings expected, both stores are expected to typically save “5% to 8% over a new, well-engineered equivalent HFC system.”

Countdown Hāwera in Taranaki is New Zealand's first «Be Accessible»-accredited supermarket, designed to be inclusive and accessible to everyone regardless of ability. Fresh Choice Papamoa, part of the Woolworths New Zealand group, boasts a unique heat reclaim system. Instead of having two heat exchangers on the rack, only one heat exchanger was used both for the hot water and the HVAC systems.

¹⁴South America: In 2019, Makro, a division of Dutch conglomerate SHV Holdings, has installed a transcritical CO₂ system at its new Valle del Lili supermarket in Cali, Colombia. With more than 3,400m² [36,597ft²] of sales space, the store has achieved Leadership in Energy and Environmental Design (LEED) certification thanks to the measures put in place to reduce water and energy.

The installation features a transcritical CO₂ refrigeration system with parallel compression. The cooling capacity is 130kW [37.1TR] on the medium-temperature side and 4kW [1.1TR] for low temperature.

As a special safety feature, the rack has been equipped with a controlled suction-gas super heater, which reduces the “oil throw” in the compressors and ensures the stable operation of the system, even if the cooling cabinets work under discontinued super heating. In addition, the installation includes a gas cooler (cooling capacity: 254kW/72.2TR), electronic expansion valves, and self-service doors – all to maximize energy efficiency and to reduce the store's carbon footprint.

¹⁵China: One of China's first transcritical CO₂ systems – installed in a remodeled store – has been installed in 2019. The transcritical CO₂ system was installed at a CSF Market store in Beijing in July 2018 as a part of a three-month store renovation project. The system replaced the store's old R22 system.

The transcritical CO₂ system installed at the CSF Market store includes a parallel-compression system. All the different configurations and technologies available for transcritical CO₂ systems such as ejectors, parallel compression and booster configurations, are directed towards gas cooler outlet temperature control. According to the manufacturer, the customer is very satisfied with the energy savings. The system deploys heat recovery, which made the system save energy compared to the former R22 system.

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INDUSTRIAL APPLICATIONS



REFRIGERATED WAREHOUSING/ COLD STORAGE

¹⁶U.S.: Hannaford, a Scarborough, Maine-based division of Ahold Delhaize, is one of the first U.S. grocers to employ a transcritical CO₂ system in a refrigerated warehouse. Hannaford's CO₂ warehouse also contains one of the world's largest refrigerated spaces (250,000ft²; 23,226m²) to use a transcritical system. The warehouse supplies 85 of Hannaford's approximately 190 stores in New York, New Hampshire, Vermont and Massachusetts.

Four transcritical racks are planned in what is a replacement of the warehouse's original, almost 30-year-old R22 system. Three of the racks are medium-temperature, two-stage, intercooled systems, while the low-temperature rack (the first installed) is single-stage, with ejector defrost.

¹⁷Japan: Japanese cold storage operator Hamamatsu Itaku Soko reduced energy use by up to 35% at one of its facilities after replacing an R22 system with a transcritical CO₂ system. In 2018, Hamamatsu Itaku Soko replaced a 22-year-old R22 system at its Yonezu Cold Center facility with the transcritical system. The cost of the installation

was supported by Japan's government subsidies for natural refrigerant systems. The old R22 unit was reaching its lifetime end after running for 22 years.

The R22 unit in 2017 consumed 854,898kWh [244,257RTh]. By contrast, in 2018, the CO₂ unit consumed 553,842kWh [158,241RTh], a drop of 35%, and in 2019, 562,417kWh [160,691RTh], a 34% reduction.

¹⁸Japan: Fukuoka-based Yoshio Ice Manufacturing & Refrigeration (Yoshio Ice) installed three Japanese-manufactured CO₂ transcritical systems at one of its cold storage facilities in April 2018. The region experiences some of Japan's hottest and most humid climates with temperatures sometimes reaching 35°C [95°F] during the summer months.

The three CO₂ transcritical systems service one 4,700m³ [133ft³] frozen storage room (at -25°C [-13°F]), as well as a 3,700m³ [105ft³] cold room (at 5°C [41°F]) and a 4,700m³ [133ft³] loading area (at 5°C [41°F]). The power consumption for the period from April to December 2018 was 27kWh/m³ [0.22RTh/ft³]-

less than what was predicted (around 35kWh/m³ [0.28RTh/ft³]), and far less than Japan's industry annual average of around 61kWh/m³ [0.49RTh/ft³].

¹⁹Australia: South Coast Stores, an Australian wholesaler in the remote town of Nowra, New South Wales, has opted for a transcritical CO₂ system that uses solar energy and employs the waste heat from the refrigeration system for hot water and heating requirements. The cold-storage component was commissioned in January 2019, followed by the retail space in February. Other refrigeration options, including ammonia and HFCs, were rejected.

The commercial viability of an ammonia plant versus a CO₂ plant with solar PV was found to be unattractive, and therefore a full CO₂ plant with booster and parallel compressors and an adiabatic gas cooler was chosen as the lowest-cost option. The CO₂ system provides 256kW [55.8TR] of total cooling capacity.

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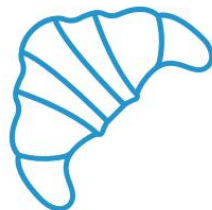
WINERIES AND BREWERIES

²⁰**Japan:** In Japan, transcritical CO₂ is experiencing an expansion into the sector of food production and food processing. Companies such as Asahi Breweries, which makes one of Japan's most well-known lagers, along with margarine production facilities and packaged ice manufacturers, are currently installing transcritical CO₂ refrigeration systems.

²¹**Europe:** High up in the picturesque mountains of South Tyrol, northern Italy, at the nine-centuries old Abbazia di Novacella/Kloster Neustift, two CO₂-based water-brine chillers serve a high-efficiency CO₂ transcritical system with gas coolers and heat recovery. Each of the chillers, installed in August 2017, has a cooling capacity of 60kW [17.1TR]. The two units are used to cool must when it increases in temperature

during the fermentation phase; at the same time, heat recovery produces sanitary water at 90°C [194°F] for cleaning the wine barrels. In the system, the water chiller, depending on the cooling load request from the air-conditioning system, generates cold water.

It can operate in several ways. In the first operating mode, it rejects the heat into the ambient air. A second operating mode is used when hot water is required. A three-way valve transfers the available heat to a water cylinder, and the mass flow of refrigerant bypasses the condenser/gas cooler. A third option is to reheat the water in the cylinder. Here the CO₂ passes through both the heat recovery heat exchanger and the condenser/gas cooler. In this manner, it is possible to produce sanitary hot water almost for free.



BAKERIES

²²**Europe:** The site of BACU Bakery in the Netherlands was equipped with its first transcritical flooded chiller. The cooling capacity is 550kW [157.1TR], the evaporation temperature is 1°C [34°F]. Propylene Glycol is used in the chiller and heat recovery is deployed for heating water.

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TTE - Technical specifications

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- Working range temperature: -10 / +160 °C (from 14 to 320 °F)
- Certifications and markings: CE for European market or UL for US & Canada market
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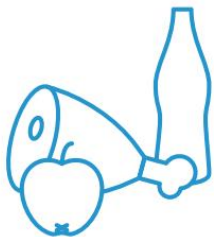
- Vertical / Horizontal receivers: RCO - RCL vessels, design pressure 130 bar, design temperature 120°C and different sizes and lengths (it can be equipped with additional & optional internal heat exchanger).
- Separators: the SEL and SED liquid separators with optional demister and different sizes and lengths for design pressure of 120 bar and temperature 130°C;
- Shell & tube heat exchangers: for gas coolers, evaporators and condensers, the WVECD and WTVECD models are both equipped with high-efficiency internal finned tubes, designed for a pressure up to 150 bar and temperature 160°C.
- Filter dryers: Klimal's FDR filter is suitable for solid core units and available for horizontal and vertical applications. The FDR filter is available with optional sight glass, and with different connection sizes.
- Mufflers: specifically for transcritical applications, the PGD pulsation muffler reduces noise.



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FOOD AND DRINKS PROCESSING



FOOD PROCESSING

²³South Africa: To meet an increase in the demand for their popular range of Mediterranean Delicacies branded products, BM Food Manufacturers opted to completely revamp their 18-year-old plant in Cape Town. The interior of the 1,200m² [12,916ft²] building, with its simplex R22 refrigeration units, was totally gutted. The new plant needed to meet EU standards, be energy efficient, and have minimal impact on the environment. In the processing of ready-to-eat soups and prepared meals, the refrigeration plant consumes the largest portion of power.

The new CO₂ plant has a trans-critical booster pack with parallel compressors. The pack has seven semi-hermetic compressors, all fitted with variable frequency drives (VFDs) for capacity control. Three compressors operate on the medium temperature (MT) circuit (-7°C [19°F]), two on the low temperature circuit (-32°C [-26°F]), and two provide parallel compression on the MT. The MT circuit maintains the temperature (0–4°C [32–40°F]) in five cold rooms, three double-blast chiller tunnels, and a blast chiller. Heat recovery is used to heat water to between 40°C and 45 °C [104°F and 113°F]. The LT circuit has a blast freezer that can also operate as -25°C [-13°F] cold room.



MEAT PROCESSING

²⁴U.S.: The world's largest transcritical CO₂ refrigeration system has been installed and commissioned at Yosemite Foods, a California-based pork and meat supply company. With a total cooling capacity of 4MW [1,137TR], it is the largest transcritical CO₂ refrigeration system installed globally. The company Yosemite recently relocated and expanded to the city of Stockton, where it opened a new 200,000ft² [18,580m²] meat processing facility.

It is here where five transcritical CO₂ refrigeration racks power the cooling needs for the facility's quick chiller, process water chiller and cold/freezer rooms. The system also employs heat reclaim to produce process hot water. In order to mitigate reductions in energy efficiency due to the plant's location in central California, where ambient temperatures can be high, the system uses adiabatic condensers and parallel compression.

²⁵South Africa: The new Meat World production facility in Springs boasts an energy efficient, state-of-the-art trans-critical CO₂ refrigeration plant that will raise the technology standard in South Africa. The heat load for

the system consisted of amongst others between 80 and 160 tons [79 imperial tons and 158 imperial tons] of fresh meat as well as 1,000 tons [984 imperial tons] of frozen meat passing through the facility daily. This all added up to a combined heat load of 840kW [240TR] for both the medium and low temperature applications. Additionally, the client required that the system could supply 10,000l [2,200gal] of hot water per hour as well as 2,000l [440gal] of chilled water for various factory and processing functions.

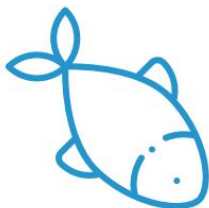
The final equipment offered and installed for the CO₂ system were as follows: Two outdoor multiple compressor rack plant rooms each handling half of the overall load to keep the system balanced. The following are specifications for each plant room: Racks capable of delivering 431kW [123.1TR] each to serve both medium and low temperature applications, each rack consists of eight compressors all equipped with service valves on the suction, discharge and oil side to allow for isolation if required, as well as pressure relief valves. Furthermore, the system is quipped with a vapor multi ejector.



FRUIT PROCESSING

²⁶South America: One of the leading fruit processing companies in Peru was recently supplied with a transcritical CO₂ system. Friopacking – an engineering and construction company specializing in food processing plants – was in charge of the installation, which took place in the city of Trujillo. The fruit-processing operator could not be identified without its permission.

The transcritical system serves 1,750m² [18,837ft²] of refrigerated storage, with a low-temperature capacity of 54TR [189.0kW], and a medium-temperature capacity of 21TR [73.5kW]. The control package keeps the system's COP at maximum levels at all times.



FISH PROCESSING

²⁷Europe: DFDS Logistics Ltd., a logistics and freight shipping company headquartered in Copenhagen, Denmark, announced in October 2019 that it had purchased 50 CO₂ refrigerated shipping containers to use in its short-sea (coastal) shipping service.

In addition to being in line with sustainability initiatives, the CO₂ shipping containers are helping shipping companies mitigate future business risks related to environmental regulations and technology phase-outs. According to the statement issued, DFDS has emblazoned each of its new 45ft [13.7m] containers with the slogan 'Naturally Chilled: No synthetic refrigerants – kinder to the environment'.

²⁸U.S.: Global Seas, a private fisheries management company based in Seattle, Washington, has installed

a CO₂-based refrigeration system using recirculated seawater on its F/V Northern Defender trawler. The system was chosen for its compactness and cost-effectiveness. The Northern Defender was built in 1979, and the original synthetic refrigeration system had become outdated, and needed replacing.

The Northern Defender, a 45m trawler fishing in the Bering Sea, off the Alaskan coast, needed a system that could keep up to 308,443kg [680,000lbs] of pollock fresh on the several days' journey back to port. For this, Highland Refrigeration built a 500kW [142.2TR] recirculated seawater (RSW) system that chills the catch with 0 to -1°C [32 to 30°F] seawater. The system had to fit into a space only 8m [26.2ft] long, 1m [3.3ft] wide, and 2m [6.6ft] high.

NICHE APPLICATIONS/ OTHER



ICE RINKS

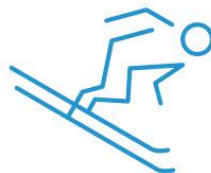
²⁹**Canada:** A transcritical CO₂ system for an outdoor ice trail was installed at the College Park section of Toronto, Canada. Opened in December 2019, the Barbara Ann Scott Ice Trail is an oval-shaped, 5m (16.4ft)-wide path that doubles for a walking loop in the summer.

The system's capacity is 50TR [175.0kW], which is enough HP to maintain the ice surface in all conditions, yet the piping and the CO₂ pumps are much smaller and more efficient than standard rink systems. According to the manufacturer's website, the system costs roughly half as much to operate as other options. In part that is because the CO₂ system is a direct system, making it more efficient than a secondary system. Instead of removing

heat at multiple steps, the refrigerant in this system goes straight to the ice floor, removes the heat from it, then uses the same refrigerant to carry it and remove it.

³⁰**China:** The Beijing 2022 Organizing Committee has officially announced its plan to use CO₂ refrigeration systems for several ice venues in the Beijing 2022 Winter Olympics. This will be the first time the technology is used in China and at the Olympic Games.

CO₂ systems will be used in «the Beijing 2022 speed skating, figure skating and short track venues, as well as the ice hockey training venues. R449 will be used in the ice hockey and curling venues.



SKI SLOPES

³¹**Europe:** In January 2020, Norway's first year-round indoor ski arena, named SNØ, opened in Lørenskog, just east of capital city Oslo. The snow for the venue is cooled by natural refrigerant CO₂. The arena is fitted with three transcritical racks and delivers 3.1MW [885TR] of cooling in what is the largest CO₂ transcritical installation in Norway.

The platform will maintain temperatures at -4°C [25°F] and be able to deliver temperatures as low as -12°C [10°F]. It integrates modulating vapor ejector technology as a standard feature to improve energy efficiency. It is asserted that the platform can deliver energy savings of up to 30% on an annual basis compared to standard transcritical CO₂ systems.

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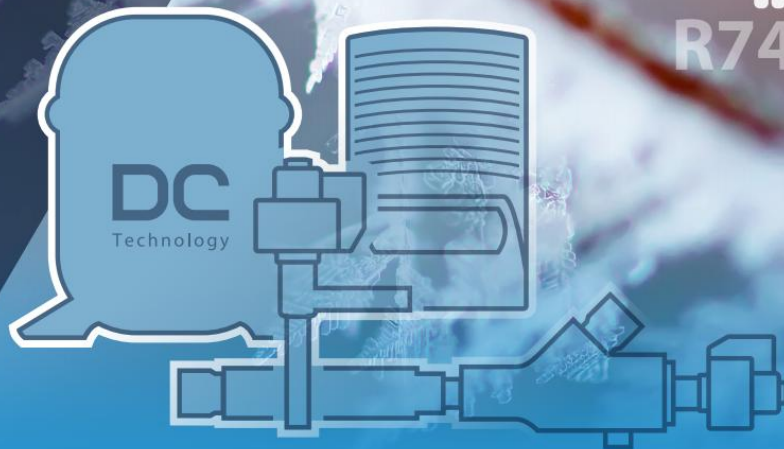
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CRUISE SHIPS

³²**China:** Two cruise ships in China are going to be equipped with a transcritical CO₂ refrigeration system. All food and beverage on the ships will be refrigerated with this system. They are the first two cruise ships ever to be built in China, according to the manufacturer of the CO₂ system. The first ship will be delivered in 2023.



FAST FOOD

³³**Europe:** U.S. fast food chain Burger King has chosen a transcritical CO₂ system as preferred condensing units for its restaurants in Spain. It marks the first time that Burger King has used CO₂ and it has since ordered more.

Spain has a warm climate throughout the year with temperatures reaching above 40°C [104°F] and so having the right and reliable refrigeration solution was essential. This system is designed to operate in warm temperatures and is using components that can handle 80 bar [1,160psi] service pressure and it can operate with ambient temperatures reaching up to 43°C [109°F].



PHARMACEUTICAL PROCESSES AND LABORATORIES

³⁴**Europe:** At the site of multinational biotechnology group in Basel, Switzerland, transcritical CO₂ is used for cold storage rooms for pharmaceuticals. A transcritical CO₂ double-stage system serves two cold rooms where most of the products are stored at -20°C [-4°F]. The cooling capacity is two x 71kW [20.2TR], with four compressors. The compressor capacity is 12.5kW [3.6TR]. A total of 110kg [242.lbs] of CO₂ per chiller are used. The system primarily runs in subcritical mode, harnessing groundwater to cool the CO₂ and improve the efficiency.



PRODUCT TESTING

³⁵**U.S.:** A new innovation/technology centre in Downtown Minneapolis where Jack Link's Beef Jerky tests new products has been kitted out with a transcritical CO₂ system. The system delivers a low-temperature capacity of 36.4K BTU/hr [10.7kW; 3.1TR] and a medium-temperature capacity of 575.5K BTU/hr [16.9kW; 4.8TR] to the 10,000ft² [929m²] processing area.

The transcritical system leverages heat reclaim to create hot water used to preheat the water required for the wash down of the processing area. A unique aspect of the Jack Link's project is that the CO₂ discharge gas is cooled in a heat exchanger by chilled (40°F-50°F/ 4.4°C-10°C) water provided via underground pipes by Clearway Energy's Energy Centre. The cooled water prevents the CO₂ system from ever entering transcritical mode, in which high ambient temperatures prevent the gas from condensing.



TRANSCRITICAL
CO₂ TODAY



An overview

This chapter provides a detailed look into the global transcritical CO₂ market today, including an overview of policy and standards affecting the use of CO₂ as a refrigerant.

By means of a rigorous data collection drive, as well as results from an in-depth industry survey, estimated figures for the global market share based on number of installations can be collated on an easy-to-read world map. The share per sector is also estimated for various key development regions.

Survey participants include representation from manufacturers, contractors and even end users to paint a well-balanced picture of the global transcritical CO₂ market and the most noticeable trends.

TRANSCRITICAL CO₂ AROUND THE WORLD

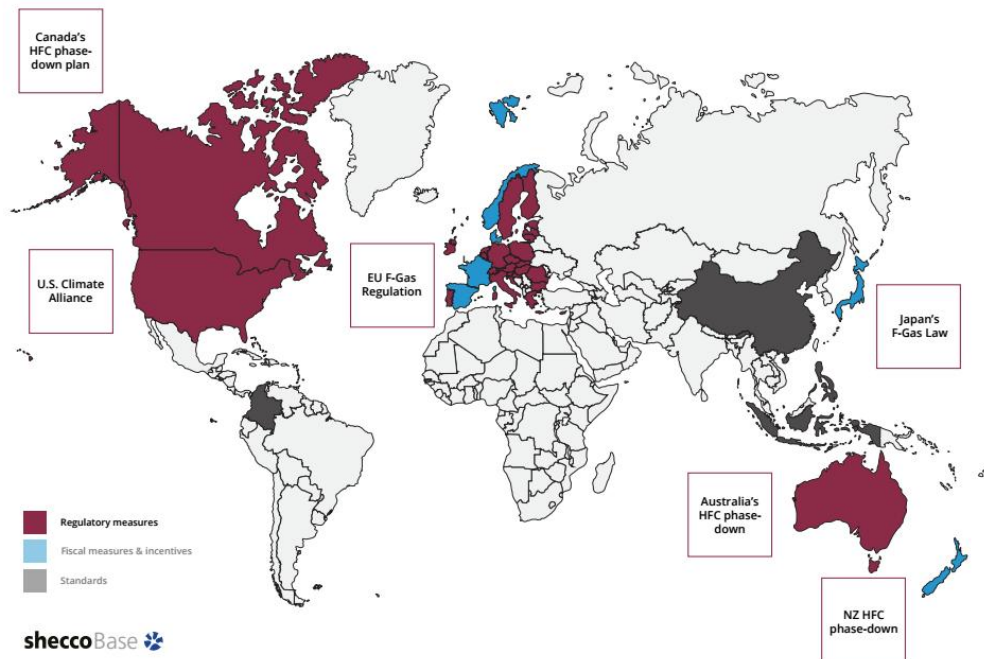
REGULATIONS AND STANDARDS

Globally, there are currently no legal uncertainties or restrictions concerning the use of CO₂ in refrigeration systems. This avoids costly replacements in the future.¹ However, there are safety requirements for working on-site and for the qualification and registration of technicians.

Under the Montreal Protocol on Substances that Deplete the Ozone Layer – an international treaty designed to protect the ozone layer – the world's economies agreed to phase out production and consumption of ozone depleting substances by 2030, with an earlier deadline of 2020 for developed countries.

The Kigali Amendment to the Montreal Protocol – which aims to phase down the use and production of HFCs globally and which entered into force on January 1, 2019 – is accelerating the uptake of natural refrigerants, including CO₂. Ninety-three (93) countries plus the EU have ratified it (as of June 2020). However, this number is every changing as more countries pledge their commitment to drastically scale down the use of HFCs.

In addition, energy efficiency in the HVAC&R sector is increasingly being scrutinized at a global level. Spurred by the Paris Agreement reached among nearly 200 countries at the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), the Parties committed to set climate and energy targets to keep the global temperature rise below 2°C [3.6°F], while pursuing efforts to limit it to 1.5°C [2.7°F] (compared to preindustrial levels) by 2100.



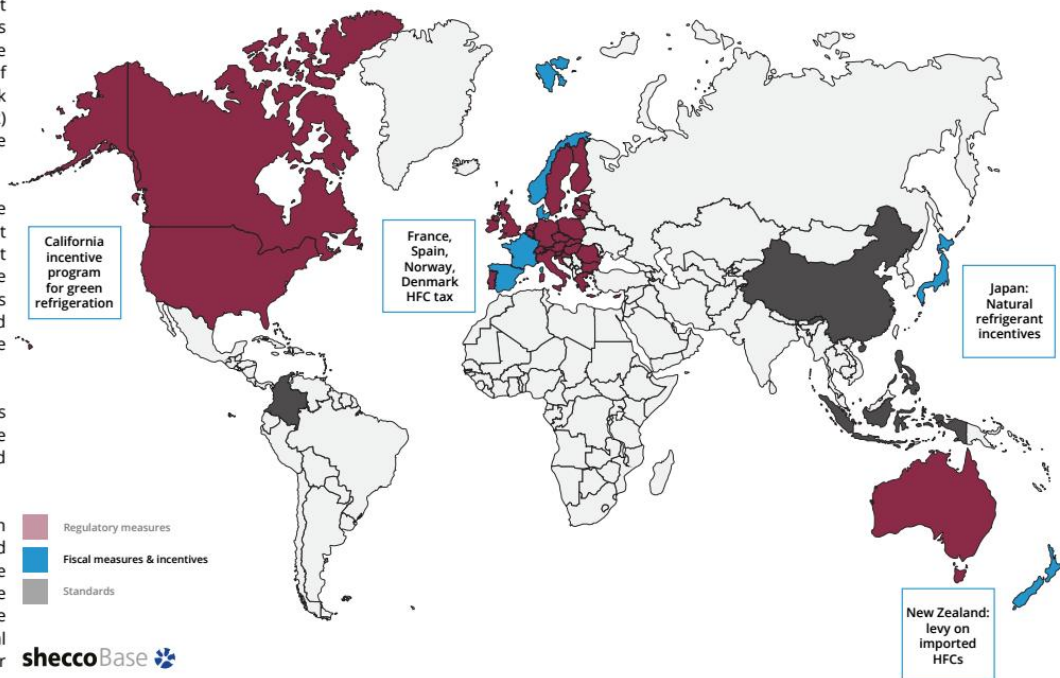
EU

The 2014 EU F-Gas Regulation (No. 517/2014) is set to phase down the use of HFCs, by 79% by 2030. It has a significant impact on users of HFC refrigerants and has led to a rapid growth in HFC prices. There are also various bans in place. For example, as of 2022, HFCs (GWP > 150) are prohibited in multipack centralized refrigeration systems (>40kW/11TR) (except in primary refrigeration circuit of cascade systems where GWP > 1,500 may be used).

The EU F-Gas Regulation also provides for leakage prevention during use and refrigerant collection at disposal. All technicians working on equipment that contains or is designed to contain f-gases require an f-gas handling training qualification. Activities under the scope include refrigerant recovery and decommissioning, as well as installation, leakage checking, and maintenance or servicing.

The regulation makes it very clear that the f-gases must be recovered or transferred to an appropriate greenhouse gas container when they are removed from the equipment.

Furthermore, there are additional restrictions in national legislation of some European countries; and some countries have introduced or will introduce an HFC tax. Countries with an HFC tax in Europe are Denmark, Norway and Spain. France's 2019 Finance Bill, published on December 30, 2018 in its official government journal, confirmed that HFC tax will enter into force as of January 1, 2021.²



U.S.

Section 608 of the U.S. Environmental Protection Agency (EPA)'s Clean Air Act establishes the National Recycling and Emission Reduction Program. The Clean Air Act (CAA) defines the EPA's responsibilities for protecting and improving the nation's air quality and the stratospheric ozone layer. Section 608 establishes the National Recycling and Emission Reduction Program. Section 608 prohibits individuals from intentionally venting ODS refrigerants (including CFCs and HCFCs) and their substitutes (such as HFCs), while maintaining, servicing, repairing, or disposing of air-conditioning or refrigeration equipment.³

On a federal level, the U.S. Senate has not yet ratified the Kigali Amendment, despite widespread industry support for ratification. It is still waiting for a referral from the Trump administration. Furthermore, the EPA has recently taken leakage-repair rules for HFCs from 2016 back.⁴ However, states are taking their own initiatives and making their own regulations. The United States Climate Alliance is a bipartisan coalition of 25 governors committed to reducing greenhouse gas emissions consistent with the goals of the Paris Agreement.

The Alliance represents 55% of the U.S. population and an US\$11.7 trillion economy – an economy larger than all countries but the United States and China. The climate and clean energy policies in Alliance states have attracted billions of dollars of new investment and helped create more than 1.7 million clean energy jobs, over half the U.S. total.⁵

The states that have passed legislation to adopt HFC use limits are: California, New Jersey, Washington, Colorado, Virginia and Vermont. States that are part of the U.S. Climate Alliance and that have committed to, or are in the process of, adopting HFC use limits are: Hawaii, Oregon, Connecticut, Delaware, Maryland, New York, Rhode Island, Massachusetts, Pennsylvania, and Maine.⁶

Other U.S. Climate Alliance States are Illinois, Michigan, Minnesota, Montana, Nevada, New Mexico, North Carolina, Wisconsin and Puerto Rico.⁴



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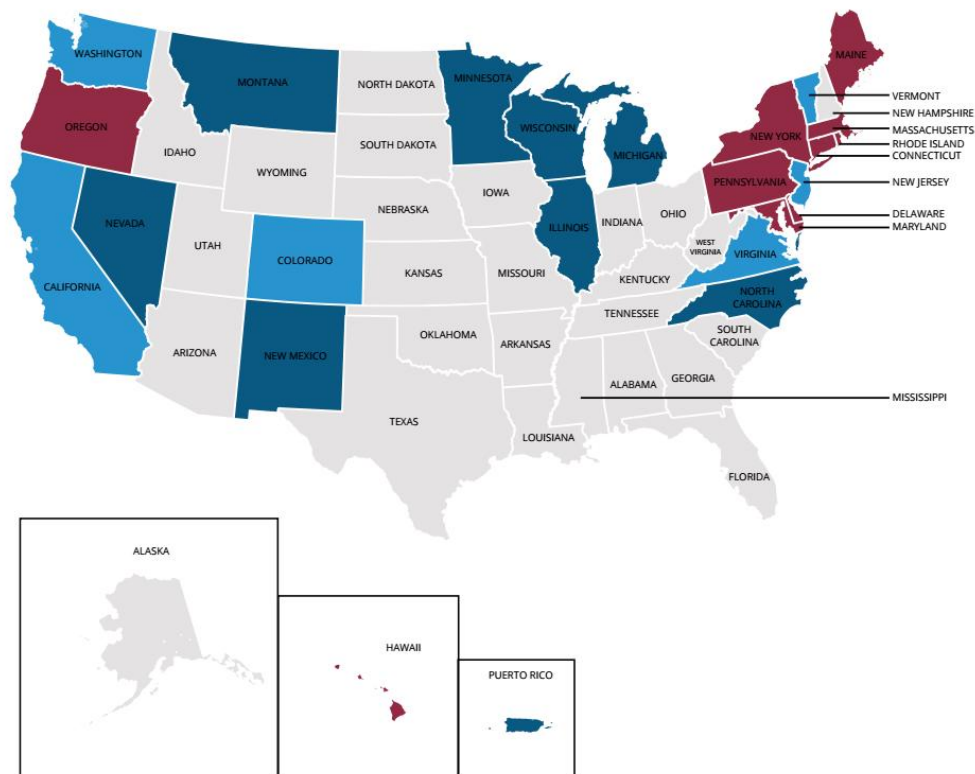
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U.S. STATES ENACTING HFC-REDUCTION REGULATIONS



Group 1

U.S. Climate Alliance States that have passed legislation to adopt HFC use limits based on U.S. EPA SNAP rules 20 and 21: California, Colorado, New Jersey, Washington, Vermont, Virginia.

Group 2

U.S. Climate Alliance States that have committed to, or are in the process of, adopting HFC use limits based on U.S. EPA SNAP rules 20 and 21: Hawaii, Oregon, Connecticut, Delaware, Maryland, New York, Rhode Island, Massachusetts, Pennsylvania and Maine.

Group 3

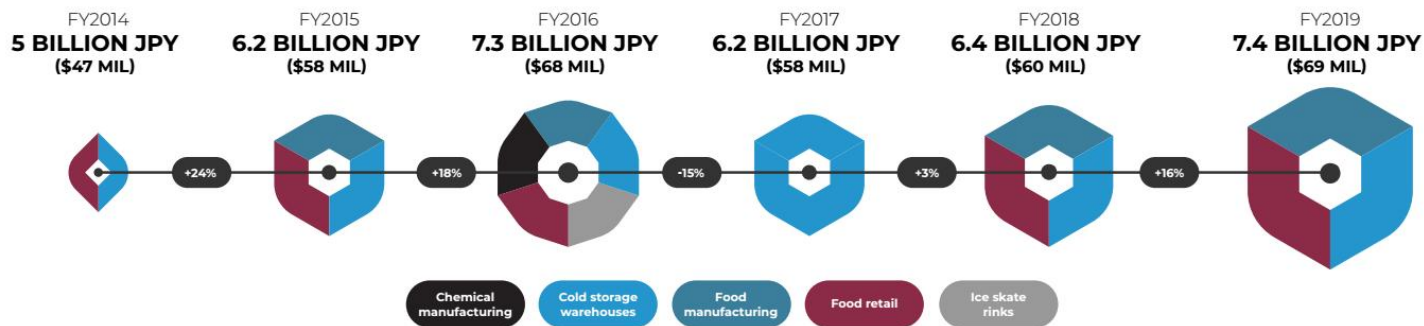
Other U.S. Climate Alliance States: Illinois, Michigan, Minnesota, Montana, Nevada, New Mexico, North Carolina, Wisconsin and Puerto Rico.

Note: The EPA abandoned SNAP Rules 20 and 21 following U.S. Court of Appeals rulings stating that the rules were not supported by federal law.

JAPAN

In Japan, government incentives play a big role in the growth of transcritical CO₂ in all applications. On July 25, 2017, the Japanese government eased restrictions on CO₂, opening the door to the wider adoption of large CO₂ systems in the Japanese market (update of High-Pressure Gas Safety Act). Before, this law had restricted the use of CO₂ in large refrigeration systems, subjecting manufacturers to heavy administrative burdens. This easing of regulations is creating new opportunities for overseas CO₂ system and component suppliers.⁷

A major growth factor for CO₂ stores and NH₃/CO₂ in industrial refrigeration is the renewed subsidy scheme for natural refrigerants running from 2018-2022. The five-year subsidy project helps end users reduce the capital cost of natural refrigerant technologies – including transcritical CO₂ installations. This scheme targets the food retail and food manufacturing sector as well as cold storage facilities. In the financial year 2018 (FY2018), the scheme operated with a budget of ¥6.4 billion [EUR47 million], while in FY2019 it increased to ¥7.4 billion [EUR58 million].



OCEANIA

Australia ratified the Kigali Amendment in 2017⁸; New Zealand ratified it in October 2019⁹, thereby committing to start phasing down HFCs. The aim is to reduce HFC consumption by 85% by 2036 in line with obligations under the Amendment. This will be achieved by gradually reducing the maximum permitted amount of bulk HFC imports.

In November 2019, New Zealand also passed the Zero Carbon Bill, committing to reduce its carbon emissions to zero by 2050.¹⁰

On July 1, 2013 the Synthetic Greenhouse Gas (SGG) Levy for goods and vehicles was introduced in New Zealand. The SGG Levy rates vary depending on the gas used, type of equipment or cooling capacity.

These regulatory measures have been adding pressure in this region to switch to more climate-friendly alternatives such as transcritical CO₂.

OTHER: NATIONAL COOLING PLANS

Other big industrial nations such as China, India and Russia have not ratified the Kigali Amendment yet.⁶ However, there are National Cooling Action Plans, such as in China and India. These have been a key driver of natural refrigerant solutions such as transcritical CO₂.

The China Cooling Action Plan sets forth targets for cooling-product energy efficiency improvement by 2022 and 2030. The Plan also describes key cooling-related priorities for China, including:

- Strengthening energy efficiency standards;
- Expanding the supply of green and high-efficiency cooling products, including through increased R&D on low-GWP and high-efficiency refrigerants;
- Promoting green and high-efficiency cooling product consumption, including through government and enterprise green procurement;
- Deepening international cooperation, including on HFC phase down pursuant to the Montreal Protocol and on the promotion of green and high-efficiency cooling for all, in both domestic and export markets, through mechanisms such as the Belt and Road Green Cooling Initiative.

The China Cooling Action Plan also calls for strengthened compliance accountability in the area of cooling energy efficiency, including through enforcement spot checks, and the release of compliance information through national credit information public disclosure platforms.

India's Cooling Action Plan was released on March 8, 2019 and sets goals of reducing by 2037-38:

- Overall cooling demand by 25%
- Cooling energy requirements by 25%
- Refrigerant demand by 30%

Furthermore, it seeks to certify 100,000 service sector technicians by 2023.



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INSTALLATIONS MAP

shecco conducted a data collection during the first half of 2020 with manufacturers of CO₂ refrigeration systems (original equipment manufacturers, OEM). The aim was to quantify the number of transcritical CO₂ installations worldwide. The companies were asked how many transcritical CO₂ installations they have completed to date. Furthermore, they were asked to differentiate

between the applications convenience stores (<400m² [4306ft²]), supermarkets (>400m² [4306ft²]), industrial refrigeration installations; ice rinks; and data centers.

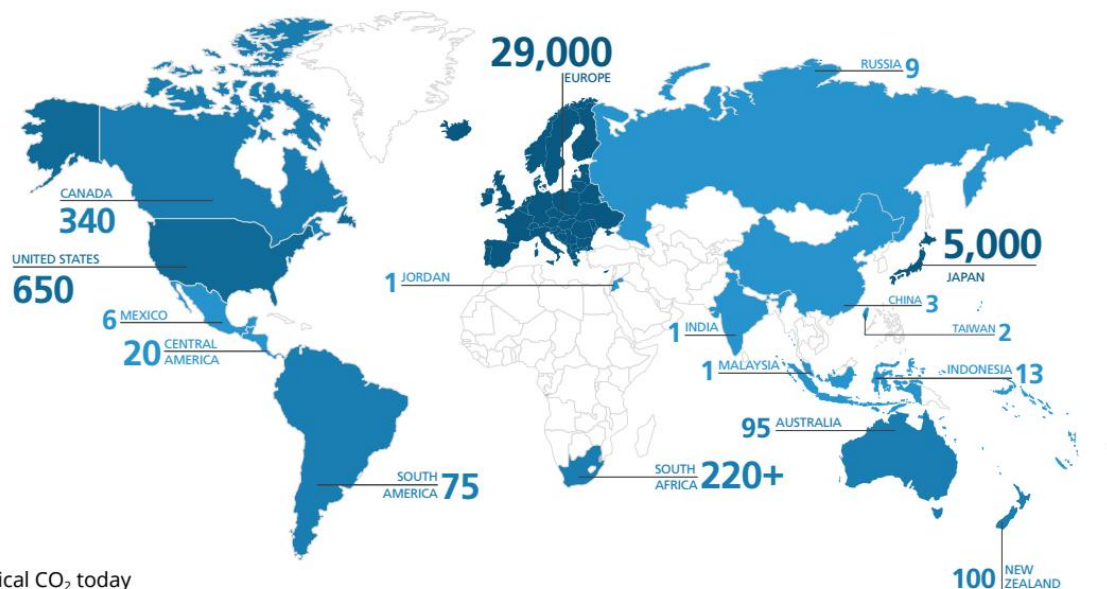
The results estimate that there are more than 35,500 transcritical CO₂ installations globally today. The use in supermarkets is still prevalent, with the share

of convenience stores and industrial applications increasing steadily.

The number of transcritical CO₂ installations in the different world regions is shown below.

CO₂ transcritical installations in the world

sheccoBase 



COMPARISON TO PREVIOUS YEARS

Looking at previous years (2008 and 2018), exponential growth can be observed within the transcritical CO₂ refrigeration sector. This is most noticeable within regions such as Europe, the U.S., Canada, Japan, Australia, New Zealand, and South Africa.

From a mere 140 installations in 2008 (all of which were in Europe), this technology has taken off rapidly across the world to reach an estimated total of 35,500 installations today globally – a number that is constantly climbing.

Region	Number of transcritical CO ₂ installations in 2008	Number of transcritical CO ₂ installations in 2018	Number of transcritical CO ₂ installations in May 2020	Growth in % (from 2018 to 2020)
Europe	140	>16,000	29,000	81%
U.S.		>370	650	76%
Canada		>245	340	39%
Japan		>3,530	5,000	42%
Australia		>20	95	375%
New Zealand		>40	100	150%
South Africa		>110	>220	100%

MARKET DATA: SPLIT BY SECTORS

Globally, transcritical CO₂ systems are still used more in commercial supermarket applications than in any other sector. However, its use in convenience stores and even in industrial projects is gaining popularity.

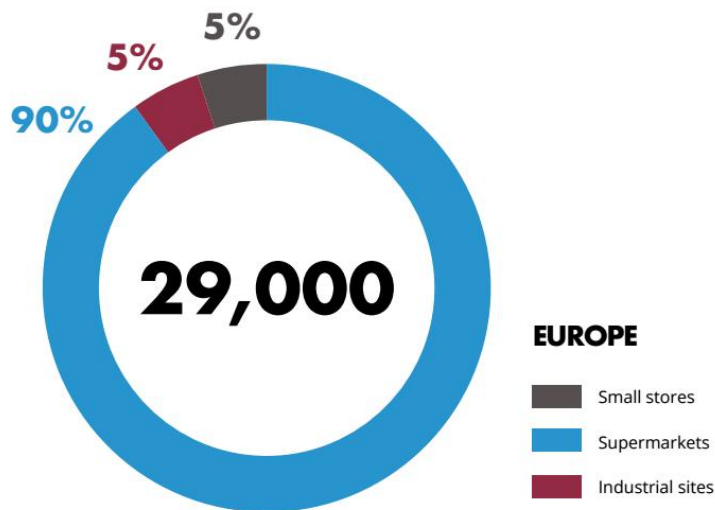
The current split by application for key regions, in relation to the transcritical CO₂ market as a whole, is reflected in the following infographics.

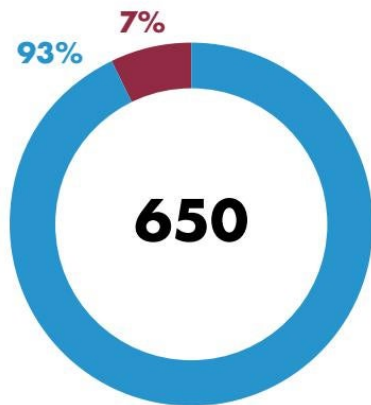
In Europe, there are an estimated 29,000 transcritical CO₂ installations in total today. On average, around 90% of all installations are in supermarkets. 5% are in convenience stores and 5% at industrial sites.

There are an estimated 650 transcritical CO₂ installations in the U.S. On average, 93% are in supermarkets and 7% at industrial sites. In Canada, there are an estimated 340 installations, including ice rinks and data centers.

In Japan, the use of transcritical CO₂ in small stores has traditionally been the most popular (compared to larger installations). However, in the past three years, there has been a noticeable shift towards using this solution in larger installations as well. This is predominantly thanks to eased government restrictions on the use of CO₂ in larger systems.

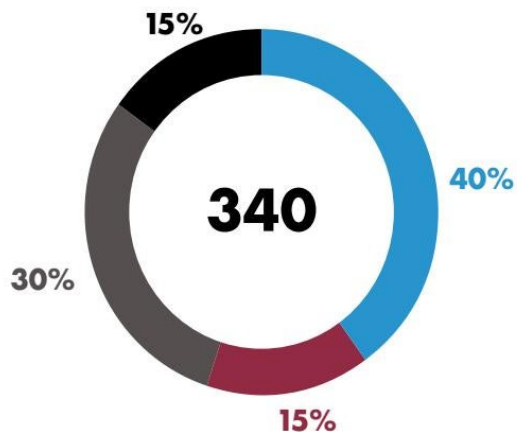
Government restrictions and incentives play a key role in the growth of transcritical CO₂ in all applications (refer to the section on "Regulations and standards").





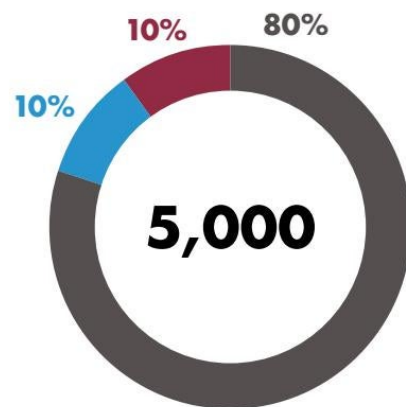
U.S.

- Supermarkets
- Industrial sites



CANADA

- Supermarkets
- Ice rinks
- Industrial sites
- Data centers



JAPAN

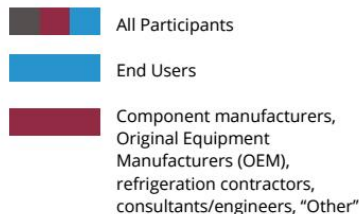
- Small stores
- Supermarkets
- Industrial sites

TRANSCRITICAL CO₂ AROUND THE WORLD TODAY – A SURVEY

During the first half of 2020, sheccoBase (part of the shecco group) conducted a global survey among 250 industry experts on the current use and future opportunities of transcritical CO₂.

The survey was addressed to all relevant stakeholders – both from industry and academia, including system and component manufacturers, refrigeration contractors, consultants, engineers, end users; and players from the education and training sector. It was addressed to all companies working with transcritical CO₂ refrigeration (whether presently or in the past), as well as companies considering working with it in future.

Key legend for survey infographics

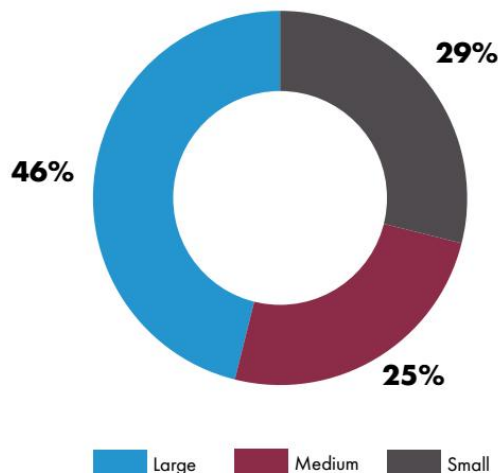


All percentages are rounded values, except when stated otherwise.

The majority survey respondents are currently working with transcritical CO₂. 77% of manufacturers, contractors and consultants/engineers who responded are working with these systems, while 76% of the end users respondents currently have transcritical CO₂ installations.

LARGER COMPANIES MORE REPRESENTED

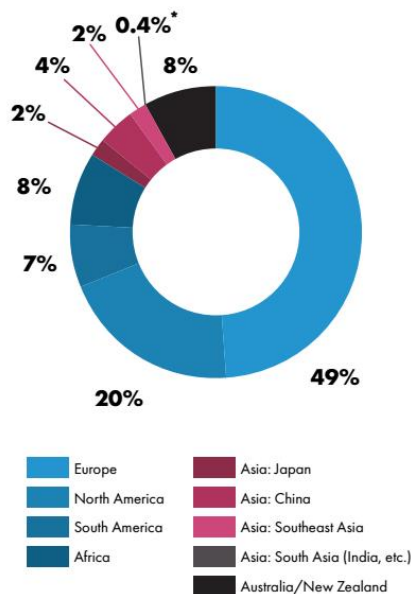
The survey collected responses from companies of all sizes, representing a good balance of respondents. The vast majority (nearly half) of the survey respondents were from organizations with more than 250 employees. The remainder of responses were nearly equally split between medium-sized companies (51-250 employees) and small companies (less than 50 employees).



Number of respondents: 239

MORE THAN HALF OF RESPONDENTS OUTSIDE OF EUROPE

The head office of the relative majority of respondents is based in Europe, representing 49% of all inputs. However, various other global regions were also represented, including North America (20%), Australia/New Zealand (8%), Africa (8%), South America (7%) and Asia (8%).

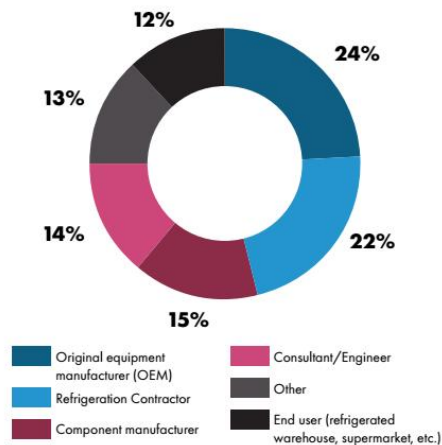


Number of respondents: 238

* Exact number

MANUFACTURERS AND CONTRACTORS PREVAIL

In terms of type of business of the respondents, representation is relatively evenly distributed among the categories, with a slight majority of inputs by manufacturing (OEM with 24%; component manufacturer with 15%) and refrigeration contractor (22%). Responses were also collected from consultants/engineer (14%) and 12% from end users (refrigerated warehouse, supermarket, etc.). 13% of respondents were from "other" categories, which could include sectors such as research and education.



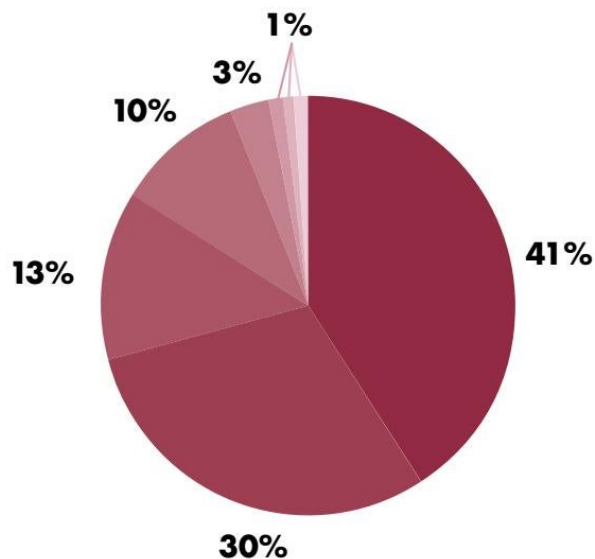
Number of respondents: 238

MANUFACTURERS AND CONTRACTORS: MAJORITY ACTIVE IN COMMERCIAL AND INDUSTRIAL REFRIGERATION

In the following section, questions were asked only to certain categories of relevant respondents, based on their main area of business/type of business. They are marked according to the color legend.

For this question, manufacturers, contractors, consultants/engineers and the unspecified "other" group were asked about their primary market sector. The data revealed that the majority of these respondents are active in the commercial HVAC&R supermarket sector (41%). A further 30% are active in the industrial HVAC&R sector which includes cold storage, food processing, pharmaceutical industry, chemical industry, etc. 10% are active in convenience stores while 13% of the respondents selected the unspecified "other" category.

These answers show that although the greatest interest for transcritical CO₂ is still in commercial refrigeration as its traditional domain, it is also becoming an increasingly more viable option in industrial refrigeration and even convenience stores.



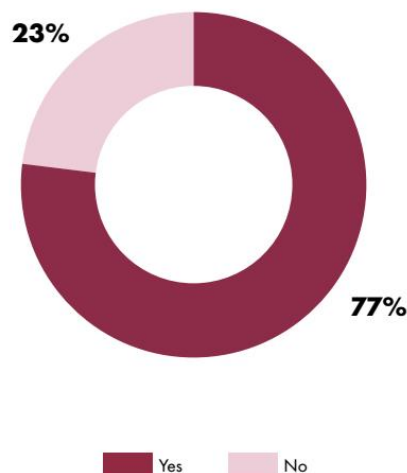
HVAC - supermarkets
Industrial refrigeration

Ice rinks
Data centers

Number of respondents: 209

MANUFACTURERS AND CONTRACTORS: LARGE MAJORITY CURRENTLY WORKING WITH TRANSCRITICAL CO₂ SYSTEMS

A large majority of manufacturers and contractors who responded to the survey are working with transcritical CO₂ at the moment – more than three quarters.



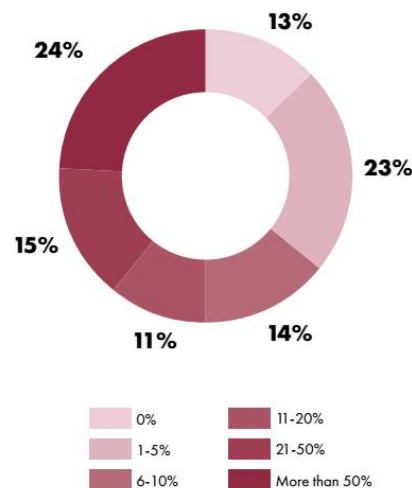
Number of respondents: 177

MANUFACTURERS: SHARE OF TRANSCRITICAL CO₂ IN PRODUCTS VARIED

The manufacturers (OEM and component manufacturers) were queried as to what percentage of their products were for the transcritical CO₂ market in 2019. The results were varied, with a tendency for a lower percentage of their total business.

24% of the respondents can be found in the highest category, with more than 50% of their products used for the transcritical CO₂ market in 2019. 15% are in the medium category (21-50%) and the other 61% combined are in the lower category (0-20%).

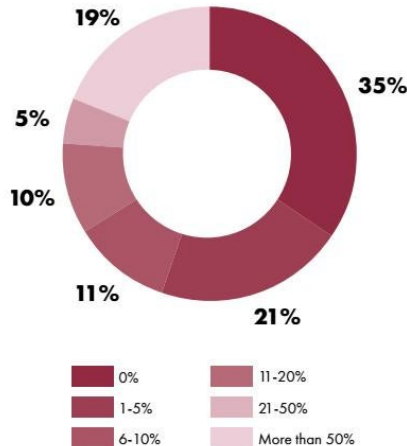
This indicates that the share of transcritical CO₂ among manufacturers' products is still quite low for the most part. However, encouragingly, there are a number of companies with a high focus on this market. This might indicate a growing specialization in transcritical CO₂ within companies that are focusing on this market.



Number of respondents: 92

CONTRACTORS AND OTHERS: TRANSCRITICAL CO₂ PROJECT SHARE STILL RELATIVELY LOW

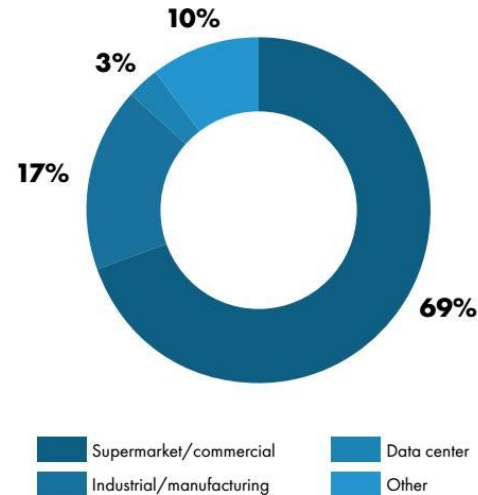
The contractors and those from the unspecified "other" category were also asked to indicate the share of transcritical CO₂ projects within their business. This share is shown to be relatively low, with only 19% of the respondents in the higher category (where more than 50% of the projects involved transcritical CO₂ in 2019) and 5% in the medium category (21-50%). A clear majority of respondents (77%) fall in the lower category range (0-20%).



Number of respondents: 84

END USERS: LARGE MAJORITY ACTIVE IN COMMERCIAL REFRIGERATION

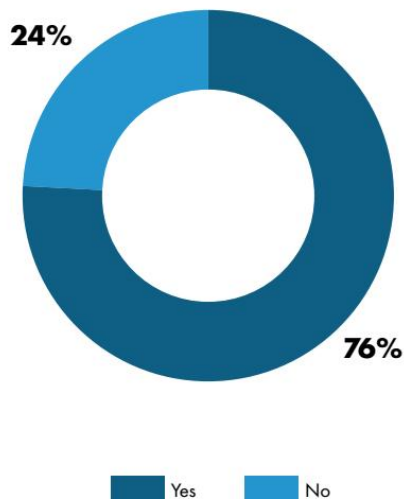
For a large majority of the end users (69%), the primary area of business is supermarkets/commercial refrigeration. This includes large supermarkets but excludes convenience stores. Commercial refrigeration is followed by industrial refrigeration (17%), "Other" (10%), and data centers (3%).



Number of respondents: 29

END USERS: LARGE MAJORITY ALREADY HAS TRANSCRITICAL CO₂ INSTALLATIONS

The large majority of the end users surveyed have transcritical CO₂ installations (three quarters) already, while the remaining quarter do not have any. Those who do not have any were later asked which factors would influence their purchasing decision. (Read more in Chapter 7, Drivers and barriers).



Number of respondents: 29

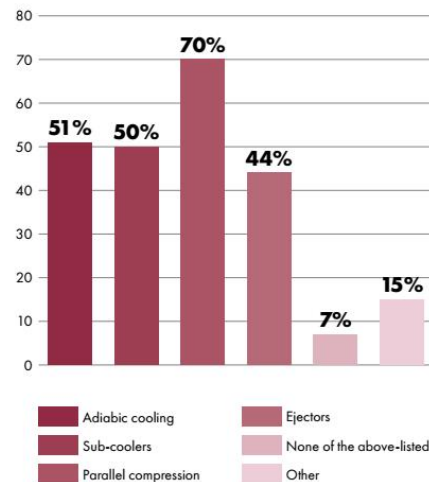
MANUFACTURERS AND CONTRACTORS: PARALLEL COMPRESSION MOST POPULAR EQUIPMENT

Manufacturers and contractors working with transcritical CO₂ were asked which equipment they currently work with. Respondents had the option of choosing adiabatic cooling, sub-coolers, parallel compression, ejectors, none of these, or other.

Multiple answers were possible. There were 325 answers in total, with 70% of respondents choosing parallel compression, 51% adiabatic cooling, 50% sub-coolers, and 44% ejectors. Only 7% do not work with any of these technologies.

This shows that parallel compression and related technologies are indeed very popular for increasing the energy efficiency of CO₂ systems. Some of these technologies are not only for transcritical/direct systems, but also for subcritical/indirect systems, like for example CO₂/NH₃ cascades; as indicated by some survey respondents.

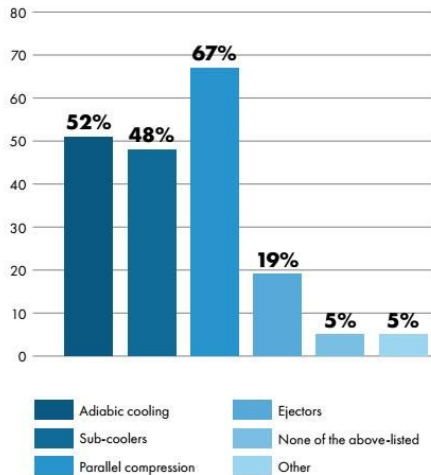
Survey participants also mentioned various other options (15%) for improving efficiencies of transcritical CO₂ systems. These include: booster systems, liquid injectors, and improved controls.



Number of responses: 325 [multiple answers possible]

END USERS: PARALLEL COMPRESSION ALSO POPULAR

End users were also asked which equipment they currently work with. Multiple answers were possible. Of the total 41 answers, 67% of responses went to parallel compression, 52% to adiabatic cooling, 48% to sub-coolers, 19% to ejectors. Only 5% do not work with any of these technologies.

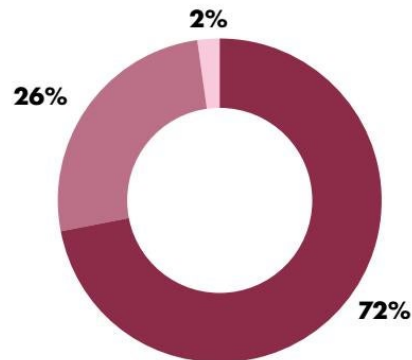


Number of responses: 41 [multiple answers possible]

MANUFACTURERS AND CONTRACTORS: ALL-IN-ONE INTEGRATED SYSTEMS VERY POPULAR

Transcritical CO₂ systems as part of all-in-one integrated systems (refrigeration, heating and air conditioning) are very popular among the manufacturers, contractors and consultants/engineers that currently work with transcritical CO₂. Nearly three quarters (72%) indicated that they work with transcritical CO₂ systems as part of all-in-one integrated systems.

Integrated HVAC&R systems are a clear way to improve energy efficiencies in transcritical CO₂ systems.



Yes No I don't know

Number of respondents: 137

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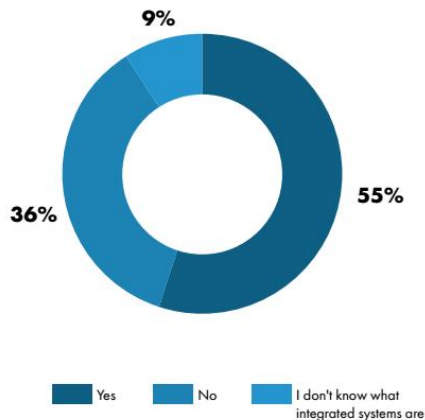
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END USERS: MAJORITY ALREADY USE ALL-IN-ONE INTEGRATED SYSTEMS

All-in-one integrated systems are slightly less popular among end users than among manufacturers, contractors and consultants/engineers. However, the large majority (55%) of the end users that currently work with transcritical CO₂ answered this question affirmatively while 36% said "No," they do not use integrated systems. There were 9% of end user respondents that stated that they do not know what integrated systems are.



Number of respondents: 22

TRANSCRITICAL CO₂ PERCEIVED AS SUITABLE, FUTURE-PROOF ALTERNATIVE TO HFCS AND HFOS

Transcritical CO₂ technology is... (Rating each from 1 star for strongly disagree to 5 stars for strongly agree)

The survey shows that respondents view transcritical CO₂ as a suitable alternative to HFO and HFC-

based commercial refrigeration systems; they also view it as the most environmentally friendly option for commercial refrigeration. This indicates that transcritical CO₂ is viewed as a future-proof solution for commercial refrigeration installations.

The most environmentally friendly option for commercial refrigeration applications



4.5

A suitable alternative to HFO, and HFC-based commercial refrigeration systems



4.5

A future-proof solution for refrigeration installations



4.5

A better natural refrigerant option than R290 or ammonia



3.5

Too expensive and complex to be a viable refrigeration solution



2.5

A solution for the future, not for now



2.5

Number of respondents: 190

Summary

Overall, the survey provides a good representation of the transcritical CO₂ sector. The results indicate that although most of the survey respondents are active in transcritical CO₂ refrigeration, their profiles are quite diverse. This is shown by the variety within the main areas of business (i.e. manufacturers, contractors, end users etc.) as well as by the varied size of the share of transcritical CO₂ within their business.

As a whole, respondents evaluated transcritical CO₂ as a suitable alternative to HFCs and HFOs. It was also found that all-in-one integrated systems are popular with all participants and that equipment such as parallel compression and adiabatic cooling are considered essential for improving energy efficiencies.



An aerial photograph of a rugged coastline. Dark, jagged rocks protrude from the sea, surrounded by turbulent, deep blue water. White, frothy waves are crashing against the rocks, creating a stark contrast with the dark water. The overall scene is dynamic and powerful.

CONVENIENCE STORE (SMALL) APPLICATIONS



An overview

With more and more OEMs offering small capacity solutions (see Euroshop trends article on [page 64](#)), there is a noticeable increase in transcritical CO₂ in convenience store applications around the world – not just in Japan where it was traditionally the most popular.

This chapter takes a closer look at the growing market for transcritical CO₂ in convenience stores today. The aim is to show the potential of transcritical CO₂ technology for smaller capacity systems as well (generally assumed <400m² [4306ft²] in this report).

It includes data from the global survey, as well as end user testimonials from around the world, sharing experiences and highlighting their reasons for using transcritical CO₂ in their convenience store.

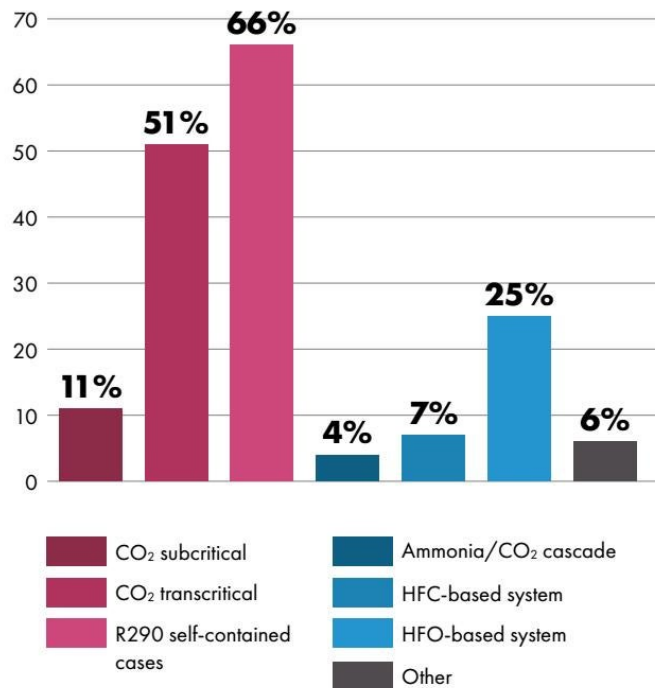
At the end of the chapter, various partner case studies show the application of transcritical CO₂ systems in real life – including an example for a small store. (More partner case studies to follow in later chapters.)

TRANSCRITICAL CO₂ IN CONVENIENCE STORES AROUND THE WORLD – A SURVEY

The global industry survey also looked specifically at convenience stores and available refrigeration equipment on the market to gauge the potential of transcritical CO₂ within this sector.

NATURAL REFRIGERANTS EXPECTED TO DOMINATE NEW CONVENIENCE/ SMALL STORE INSTALLATIONS

When asked as to what technology respondents expect to dominate new installations in convenience/small stores 10 years from now, respondents were clearly in favor of R290 self-contained cases (66%), followed by transcritical CO₂ solutions (51%). The lowest-ranking options were HFC-based systems (7%) and ammonia/CO₂ cascades (4%). In the category "Other" (6%), R290 water-loop systems were often mentioned as another suitable option.



Number of responses: 341 [multiple answers possible]

USING CO₂ IN CONVENIENCE STORES – END USERS SHARE CHALLENGES AND OPPORTUNITIES



Worldwide, sheccoBase estimates that there are around 5,500 convenience stores using transcritical CO₂ systems, most of which are in Japan.

There is a noticeable growing global trend for specifying transcritical CO₂ systems for convenience stores as well. Previously, this technology dominated the commercial (retail) space with larger installations (with exception of Japan where convenience stores have been installing CO₂ systems since 2001).

However, it is becoming more economically viable to consider CO₂ in convenience stores as well. This is largely thanks to impressive product innovation, the improvement of skills, and increasing commercial availability of suitable equipment – amongst others. (Read more in the upcoming Part 3 of the Guide for more about barriers and drivers.)

SOUTH AFRICA¹

During ATMOsphere Cape Town in March 2020, three of the biggest food retailers presented on their journey with transcritical CO₂ and the challenges they've faced along the way. All three made mention of convenience store applications specifically.

Pick n Pay

Richard Taylor, General Manager of Store Design and Implementation of Cape Town-based food retailer Pick n Pay (PnP) explained that they are quickly moving over to transcritical CO₂ installations for their larger store formats. However, this is still a challenge for smaller stores.

PnP operates over 1,600 stores of various formats, of which 151 are express stores (300m²/ 3,229ft²); and 467 liquor stores (of which 241 are corporate and 225 franchises). PnP aims to have 32 transcritical CO₂ stores by the end of 2020 – none of which are convenience.

Taylor explained that it's easier to motivate an investment in transcritical CO₂ for a large store or hypermarket, but it becomes much more difficult for a smaller store where there is a smaller budget to work with. The smaller stores are also sometimes situated in more rural areas where the specialized skills are not as easy to come by – driving up the price of opting for this technology.

Motivating for CO₂ over a conventional HFC system is especially difficult for the franchisees that are investing their own money. "It is very difficult to get the franchisees to invest more," said Taylor. "The economy is tight, there is a lot of competition in the market – it makes it difficult for small stores to select a system with a higher CAPEX. The CAPEX has to be reduced as far possible for them to get the funding to go ahead with the store..."

Woolworths

Alex Kuzma, Head of Engineering Services at Woolworths – the first retailer in South Africa to move to CO₂ – presented the benefits of this move.

Cape Town-based Woolworths operates over 200 full-line stores with food offerings and more than 400 stand-alone food stores, with about 60 more in other African nations.

In November 2010, Woolworths switched on to transcritical CO₂ and today uses it at more than 100 stores.

According to Kuzma, in larger stores, transcritical CO₂ becomes almost cost neutral – but the challenge lies in smaller stores. "I want to make CO₂ the default for all formats but we are battling a bit with the smaller stores," he said.

Despite this, Woolworths is currently busy fitting out three convenience stores (300-400m²/ 3,229-4,306ft²) with transcritical CO₂. The installed refrigeration capacity is 26-40kW [7.4-11.4TR] for medium temperature and 7kW [2TR] for low temperature.

According to Kuzma, the price premium for transcritical CO₂ above an HFC refrigeration system, is about 16% at smaller stores. Things that cost more than an HFC system include compressors and components capable of withstanding higher pressures, while the piping itself is cheaper (less copper) as is the price of the gas (with less needed).

So, what are the solutions to higher cost? First, economies of scale, Kuzma said. He was encouraged by seeing the other retailers on stage talking about CO₂. "CO₂ and other natural refrigerants need to become more mainstream," he said. "We see it as a commodity."

SPAR

The third panelist was Wayne Derdekind, Group Development Manager of SPAR, which only recently started using transcritical CO₂ in retail stores in South Africa. SPAR, based in the Netherlands, operates more than 13,000 mostly franchised stores in 48 countries. In South Africa, there are more than 800 stores, with a relatively small footprint (1,164m²/12,529ft²).

Although transcritical CO₂ is nothing new for SPAR's European retail stores, South Africa has been slow to catch up, so far with only three transcritical installations, said Derdekind. This is because in South Africa, SPAR is a voluntary trading organization (similar to a franchise), he explained. Retailers pay a fee to belong to the brand, but SPAR doesn't dictate things such as what refrigeration system should be put in. Its retailers have a lot of freedom regarding what they use – and usually cost is a primary consideration.

Derdekind echoed the other retailers in saying that, traditionally, transcritical CO₂ didn't have potential for a great return on investment for retailers. This was predominantly because of South Africa's warm climate. As such, the only angle is the environmental benefit. "Our challenge comes with convincing these retailers to invest in something for a 'noble cause,'" said Derdekind.

That has been SPAR's biggest difficulty – until now. Fortunately, as technology and the industry evolved, the costs came down and efficiencies went up. Available expertise was a problem, as were availability and cost of components. But as South African retailers' demand for transcritical CO₂ grows, so does the local industry and expertise. "Transcritical CO₂ systems are getting more efficient and we're now seeing them match or even exceed efficiencies on R404A plants," he added. "It is becoming a great motivator for our retailers."

It's not a no-brainer yet, because the savings don't yet justify the premium. "It still involves a bit of sacrifice, but retailers are starting to see the long-term benefits," said Derdekind.

Trading on the successes of the other retailers, SPAR has since completed three transcritical CO₂ stores. The hope is to be able to show a significant improvement in energy savings, which will incentivize other stores to follow suit. "We hope there will be a knock-on effect," Derdekind said, mentioning that there are already another eight transcritical CO₂ stores in the pipeline for 2020.

EUROPE

Delhaize, Belgium²

A 250m² [2,691ft²] Delhaize 'Shop & Go' convenience store in Belgian capital Brussels uses CO₂ condensing units, installed in 2018 already. One of the Sanden units serves the medium-temperature cabinets, and the other serves the frozen food cabinets.

"In some store configurations, CO₂ condensing units are the preferred option to address the refrigeration needs, and also due to the limits of propane waterloop systems," said Benjamin Tissot, Sales Engineer at Sanden International Europe.

"We're always looking for opportunities to share our expertise (with CO₂ and natural refrigerants) with our franchise partners: with this project –developed by Delhaize engineers and Sanden – Delhaize is showing to its affiliates that CO₂ can also be a valid solution for smaller-sized stores," David Schalenbourg, Director of Department – Building Projects, Format and Maintenance at Delhaize Belgium.

"There is no stronger argument than a real live test," Schalenbourg said.

Tissot argued that condensing units are "a good option" for stores such as the Adolphe Max Shop & Go, which is fitted with remote multideck cabinets and has frozen as well as chilled produce.

Asked whether Delhaize would install more Sanden units in other stores, Schalenbourg said: "First we'll evaluate the performance of this installation. Looking forward, we confirm that we want to go forward in this direction."

"Recently we also built (with Panasonic) a cold room running on a small CO₂ unit (content 2kg/ 4.4lbs)," Schalenbourg said. "The engineering team is continuously scanning the market for solutions to improve energy efficiency and simultaneously decrease the environmental impact of our stores," he added.

Carrefour, France³

The European retailer opened its first full-CO₂ transcritical remote unit at a convenience store in Vannes, Brittany (France) in October 2017.

"The opening of the store is a very positive signal for all retailers who are waiting for natural refrigerants-based refrigeration solutions for small shops," Jean-Michel Fleury, Project Director at Carrefour, explained.

The store is located in the city center of Vannes and has a commercial trading area of 293m² [5,307ft²]. To save space for the refrigeration plant, Carrefour installed the refrigeration systems in the store's yard.

In addition, according to Carrefour, indirect emission, or in other words the energy consumption of the system, is considerably lowered as CO₂ transcritical technology is very energy efficient compared to traditional HFC-based systems.



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AUSTRALIA

Coles⁴

City Holdings has commissioned its fourth CO₂ transcritical project, fitting an SCM Frigo plant at a small-format Coles Local store in Melbourne, Victoria in December 2018. Italian multinational SCM Frigo, part of the Beijer Ref Group, provided the system.

“Coles Local gives the Surrey Hills community the convenience of a supermarket with the character of a specialty store,” said Coles Chief Executive Steven Cain.

The Melbourne store is about half the size of the retailer's regular supermarkets. It sells local gourmet produce and specialty ranges, with exclusive Coles Local-branded.

The use of natural refrigerants corresponds to Coles' vision of environmentally friendly Coles Locals featuring 100% Australian-grown fresh fruit and vegetables and a zero-food waste policy.

Coles plans to extend the format to other parts of Australia, and will “listen carefully to customer feedback on the Surrey Hills store as we seek to roll out smaller format stores in coming years.”

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JAPAN

Lawson⁵

Japanese convenience store chain Lawson installed its first CO₂ condensing unit at one of its stores in 2010. In Q1 2020, Lawson has confirmed 3,700 stores using CO₂ systems with projections of surpassing the 4,000 mark this year.

In general, the most common type of transcritical CO₂ system used in Lawson's convenience stores are outdoor condensing units. Typical systems consist of 2HP or 10 HP condensing units delivering medium to low temperatures in the range of -20°C to 8°C [-4°F to 46°F].

"We're taking a long-term perspective by proactively introducing natural refrigerants," said Shinichiro Uto, who heads Lawson's store Development Division in a presentation at an ATMOSphere networking event in Tokyo in 2013.

"As the CO₂ refrigeration market expands, we're endeavoring to advance the HVAC&R industry as a whole by field-testing products from a number of manufacturers," Uto said. "We're seeking to move towards a multi-supplier system by FY 2020, to establish a stable supply, improve cost-competitiveness, and hedge risks," he added.

Tokyo Department store⁶

In November 2019, Tokyo Department Store, a major Japanese chain, opened a new 47-story high-rise commercial complex called Shibuya Scramble Square.

The company installed several CO₂ plug-in display cases combined with a water loop system in the complex's basement food-shopping area. The combination of CO₂ plug-in equipment with a water loop system in a retail department store setting is relatively new in Japan, where CO₂ outdoor condensing units in convenience stores are dominant.

The innovation represents a new opportunity for end users such as department store retailers to employ natural refrigerant systems, especially those located in densely populated Tokyo neighborhoods, where space is always limited.

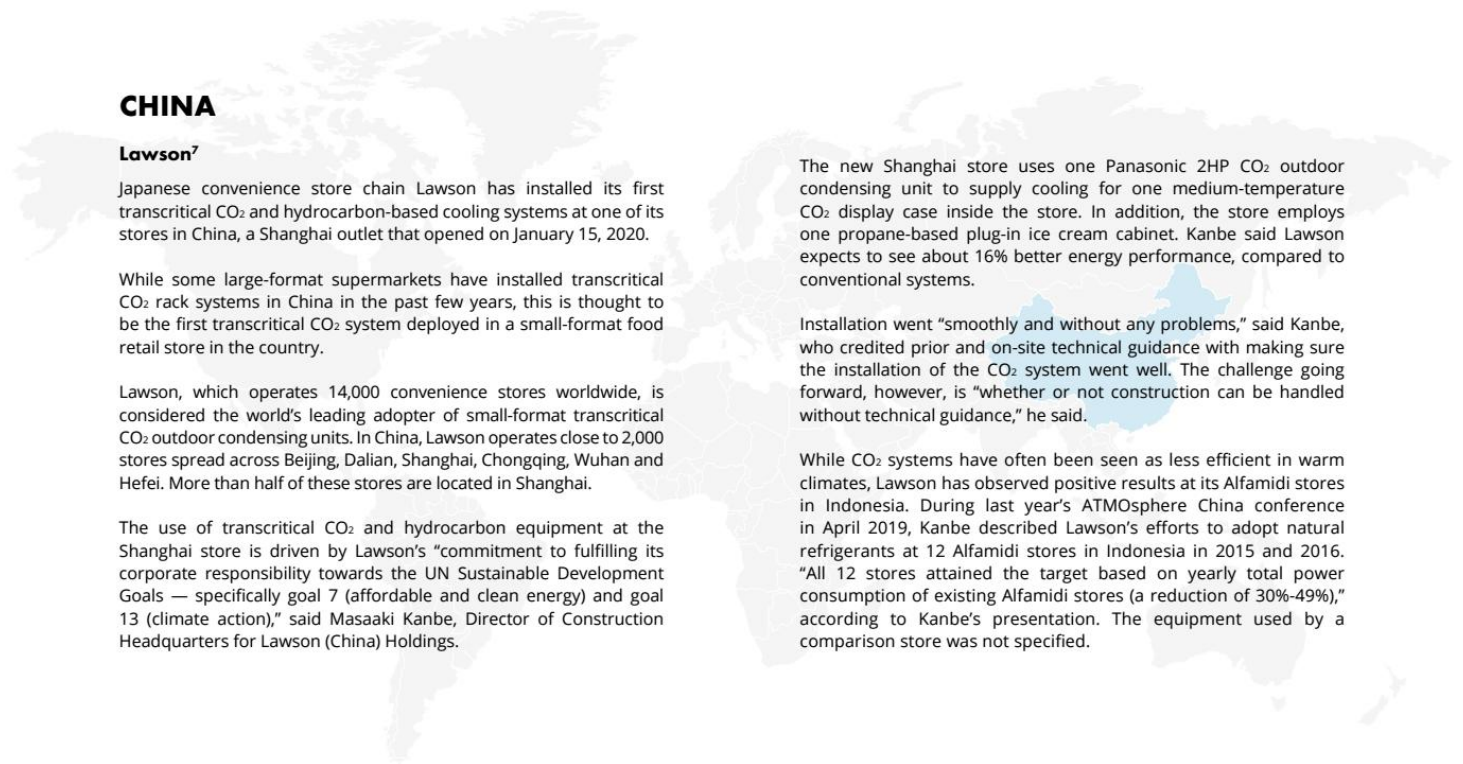
In the second-floor basement of the Shibuya Scramble Square high-rise tower, two food suppliers, Head Line (a rotating showcase of various food makers) and Sanwein (a vendor specializing in Taiwanese delicacies), use seven pieces of specially designed CO₂ water-cooled plug-in showcases.

While Tokyo Department Store aimed to use natural refrigerant equipment, the space restrictions and the underground location of the food sales area meant that the conventional CO₂ air-cooled condensing unit type system was not seen as a viable option.

Tokyo Department Store worked with Japanese OEM Panasonic and Japanese refrigeration installer Hama Refrigeration Industries to design and install CO₂ plug-in showcases that would be cooled by a water loop. The cooling tower is located outside on the 13th floor.

Tokyo Sato, Director of Hama Refrigeration Industries, said that in addition to preventing waste heat from being released on the sales floor, water-cooled systems are a good option for commercial facilities with limited space, and help businesses transition away from synthetic refrigerants.

"Several major department stores have called for water-cooled CO₂ showcases," said Sato. "Looking ahead, it is better to transition away from fluorocarbons now rather than half-way through with low-GWP refrigerants such as mixed fluorocarbons."



CHINA

Lawson⁷

Japanese convenience store chain Lawson has installed its first transcritical CO₂ and hydrocarbon-based cooling systems at one of its stores in China, a Shanghai outlet that opened on January 15, 2020.

While some large-format supermarkets have installed transcritical CO₂ rack systems in China in the past few years, this is thought to be the first transcritical CO₂ system deployed in a small-format food retail store in the country.

Lawson, which operates 14,000 convenience stores worldwide, is considered the world's leading adopter of small-format transcritical CO₂ outdoor condensing units. In China, Lawson operates close to 2,000 stores spread across Beijing, Dalian, Shanghai, Chongqing, Wuhan and Hefei. More than half of these stores are located in Shanghai.

The use of transcritical CO₂ and hydrocarbon equipment at the Shanghai store is driven by Lawson's "commitment to fulfilling its corporate responsibility towards the UN Sustainable Development Goals — specifically goal 7 (affordable and clean energy) and goal 13 (climate action)," said Masaaki Kanbe, Director of Construction Headquarters for Lawson (China) Holdings.

The new Shanghai store uses one Panasonic 2HP CO₂ outdoor condensing unit to supply cooling for one medium-temperature CO₂ display case inside the store. In addition, the store employs one propane-based plug-in ice cream cabinet. Kanbe said Lawson expects to see about 16% better energy performance, compared to conventional systems.

Installation went "smoothly and without any problems," said Kanbe, who credited prior and on-site technical guidance with making sure the installation of the CO₂ system went well. The challenge going forward, however, is "whether or not construction can be handled without technical guidance," he said.

While CO₂ systems have often been seen as less efficient in warm climates, Lawson has observed positive results at its Alfamidi stores in Indonesia. During last year's ATMosphere China conference in April 2019, Kanbe described Lawson's efforts to adopt natural refrigerants at 12 Alfamidi stores in Indonesia in 2015 and 2016. "All 12 stores attained the target based on yearly total power consumption of existing Alfamidi stores (a reduction of 30%-49%)," according to Kanbe's presentation. The equipment used by a comparison store was not specified.

ACCELERATING THE USE OF CO₂ IN SMALLER STORES



The ongoing 'Refrigerants, Naturally! for LIFE' project aims to accelerate the uptake of climate-friendly Refrigeration, Air Conditioning and Heat Pump (RACHP) equipment in small-store food retail applications. This includes transcritical CO₂ equipment.

Funded under the EU-LIFE Programme, the project particularly addresses end users in the organic food retail sector. Many of these are individual retailers independent from larger supermarket chains, but they do have a strong potential to grow in urban settings. The second key target group is the servicing sector, providing store owners with the needed RACHP equipment, as well as commissioning, servicing and repair.

While many supermarket chains in Europe have started installing climate-friendly cooling over the last years to meet future regulatory requirements, this challenge has not been in the focus of the majority of smaller stores yet.

The project therefore prioritizes the building of capacities and raising of awareness among small store owners and the RACHP servicing sector by providing information and training needed to accelerate the shift to climate-friendly cooling.

The main objectives of the project are to:

- Raise awareness among end users and the distribution chain on climate friendly cooling and natural refrigerants.
- Increase the uptake of training and certification on climate-friendly alternatives.
- Accelerate the shift towards climate-friendly technologies and develop technical specifications for the use of non-fluorinated technologies using natural refrigerants.
- Support an effective and timely achievement of the EU 2030 climate targets (for small supermarkets up to 1,000m²/10,764ft²).

The project consortium consists of eight partners from across Europe, bringing together organic retail associations, experts and technicians of the refrigeration sector and market developers:

1. HEAT (project leader, Germany);
2. shecco (Belgium);
3. AgroBio – Associação Portuguesa de Agricultura Biológica (Portugal);
4. BNN – Bundesverband Naturkost Naturwaren (Germany);
5. SEAE – Sociedad Española de Agricultura Ecológica/ Agroecología (Spain);

6. BIV – Bundesinnungsverband des Deutschen Kälteanlagenbauerhandwerks (Germany);

7. KNVVK – Koninklijke Nederlandse Vereniging voor Koude (The Netherlands); and

8. STEK – Stichting Emissiepreventie Koudetechniek (the Netherlands).

Project activities started in June 2019 with a kick-off workshop in Germany and will continue until end of 2021. In its first phase, a market survey will give insight on the current as well as future situation and needs of RACHP end-users in the organic retail / small food retail sector. In a second step the project partners will develop a European stock model about RACHP technology and its related emissions.

Find out more about this project and how to get involved: <https://www.refnat4life.eu/>



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ABOUT THE COMPANY

Based in Italy, the Arneg Group is an international leader in the design, manufacture and installation of complete equipment for the retail sector. Its leadership position in the commercial refrigeration sector finds its origins in the exploitation of synergies created between the various group companies spread all over the world.

The group's project is a high sustainability evolving hand in hand with intelligent technologies, interacting with the environment, society and its customers who then benefit from its activities. Continually improving quality of life is a fundamental part of this project, as well as CO₂ systems.

INTRODUCTION

When an existing retail store in Cape Town, South Africa was in need of revamping, it was replaced with a newly designed store, complete with a brand-new energy efficient CO₂ system. The new format also included more refrigerated cabinets than before. The new store offers a 2,200m² [23,681ft²] shop floor with a variety of products – from fresh fish to hot foods.

The total cooling capacity required from the cabinets and cold rooms is 75kW [21.3TR] for medium temperature (MT) and 15kW [4.3TR] for low temperature (LT). The installed power for the refrigeration compressors rack is 91kW [26.0TR] for the MT and 25kW [7.1TR] for the LT.

- Summer design conditions: 34°C [93.2°F], 60% ambient condition
- Winter design conditions: 0°C [32°F], 90% ambient condition
- Refrigerant type: CO₂ (R744)
- LT evaporating temperature: -30°C [-25.6°F]
- MT evaporating temperature: -7°C [19.4°F]
- Gas cooler outlet temperature: 36°C [96.8°F]

THE SYSTEM

Considering Cape Town's ambient condition, Arneg decided to install its standard transcritical CO₂ system, complete with parallel compression. This technology is perfect for summertime and reduces the energy consumption. Parallel compressor takes the gas generated after the back-pressure valve and moves it directly to the gas cooler without passing through the whole circuit.

An Arneg booster rack was installed, including: three compressors for LT; three compressors for MT; one parallel compressor; inverter for all the pressure levels; and an easy to maintain filter.

THE RESULTS

The results show a minimum daily COP of 2.5 in January (traditionally one of the hottest months in Cape Town). This is a great result that can be compared to other similar plants running on different refrigerants – such as R404A, for example. The results are shown in the Figures below.

For **Figures 1-4**, orange dots show the energy consumption of the Cape Town system. The blue depicts a similar application in southern Italy with the same ambient temperature conditions.

The **Figure 1** graph shows the daily energy consumption [kWh/day] correlated to the external ambient conditions [C°]. **Figure 2** shows the relation between temperature and COP.

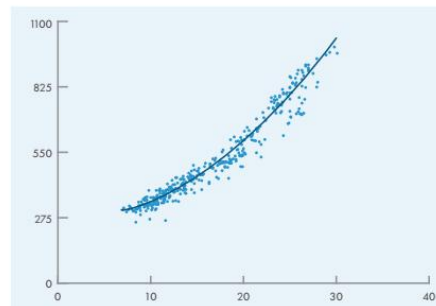


Figure 1: Power consumption vs ambient temperature.

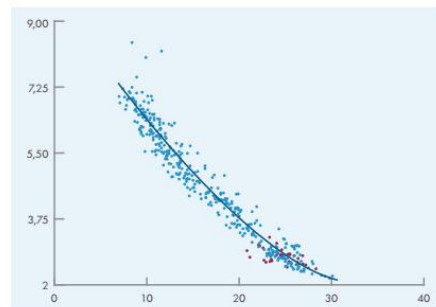


Figure 2: COP vs ambient condition.

In **Figure 3** and **Figure 4**, the grey shows an R404A application, measured in similar ambient conditions. The graph shows the daily energy consumption

[kWh/day] with the external ambient condition [C°]. Summer season is shown in Figure 3 and winter in Figure 4. It is easy to see that R404A offers better performance compared to CO₂ when the ambient temperature is greater than 25°C [77°F], but for the most part of the year, the CO₂ performance (parallel compressor) is better than R404A.

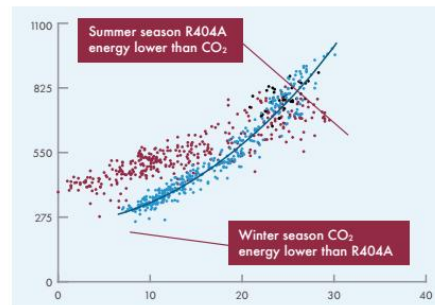


Figure 3.

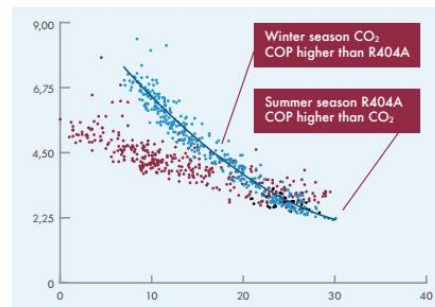


Figure 4.

Although the CO₂ maximum consumption is higher than R404A, when considering an entire year, CO₂ boasts an overall lower energy consumption (as can be seen in **Table 1**).

Technology	Min kWh/day	Max kWh/day	Average kWh/day	Total kWh/year
CO ₂	256	992	513	187.215
R404A	277	830	554	202.432

Table 1

CONCLUSIONS

- Although the purchasing cost of CO₂ refrigerating systems is still higher than R404A technology, this is balanced by the extremely lower cost of gas.
- Using energy saving solutions such as parallel compressor makes transcritical CO₂ systems competitive against other systems – even in warm climates.
- Analysis of the entire lifetime cycle of a refrigeration system is mandatory to select the best solution. This shows that despite the initial higher investment, transcritical CO₂ systems have the lowest cost during a lifespan of six years.



FOOD RETAILER SPAR OPENS FIRST TRANSCRITICAL CO₂ STORE IN SOUTH AFRICA

Sphere.

CONTACT INFORMATION

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ABOUT THE COMPANY

For over 10 years now, the Sphere group of companies has equipped more than 150 stores with transcritical CO₂ refrigeration, helping its clients save over 150,000MWh [42,857RTh] of energy, over 3,500,000 metric tons of CO₂e, and over 320,000Mℓ [84,535 Mgal] of water.

The group includes Commercial Refrigeration Services (CRS), a Sphere company for over five years now, and celebrating 45 years of service to its customers. CRS has been a pioneer for developing CO₂ technology in Africa. Matador Refrigeration, founded in May 1958, also became part of the Sphere Group in 2017. Over the past 60 years, the company has grown into a national operation specializing in installation and servicing of supermarket refrigeration as well cold storage and industrial refrigeration.

ABOUT THE PROJECT

In a total refurbishment, SuperSPAR Wonderpark in Middelburg, South Africa not only completely rebuilt its premises from scratch, but replaced its existing R22/R404A refrigeration system with a transcritical CO₂ system built by Sphere's Matador Refrigeration contracting division. This is the first SPAR in South Africa to install a natural refrigeration system and the end user is very happy with the result.

The 3,700m² [39,827ft²] SPAR Wonderpark project commenced late 2018 and was completed on time by September 25, 2019. The store belongs to the Patricio Group, who owns five SPAR stores across the Limpopo and Mpumalanga provinces in South Africa. It has worked with Matador Refrigeration before on various other projects and the two companies have a good working relationship. As such, upon deciding to go the CO₂ route, Matador was a natural choice for Patricio.

Matador then pitched the idea of a transcritical CO₂ system to the client, explaining the various benefits such as future-proofing the installation. "We were aware of the fast-growing increase in the price of synthetic refrigerants," explained Firmino Patricio, Owner of SuperSPAR Wonderpark. "And by installing a CO₂ system, it would help us negate this future problem."

ABOUT THE REFRIGERATION SYSTEM

Matador then supplied and installed a CO₂ booster system with parallel compression, including evaporator coils and expansion valves. Carel electronic controls and a monitoring system was also installed with dial-in facilities. It was designed to operate at 36°C [96.8°F] ambient conditions, 1,371m [4,498ft] above sea level.

The system's capacity is 265kW [75.35TR] at -6.5°C [20.3°F] on the medium temperature (MT) side with low temperature (LT) on: 23kW [6.54TR] at -35°C [95°F], which offers a greater capacity than the previous refrigeration system). It is used for the cooling of all cabinets, cold rooms, and freezer rooms. A custom biltong (local dried meat) drying room was also installed on site. There are 49 cabinets and 12 rooms operating on the MT side, with 18 cabinets and four LT rooms as well.

The system was designed complete with hot water reclaim, heating 500L [132 gal] of water from 20°C to 55°C [68°F to 131°F]. An Adiabatic gas cooler was also installed to maintain a 28°C [82.4°F] gas cooler outlet temperature for maximum energy savings. All cabinets are fitted with acrylic doors to further improve energy efficiency.

There were no challenges on this project and things ran according to plan. This was because of great planning and coordination between client and contractor, explained Maurice Robinson of Sphere Solutions. The client reported that they are happy with how the plant is running. "The installation and running of the plant have been seamless," according to Patricio.

Although it's too early to tell exactly how much the new refrigeration is saving SPAR, it is performing as it should. "Through careful commissioning and monitoring, it's apparent that the system is running optimally and efficiently," confirmed Robinson.

"We have been monitoring the development of CO₂ refrigeration systems for some time, however prior to transcritical systems, the South African climate had a



Inside the machine room of SPAR Wonderpark.



Inside the shop.

significant impact on the efficiencies of these systems," Wayne Dedekind, Group Development Manager for SPAR South Africa stated. "With the advancements in transcritical CO₂ refrigeration, we were confident that our retailers would eventually be able to combat not only the environmental issues surrounding HFCs, but also be able to surpass the energy efficiencies of HFC plants."

"Mr. Patricio was the first of our independent retailers to acknowledge the inevitable future of refrigeration for The SPAR Group South Africa, and we have since opened a second CO₂ site, with the objective to open another 10 sites for 2020," said Dedekind.



DUTCH NET ZERO LIDL STORE: A PRIME EXAMPLE OF CO₂ IN CONVENIENCE STORES



Made in Germany.

CONTACT INFORMATION

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ABOUT THE COMPANY

Established in 1982, TEKÖ designs and manufactures industrial and commercial heating and cooling solutions using natural refrigerants CO₂ (R744), ammonia (NH₃, R717), and hydrocarbons (R290). TEKÖ offers tried-and-tested, tailored solutions for tens of thousands of applications in the areas of food retail; food production; commercial refrigeration; industrial refrigeration; medical refrigeration; transport refrigeration; warehouses.

The company is headquartered in Altenstadt, Germany. As an internationally active company, TEKÖ is represented by subsidiaries and affiliates in Europe and Asia, and also delivers to South America.

HOW NET ZERO COOLING WAS REALIZED

The upgraded Lidl Zero store in Woerden, the Netherlands, was a complete new build as the original building from 1972 was demolished. It opened less than a year after closing down in November 2018 – on September 4, 2019.

The HVAC&R system for this supermarket features a state-of-the-art smart design and combines multiple exciting features in this one building, including a special heat pump with thermal precast concrete piles in the ground, heat recovery to heat the store from the excess heat of the cooling system, and a smart, adaptable control system.

The basis for all this is a CO₂ ground source heat pump complete with special thermal precast concrete piles in the ground underneath the store and carports to create a thermal reservoir. Glycol is circulated via hollow tubes inside these precast concrete piles to transport the heat to and from the thermal reservoir, taking advantage of the natural ground temperatures during all seasons to complement the cooling and heating cycle in the building.

This heat can also be used to create a comfortable climate inside the store when the refrigeration system doesn't produce enough excess heat in the heat recovery process (e.g. during the colder winter months). Additionally, the heat pump also serves as an air-conditioning system during summer by reversing its operation, i.e. to pump the cooler ground temperatures up into the store.

Another benefit of this system is that, as a result of pumping excess heat back into the thermal reservoir, the system's high-pressure CO₂ refrigerant is cooled, increasing the efficiency of the refrigeration system for store and warehouse, further reducing the energy needs of the whole building.

Lidl's Marcel Ganzeboom, Senior Manager in the Construction Department of Lidl Netherlands and the initiator of this project, confirms their satisfaction of the technical solutions: "It is a very closed chain of electricity generation and waste streams from cold and heat, which are used immediately or stored immediately. Very genius to see how it works," he explained.

THE COOLING POWER BEHIND NET-ZERO

Lidl Zero's refrigerated cabinets are cooled by an energy efficient transcritical CO₂ refrigeration system.

A total of 85m [279ft] of medium temperature cabinets in the sales area, plus two cold rooms, and one freezer room in the back-of-house areas are cooled with TEKO's ROXSTAsmart rack. The unit offers a capacity of 112kW (-8°C) [32TR/17.6°F] on the MT side and 4kW (-33°C) [1.2TR/-27.4°F] on the LT side. A chiller with a cooling capacity of 90kW (2°C) [25.6TR/36.5°F] and a heat pump (50kW/14.2TR) was also installed.

In addition to aiming for net zero, Lidl required that zero synthetic refrigerants were used. As such, local installer Frimex opted for a natural refrigerant CO₂ system that offers environmental advantages. "Most commonly used synthetic refrigerants have a very high Global Warming Potential (GWP), and thus contain a large amount of active greenhouse gasses," explains Hendrine Kalkman, Head Engineer at Frimex. "By using CO₂, even though it is a greenhouse gas as well, we designed a system with minimal impact on the environment." The GWP of CO₂ is only 1, making it one of the most sustainable refrigerants in existence.

The ROXSTAsmart system was installed in a separate plant room above the warehouse, taking up minimal space. It compactly only measured 2,614 x 1,904 x 984mm [8.6 x 6.2 x 32.3ft], including a sound enclosure, three MT compressors, and one LT compressor to cool the whole building of 2,057m² [22,141ft²].



NO MORE ENERGY BILLS

An important requirement from Lidl for this zero-net store was to create an energy-neutral building, meaning that the power consumption of the whole building had to be fully self-sufficient and that no energy bills should be paid at any time during the year. All energy that is used in the store, such as for lighting, heating and cooling, the cashier tills and more, is in fact produced by the store itself from green energy sources.

Whilst Lidl confirms that the investment costs for this zero-net store were higher than an average supermarket, the expected pay-back time will be around five to 10 years – a perfectly acceptable period for an energy self-sufficient supermarket that never has to pay any energy bills.

Lidl goes even further and has put high emphasis on the fact that the supermarket customer should not be paying a premium for the sake of shopping in a sustainable store like this: "We do not charge sustainability to the customer; it is the other way around: it makes the shopping cheaper," said Ganzeboom.

**With inputs sourced by TEKO from RTL Nieuws, AD, and Indebuurt.*



INDUSTRIAL CO₂ SOLUTION FOR MAITRE PAUL'S DUTCH CHOCOLATE PLANT



A BEIJER REF Company

CONTACT INFORMATION

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ABOUT THE COMPANY

SCM Frigo (now part about the Beijer Ref Group) was established in 1979 in Padova (Italy, 30km from Venice). Since 2004, we have worked to develop technologies that use natural gases as refrigerants, thus becoming leaders in the production of CO₂ refrigeration systems.

SCM Frigo's goal is continuous innovation pursued through research, design and production of CO₂ refrigeration systems which are highly sustainable for the environment.

All this is made possible by a close-knit team of highly skilled professionals all working toward one end goal. We are natural born optimists, always striving to become better and better at doing what we believe in.

ABOUT THE PROJECT

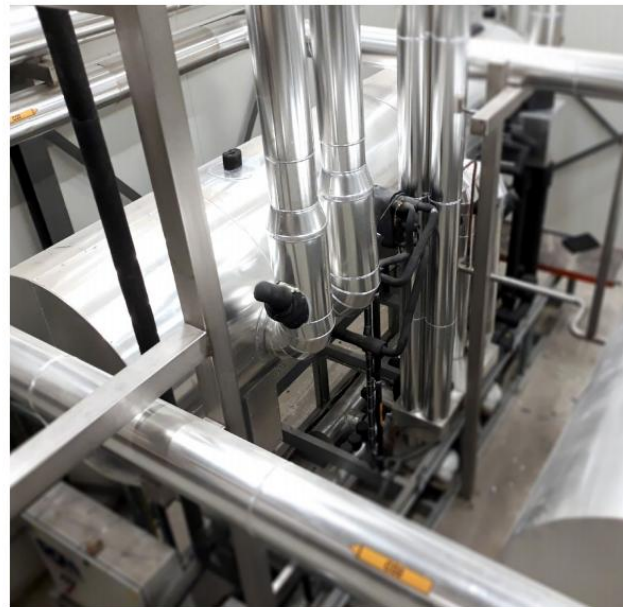
Thanks to the good relationship that SCM Frigo has with many of its suppliers, it joined forces with Japanese Miyazawa in October 2019 to support the design of Maître Paul's chocolate plant in the Netherlands (head quartered in Japan). GEA Netherlands was selected as installer and design company for the refrigeration plant.

It was a challenging project due to the important dimensions and the short timeline for developing the entire project. The units had to be running by mid-February 2020 as not to lose Easter production.

Within five weeks, the project scope was defined and by mid-November 2019 SCM could start to develop and build the required refrigeration units. The first booster rack (DX) was supplied before Christmas and all the other units in week 3 of 2020.

The first part of the commissioning was done in week 8 of 2020 and SCM Frigo supported GEA to ensure a smooth operation of the compressor racks and the pumping stations.

There was a clear message from the Japanese HQ to develop a refrigeration system with a natural refrigerant solution and CO₂ was selected as the preferred choice.



SYSTEM REQUIREMENTS

The required cooling capacity was:

- 830kW [236TR] at -43°C [-45.4°F]
- 115kW [32.7TR] at -30°C [-22°F]

In November 2019, SCM started to work on the design of a CO₂ system that was to supply a total low temperature capacity of 945kW [268.7TR]. SCM Frigo designed and supplied four transcritical CO₂ booster racks (only low temp), three of which were connected to the two pump stations.

The system specifications were as follows:

- 2x transcritical CO₂ booster rack connect to a CO₂ pumping station of 3,500L [924.6gal] to supply 470kW/133.6TR at -43°C [-45.4°F].
- 1x transcritical CO₂ booster rack connect to a CO₂ pumping station of 2,300L [607.6gal] to supply 360kW [102.4TR] at -43°C [-45.4°F].
- 1x transcritical CO₂ booster rack standard direct expansion solution to supply 115kW [32.7TR] at -30°C [-22°F].



RESULTS

Thanks to the good collaboration between SCM Frigo, Miyazawa and GEA, it was possible to supply the entire solution on time and on schedule. At the end of February 2020, Maître Paul started the production as planned, without losing any days.

"We are very happy to have met customer expectation and collaborating with GEA, Miyazawa and Maître Paul to realize this successful installation," said Alessandro Franchin, SCM Frigo Head of Sales. "We are also happy to once more show that CO₂ is a sustainable solution that can be applied in many applications."

According to Maître Paul's service manager, after more than two months of production, the installation is running fine.



CANADIAN TELECOMS COMPANY COOLS SERVER ROOMS WITH CO₂ SOLUTION



CONTACT INFORMATION

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President and Founder
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ABOUT THE COMPANY

Carnot Refrigeration is a Canadian company headquartered in Quebec and established in 2008, with the goal of addressing the HVAC&R industry's failure to provide industrial and commercial clients with a thermodynamic option that would reduce environmental impact. Carnot Refrigeration makes a conscious effort to design refrigeration systems and heat pumps that cut down on the use of polluting refrigerants. It has taken the lead in its field by creating high-efficiency refrigeration systems designed by specialized engineers and manufactured in an environmentally controlled plant or at a constraint-free site. Carnot Refrigeration is experienced in meeting the needs of sports facilities, supermarkets, distribution centers and data centers.

INTRODUCTION

In 2012, Carnot Refrigeration designed and manufactured a CO₂ cooling unit for server rooms. Since then, the unit was tested extensively and installed for several communication companies in Canada. It was in 2018 that Telus launched a pilot project to test the Carnot Aquilon CO₂ air-conditioning unit in order to evaluate the feasibility of this product in larger deployments. The telecommunications company has ambitious energy and greenhouse gas reduction objectives, and the Aquilon unit could help achieve these goals.

ABOUT THE PROJECT

The pilot project involved replacing an old R22 refrigeration system with a CO₂ system with a cooling capacity of 84kW [23.9TR] in a telecommunications facility of approximately 465m² [5,000ft²] located in Matane, Quebec, Canada. With the environmental protection agency phasing out the ozone depleting refrigerant, Telus needed a greener solution to cool their centers, one that they knew would not be phased out and need to be changed in the years to come. The old cooling units contained around 91kg [200.6lbs] of R22, the equivalent of about 165,000kg [363,763lbs] of carbon dioxide. The Aquilon Computer Room Air Conditioning (CRAC) unit maintains the room at 23°C [73.4°F] year-round, using free cooling when outside temperatures permit it.



AVERAGE ENERGY CONSUMPTION USING RAIN CYCLE™



CARNOT PATENTED RAIN CYCLE™ FREE COOLING

STANDARD INSTALLATION

The free cooling process, patented under the name Rain Cycle Free Cooling, allows the refrigerant to flow between the outside condenser and inside evaporator without the use of a pump or a compressor. This is in part due to the pressure differential between the two components. The process can be compared to the rain's natural cycle, where water evaporates on the ground and condenses in the clouds, falling back down in droplets to start the process again. In the Aquilon Unit, R744 evaporates in the evaporator, goes up to the condenser where it condenses to liquid form and drains by gravity back towards the evaporator, where the process starts again.

The 24T Aquilon Unit is equipped with an industrial type semi-hermetic compressor with a variable frequency drive, some electronic control valves, ECM motor fans and an integrated control system. In addition, the system integrates Rain Cycle technology, patented by Carnot Refrigeration, which allows for the continuation of refrigeration in the room without running using the compressor. The integrated controls system switches the unit from compression mode to free cooling mode without needing prompting from a technician. It is adaptive and self-learning, maximizing the free cooling hours as cooling load varies.

The unit is built with stainless steel piping and installed with bended tubing and orbital welding. The welding and advanced repairs require qualified contractors that were available in different cities across Canada. Some training was required for the Telus technicians.

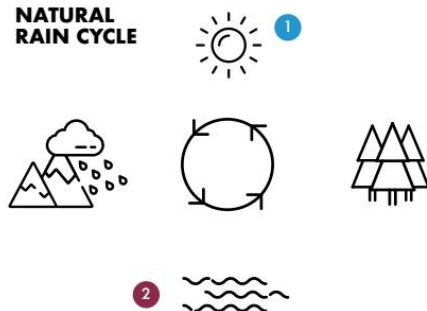
RESULTS

No estimations on the reduction of greenhouse gases have been done, but no leaks have been experienced on the CO₂ unit. Telus estimates energy savings of 60% with the new unit during the first year of operation, this equated to around 14% decrease in the energy consumption of the entire building. This decrease is explained by the fact that cooling is a huge portion of the energy consumption of a data center.

The initial cost of the unit is around 40-50% more expensive than a standard unit. But given the energy saving Telus has seen within the first year of operation, the payback period for the Aquilon units run at around two years.

In summary, a suitable alternative to synthetic refrigerants in the data center industry is now available at a competitive price. The Aquilon Unit uses 100% natural refrigerant, is more energy efficient, greener, and cheaper to maintain. Telus has since the pilot project installed three more units in different locations across Canada.

NATURAL RAIN CYCLE



CONDENSATION

EVAPORATION

BENEFITS:

- Elimination of any future phase-outs by using R744 (CO₂), a natural refrigerant.
- Significant decrease in the energy consumption related to the cooling.
- Improvement in reliability and efficiency
- Reduction of maintenance costs (due to its simplicity)
- Payback period of implementation around two years
- Greenhouse gas emission reduction due to low GWP of R744



FTE: FULL TRANSCRITICAL EFFICIENCY



KYSOR WARREN

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ABOUT THE COMPANY

Epta was founded in 2003 and has quickly become a leader in the commercial refrigeration industry. Family-owned and headquartered in Milan, Italy, Epta ensures efficient coverage of world markets through Group brands which include Costan, Bonnet Nève, Eurocryor, Misa, Iarp, and Kysor Warren. With the skill and specialization provided by each individual brand, Epta is able to offer innovative refrigeration solutions anywhere in the world. Epta Group has an extensive technical and sales force worldwide, comprised of over 40 direct branches and 11 production facilities in eight different countries. The company currently employs over 6,000 employees dedicated to providing the highest quality products and a customer experience that is second to none.

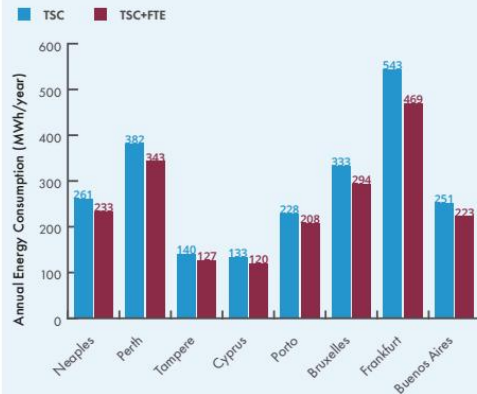
INTRODUCTION

Epta's Research and Development team is consistently pushing the envelope of cutting-edge technologies and designs in the rapidly developing area of CO₂ refrigeration systems. Being that CO₂ is non-flammable and non-toxic, it is an ideal refrigerant to aid in the advancement of natural refrigerant solutions around the globe; however, there are many factors that affect the adoption rate of new technologies. The three obstacles that were most prevalent amongst customers were defined as reduced efficiency in warmer climates, increased capital investment, and serviceability/technical constraints. As a result, Epta developed the Full Transcritical Efficiency (FTE) system which minimizes the impact of these obstacles, making transcritical CO₂ systems a more attractive solution and ultimately increasing the adoption rate.

ABOUT THE PROJECT

The innovative design of the FTE system provides many benefits as compared to standard transcritical systems. FTE increases efficiency and reliability of CO₂ booster systems by flooding the medium temperature evaporators, without risking compressor flood-back. Flooding the medium temperature evaporators allows the suction temperature and pressure to increase,

FTE ENERGY SAVINGS IN MULTIPLE CLIMATE REGIONS



thus decreasing the compression ratio of the medium temp compressors. The effect of the lower compression ratio not only improves the efficiency of the system it also decreases the compressor discharge temperature. Lower discharge temperatures reduce the risk of overheating and degrading the quality of the oil, ultimately extending the compressor life cycle.

Since FTE is an enhancement implemented on the low-pressure side of the system, the efficiency benefits from flooding the medium temperature evaporators are recognized year-round, regardless of the ambient temperature. For this reason, FTE is the ideal solution for customers looking into options to reduce the need for expensive adiabatic or evaporative gas coolers which provide benefits only during the warmer seasons.

The simplicity and serviceability of the FTE system sets it apart from the

competition. The technology requires only a few additional standard, easily-sourced components (tank/receiver, solenoid valves, check valves, and control boards) that service contractors use on a daily basis. Best in class training and support are available for installers and end users.

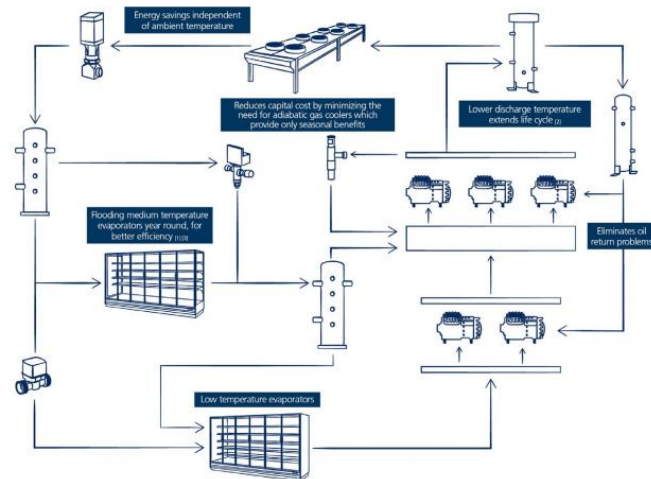
The importance and effectiveness of FTE is confirmed by the fact that it is at the heart of Life-C4R Carbon 4 Retail Refrigeration, the three-year Epta project co-financed by the European Union (under grant agreement n° LIFE 17 CCM/IT/000120). The project was conceived to accelerate the spread of highly efficient CO₂ refrigeration systems and is aimed at finding new technologies and standards for natural refrigeration in retail sector, highlighting Epta's commitment to research and development. It is part of the European program LIFE that includes a numerous array of projects to combat climate change.



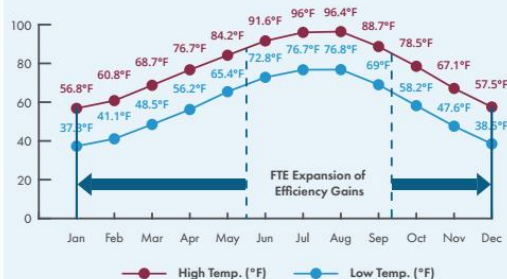
FULL TRANSCRITICAL EFFICIENCY



SIMPLE. RELIABLE. EFFICIENT.



TEMPERATURE - DALLAS, TX



ECO-FRIENDLY R-744

Natural refrigerants that are both non flammable and non-toxic like CO₂ offer environmentally sound solutions for your refrigeration & sustainability goals

FIELD TEST DATA

- (1) 6-8°F ↑ MT Suction
- (2) 16-18°F ↓ CDT*
- (3) Efficiency ↑ > 10%

* CDT = compressor discharge temperature

** Test Data based on global FTE installations utilizing Epta display cases



RESULTS

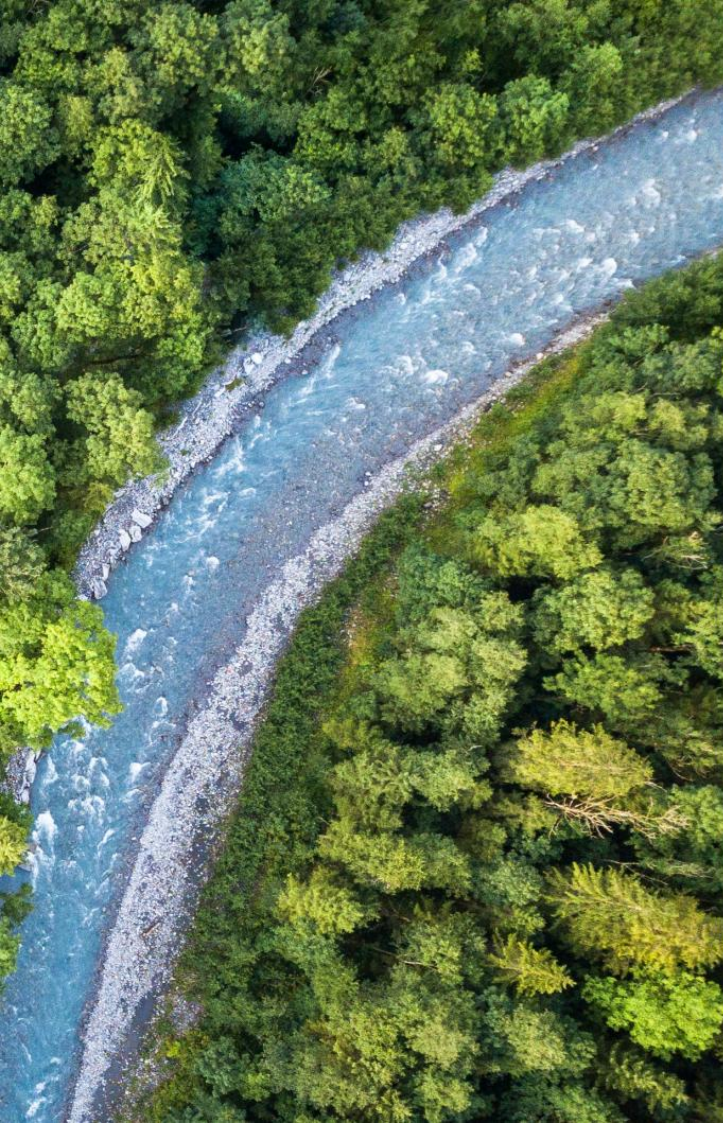
With more than 300 FTE installations globally and five U.S. installations planned by end of 2020, Epta and Kysor Warren continue to see growth for this innovative design. The data collected from the global installations provide conclusive evidence of a 10% reduction in energy consumption. The data shows that flooding of the medium temperature evaporators allows the average suction temperature to increase by 6-8°F [by 3-4°C], while also maintaining product

temperature and integrity. The discharge temperature of the medium temp compressors decreases by 16-18°F [by 9-10°C] which again reduces oil degradation and extends the compressor life cycle. Combining the simplicity, reliability, and energy efficiency of the FTE system make it the best option for customers interested in a future-proof, sustainable CO₂ refrigeration system.

Convenience store (small) applications

An aerial photograph of a dense, lush green forest. The trees are tightly packed, creating a vibrant, textured canopy of various shades of green. The perspective is from directly above, looking down on the forest floor.

COMMERCIAL/ SUPERMARKET APPLICATIONS



An overview

Commercial retail applications are where transcritical CO₂ refrigeration systems first found their niche in the early 2000s already and the total number of installations has been increasing globally at a rapid pace. With increasing pressures from global HFC-reducing policies and standards, specifying a transcritical CO₂ refrigeration system for commercial applications has become a standard way of future-proofing the installation.

As the demand for these climate-friendly systems grew, so did the number of players on the market and the availability of systems and specialized skills. Prices became more cost competitive, efficiencies went up – even in warmer climates previously considered unsuitable. (Read more on “drivers and barriers” in the upcoming Chapter 7.)

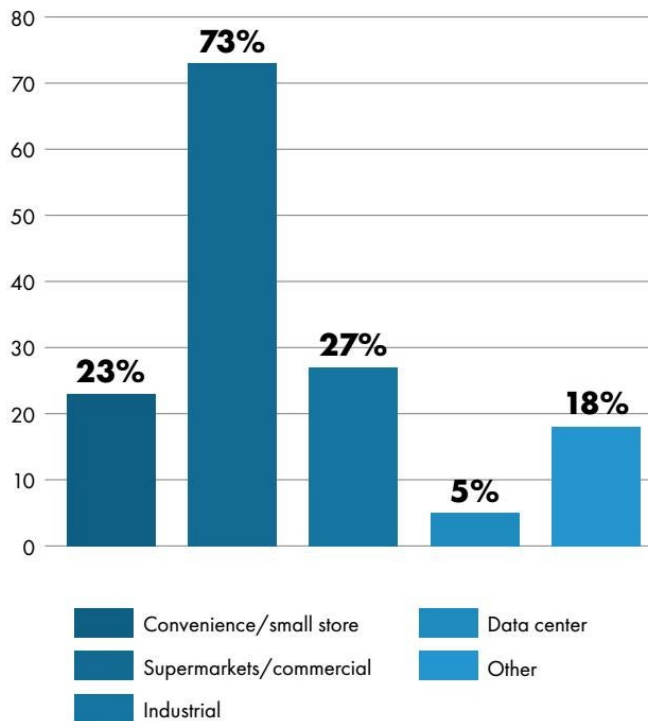
What does the market for transcritical CO₂ in supermarkets and commercial installations (>400m² [4306ft²]) look like today?

This chapter investigates the global use of transcritical CO₂ in commercial applications – retail in particular. We take a look at global market trends, innovative technologies launched at EuroShop 2020, end user testimonials, and survey results to get a better picture of this.

TRANSCRITICAL CO₂ IN COMMERCIAL REFRIGERATION AROUND THE WORLD – A SURVEY

END USERS: LARGE MAJORITY ACTIVE IN COMMERCIAL REFRIGERATION/SUPERMARKETS

End users working with transcritical CO₂ systems were also asked where they use this technology predominantly. Multiple answers were possible. There were 32 responses in total and 73% indicated the commercial supermarket sector, while 27% selected industrial and 23% convenience/ small stores. Data centers received 5% of the answers with 18% unspecified as "Other". Examples of "Other" are dairy farms, hypermarkets, regional distribution centers and warehouses/depots.

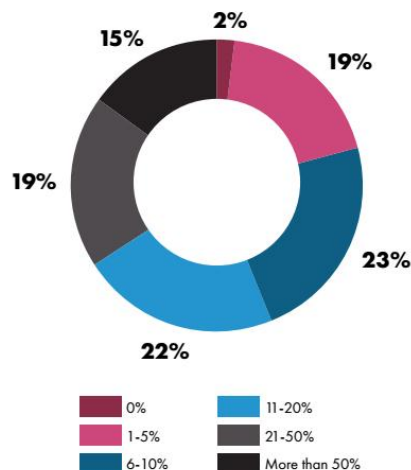


Number of responses: 32 [multiple answers possible]

MARKET SHARE ESTIMATES FOR TRANS-CRITICAL CO₂ MODEST

The survey respondents were asked to estimate the market share of transcritical CO₂ in its traditional sector – commercial refrigeration. Responses were varied and only moderately ambitious. Results were rather evenly split between the possible ranges. The greatest exception was those (2% of the total respondents) who believed the market share to be 0%. More positively, 15% selected a market share of more than 50%.

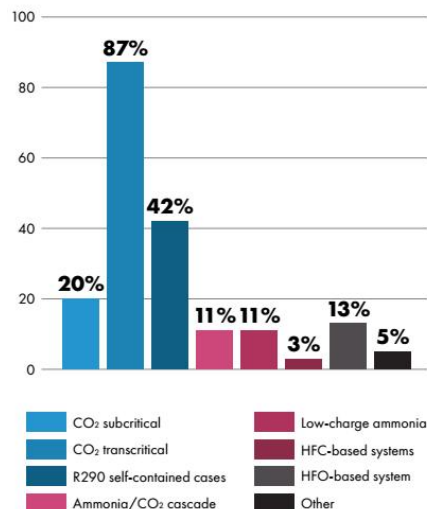
This shows that transcritical CO₂ has already penetrated the commercial refrigeration market to a considerable extent. However, there is still potential for even more growth in this market.



Number of respondents: 204

TRANSCRITICAL CO₂ EXPECTED TO DOMINATE COMMERCIAL REFRIGERATION IN SUPERMARKETS IN THE FUTURE

When respondents were asked what technology will dominate new supermarket installations 10 years from now, estimates were clearly in favor of transcritical CO₂ (an overwhelming 87%). R290 self-contained cases and subcritical CO₂ are also estimated to take a large share at 42% and 20% respectively. In the category "Other" (5%), R290 water-loop systems were often mentioned. Multiple answers were possible.



Number of responses: 394 [multiple answers possible]

GLOBAL TRANSCRITICAL CO₂ TRENDS IN RETAIL FROM EUROSHOP 2020

A first-hand look into the future of retail refrigeration shows an undeniable shift towards natural refrigerants – transcritical CO₂ in particular.

- by sheccoMedia

Every three years, the retail world converges in Düsseldorf, Germany, to attend EuroShop, which bills itself as “the World’s No. 1 Retail Trade Fair.” We take a look at the main trends from the February 2020 show to see where the global market is heading for transcritical CO₂ – for retail and beyond.

*[*Disclaimer: This is by no means a comprehensive report of all the exhibitors and innovations displayed at the 2020 show. This summary account is based on information gathered before, during, and after the show by various shecco team members.]*

More CO₂ solutions for small stores

EuroShop 2020 confirmed the expansion of CO₂ beyond mid-sized commercial retail applications – a noticeable trend that has been emerging worldwide. A number of companies displayed solutions for smaller convenience stores and large industrial projects.

CO₂, though primarily used in rack systems in larger stores, is increasingly being used in condensing units in small stores. For example, since introducing outdoor CO₂ condensing units in Europe in 2017, Japanese OEM Panasonic, has sold 600 units as of last October (2019),



according to Gaku Shimada, Overseas Sales Manager for Panasonic's Refrigeration System Sales Department. In marketing these units, Panasonic has targeted small-format stores, gas stations, fast-food chains and restaurants, said Shimada during a presentation at ATMOSphere Europe, in Warsaw, Poland, on October 16.

This year, **Panasonic Heating and Cooling Europe** introduced a 4HP [3.0kW; 0.9TR] CO₂ condensing unit for medium-temperature and low-temperature cases. With this new model, Panasonic's line-up (2HP/4HP/10HP [1.5kW; 0.4TR/ 3.0kW; 0.9TR/ 7.5kW; 2.1TR]) for medium- and low-temperature applications "can meet almost all the requirements for small stores," said Lena Ansorge, Communication Manager for Panasonic Appliances Air-Conditioning Europe.

In another example, **Area Cooling Solutions**, based in Barcelona, Spain, has developed an indoor CO₂ condensing unit, the iCool Max CO₂, for small urban stores. The system is designed for retail outlets such as supermarkets, grocery stores, markets, petrol stations and convenience stores of up to 200m² [2,153ft²].

Even Danish OEM **Advansor**, which has installed more than 6,000 transcritical CO₂ racks, is catering to small stores now with its Minibooster and Tower units, which have a small footprint for stores where space is limited, said Jasmine Lange, marketing coordinator for Advansor.

German OEM **Teko** launched its ROXSTAmicro condensing unit for smaller convenience stores at EuroShop. The ROXSTAmicro is an air- or water-cooled unit for plug-and-play cabinets offering the same performance as similar propane (R290) units, but without the flammability risk, said Teko. It is suitable for applications up to 5kW [1.4TR] for medium-temperatures and as low as 500W [0.1TR] for low temperatures, thereby expanding Teko's overall range to include solutions from 500W [0.1TR] to 550kW [156.4TR]. The unit will be commercially available before the end of 2020.

Carrier presented its new Power CO₂OL solution, capable of delivering up to 550kW [156.4TR] low-temperature capacity, and up to 1,500kW [427TR] for medium temperature. The Power CO₂OL uses modulating vapor ejectors, allowing the compressors to operate at higher suction pressure.

Meanwhile, in December 2019, OEM **Daikin Europe** completed the installation of a prototype "Conveni-Pack" integrated refrigeration/air conditioning/ heating system for convenience stores, using CO₂ refrigerant, at a demonstration shop at its headquarters in Ostend, Belgium.

Co-funded by the European Union, this product was developed for Natural HVACR 4 LIFE, a sustainability focused research project exploring the use of CO₂ as a natural refrigerant.

This CO₂ version of the Conveni-Pack is based on an existing version that employs R410A as the refrigerant. (More about all-in-one integrated systems later on in this article.)

Daikin Europe will test the CO₂ prototype in a simulated convenience store, followed by demonstration and monitoring in stores in Germany and Spain, in average and warm climates, respectively. According to the European Commission, the project intends to install and monitor the system in 20 European stores. It will mainly monitor the energy efficiency and safety performance of the equipment "to provide a risk mitigation strategy as the basis for a large-scale application of CO₂ as a natural refrigerant."

Through Natural HVACR 4 LIFE, Daikin intends to remove market barriers by exploring the viability (in terms of energy and safety) of an integrated refrigeration, heating and comfort cooling system that uses CO₂ as a natural refrigerant, according to the website. The company will raise awareness among installers, engineers, customers and the general public on the potential benefits of using CO₂ as a natural refrigerant in convenience stores through exhibitions, conferences and online tools.

Improving rack efficiency for larger installations

Despite the inroads made by CO₂ condensing units in smaller stores, in medium- to-large supermarkets, CO₂ rack systems are still king.

CO₂ racks “have been growing a lot and fast in the past few years, not only in the commercial retail segment but also with growing interest from the industrial market, for example in food manufacturing such as bakeries and meat processing,” said Lydia Matthäus-Wiltink, Business Development Manager for German OEM Teko, which had installed more than 4,000 CO₂ racks in the market by the end of 2019. “We expect this trend to continue and most likely to grow even further in 2020 and beyond.”

The use of efficiency-enhancing technologies like ejectors and parallel compression in transcritical CO₂ systems continues to grow, enabling the systems to be used efficiently in high ambient climates. “The efficiency of transcritical CO₂ systems is improving year over year,” said **Advansor’s** Lange. “Ejectors are playing a role in warmer climates, and we believe very strongly in this technology. We are also introducing it on smaller systems now.”

Last year, **Carel** supported the start-up of modern centralized transcritical CO₂ systems in China, South America, South Africa and Australia, some of which equipped with modulating ejectors, said Carel’s Di Lena.

Enrico Zambotto, Refrigeration Director for Italian OEM **Arneg**, expects parallel compressors to become a “standard” feature in transcritical systems, while in warm climates, ejectors will increase in use.

Manufacturers are continuing to come up with new ways to improve efficiency of refrigeration systems. For example, Advansor is seeing “very good efficiency gains with permanent magnet motors in compressors,” said Lange. With all efficiency measures taken into account, “there can be a difference of more than 25% seasonal energy performance ratio (SEPR) in warm climates between a standard solution that was top of the line five years ago and a high-end solution today.”

Epta has developed its own energy-saving transcritical technology, the full transcritical efficiency (FTE) system. The company is promoting this technology through its participation in the Life-C4R (Carbon 4 Retail) project, which is co-funded by the EU and coordinated by Epta. There was a Networking Event organized by shecco around this project.

Francesco Mastrapasqua, Advocacy and Regulatory Affairs Manager at Epta, explains that “in a traditional system, superheating at evaporator is necessary to be certain of having only vapor at the outlet of the evaporator, since the presence of liquid sucked in by the compressors would irreparably damage them, but it also introduces a considerable waste of energy and greater compression work. With the evaporator flooding applied to the MT (medium temperature) loads the superheat is eliminated, so there is an improvement in the heat exchange as the entire surface of the evaporator is used in an optimal way obtaining a significant increase in evaporation temperature (up to 6 K), reducing energy consumption on MT compressors. Eliminating superheat by flooding the evaporators is the key to increasing efficiency in all the climates and during the whole year.”

The FTE solution combines the efficiency of flooded evaporators with reliability and simplicity in any country with any external temperature, reducing the energy consumption of the refrigeration system all year round, without adding any significant cost or complexity compared to a basic CO₂ transcritical booster system. One of the main advantages is the simplicity, because it does not need complex control logic or any sophisticated components. Mechanically the FTE system operates with the same components as the basic CO₂ transcritical system, plus the FTE low-pressure liquid receiver and a solenoid valve (double for safety), able to stop the flow of liquid from the main liquid receiver to the LT cabinets.

Another solution by Epta to increase the energy efficiency in CO₂ refrigeration systems, especially in hot climates, is the Extreme Temperature Efficiency (ETE) System solution. This solution is an evolution of standard mechanical sub-cooler unit, integrating this system in a transcritical CO₂ system. With the Extreme Temperature Efficiency solution, the refrigerant flow coming out of gas cooler is sub-cooled by an integrated CO₂ unit, composed of a heat exchanger,

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an electronic expansion valve (EEV) and a compressor. The sub-cooler is usually activated in transcritical conditions for energy saving, peak shaving and to address all the issues related to the high compressor discharging pressure and temperature. The ETE system ensures there is no performance loss in warm and hot climates, increases the total energy efficiency and can be used for both commercial and industrial applications. To be more precise, for ambient temperatures below 30°C [86°F], a standard transcritical CO₂ system is used, and ETE recommended. For ambient temperatures higher than 37°C [99°F], both FTE and ETE are recommended. Higher than 40°C [104°F], FTE is always included; and higher than 43°C [109°F], both FTE and ETE are always to be included.

Energy saving is key

An important reason for manufacturers to develop ever more energy saving products is the new EU Ecodesign and Energy Labeling Regulation, which will come into effect in March 2021, promising stricter energy efficiency requirements for the commercial refrigeration industry, and a shift in existing products in retail.

The European HVAC&R industry association **Eurovent**, with participation from the European Commission, hosted a seminar on February 17 at EuroShop to elaborate on the upcoming legislation. The aim was to offer the attending HVAC&R professionals an introduction to the new product requirements.

The new regulations “are game-changers for the commercial refrigeration sector,” said Francesco Scuderi, Deputy Secretary General of industry group Eurovent. “They are expected to result in a phase out of certain products on the European market and increase the demand for the best market-available technologies.”

CO₂ Moving Outdoors

Not all the CO₂ trends at EuroShop were about efficiency or size. Several companies also introduced products for outdoor installation.

One of them was **Danfoss**, which introduced its Optyma iCO₂, a plug-and-play stackable condensing unit for medium-temperature applications with a cooling capacity of 1.5-4.7kW [0.4 to 1.3TR]. The capacity is suitable for display-cabinet lineups of 1.5m-10m [5 to 33ft], but the unit can also be used to refrigerate cold rooms.

With the Optyma, Danfoss aims to bring CO₂ refrigeration to a new segment of convenience stores that have reduced indoor space. The unit will be commercially available later in 2020, and Danfoss is already planning a range extension, said John Broughton, Global Application Expert at Danfoss.

Another company with a new outdoor CO₂ offering is Swiss OEM **Biagini Frigoriferi**. The company introduced TotalGreEnergy, an integrated transcritical CO₂ booster system that includes refrigeration, heating and air conditioning.

The TotalGreEnergy is a ready-to-install unit, aimed at supermarket applications and suitable for all climates. The system can save up to 30% in energy consumption, compared to traditional HFC systems and other CO₂ booster systems, according to Luca Rossi, Project Manager at Biagini Frigoriferi. The saving is mainly due to an added subcooling section, and the “unique machine architecture,” Rossi said.

The TotalGreEnergy system is customizable and available in refrigeration-and-HVAC-only versions. It is already commercially available in four size configurations. The smallest version with two fans has a chiller capacity of 15-35kW [4.3-10.0TR] while the largest, with five fans, offers 55-135kW [15.6-38.4TR].

The Growth of Integration

Another driver of efficiency in retail refrigeration is system integration: refrigeration, air conditioning and heating served by one rack system (as also seen by some of products mentioned already in this article). It is becoming ever more popular to use integrated functions to save energy, by for example using the waste heat from refrigeration for heating and/or hot water production.

Bitzer is expecting growing market share for integrated systems in stores greater than 1,000m² [10,764ft²] in size, said Patrick Koops, Head of Public Relations for Bitzer.

Frascold sees “an incredible growing demand for compressors used in integrated systems, because stores are really focused on maximizing system efficiency,” said Elisa Argenta, Marketing & Communications Manager for Frascold.

“System integration is something we’ve already been doing for some time in partnership with WURM Systems and GTM Gebäudetechnik Management,” said **Teko’s** Matthäus-Wiltink. The partnership “combines heating, cooling, lighting, controls, etc. all in one system, right from first design.”

Integrating systems increases the overall store efficiency and reduces costs, noted Matthäus-Wiltink. “This makes total sense for supermarkets and others, and many successful installations we’ve been involved in are proof that this concept is the right way forward.”

Advansor has been selling integrated transcritical systems for many years with its Sigma units, “and this is a standard for us now,” said Lange.

Meanwhile **Danfoss** is participating in the MultiPACK project funded by the EU, which focuses on integrated systems in warmer climates, said Carina Brandt, Senior Director Marketing Communication Danfoss Cooling.

For many HVAC&R companies, the adoption of efficient natural refrigeration technology is a vital part of confronting the climate emergency. “We are living in an era of change and transformation towards a more environmentally friendly model,” said **Epta’s** Mastrapasqua. “We must support our clients who share our same vision in creating climate-neutral stores.”

Omnipresent Digitalization

Digitalization (sometimes called Industry 4.0) was everywhere as manufacturers showed off new innovations in controls and data management, making products more intelligent than ever.

One example was the aforementioned Optyma iCO₂ from **Danfoss**, which can be connected with the company’s ADAP-KOOL case controller solution to enable remote monitoring and management. The ADAP-KOOL is part of Danfoss’ Smart Store Concept, which intends to save not only energy and heating costs, but also reduce service calls and overall carbon footprint.

Custom components

When German manufacturer **Wieland** displayed its K65 CO₂ copper-alloy piping solution – which contains 2% iron – 15 years ago, sales moved slowly, but now “everyone wants it,” said Florian Diesch, Sales Manager of Wieland, during EuroShop.

The K65 piping is designed to be both lightweight and easy to weld, making it a great solution for CO₂ projects around the world, said Wieland. Because the pipe is mainly made of copper, it behaves like copper – except that it’s much stronger and can withstand the high pressures of CO₂, explained Diesch. “This increases the strength of the copper without making the pipe heavier.”

As copper in itself isn’t strong enough to withstand the pressures of CO₂, stainless steel has often been the preferred choice for piping. However, stainless steel piping is heavy and requires a qualified welder. K65 piping, behaves the same as copper, so any plumber who can work with normal copper piping, can weld it, Wieland said. It is also much quicker to weld, reducing downtime for maintenance or repairs, the company added.

WHY USE (TRANSCRITICAL) CO₂ IN COMMERCIAL REFRIGERATION?

Today, many end users from around the world consider it a “no-brainer” to opt for transcritical CO₂ in commercial applications in particular – why?

- by sheccoBase and sheccoMedia

End users from around the world have been using transcritical CO₂ for their refrigeration needs since the early 2000s. In Europe, these systems have been the norm for many years and even eastern European companies are now getting on board. Globally, regions such as South Africa and Australia are also seeing a fast spike in number of installations. These are not the only warm climates opting for transcritical CO₂ – even Mexico and the Middle East now boast installations.

Examples of happy customers in the commercial space are plentiful... Why are end users switching to transcritical CO₂ at such a rapid pace?

SOUTH AFRICA

Woolworths¹

During ATMosphere Cape Town in March 2020, three of the biggest food retailers presented on their journey with transcritical CO₂.

Alex Kuzma, Head of Engineering Services at Woolworths said: “For us it’s a no-brainer; CO₂ is business as usual now. We generally go for CO₂ wherever we can – because it works, and it works well.”

“We found it reliable and simple – and of course, sustainable,” Kuzma said about transcritical CO₂. He said that he had a lot of support from Woolworths’ board as the company’s strategy aligned with going “green.” Transcritical CO₂ is also future proof, a major plus, he said. “This is Africa, I have enough to worry about already – I want to just put a system in and not worry about it again. Transcritical CO₂ allows for that.”

SPAR²

Dutch food retailer SPAR opened its First Transcritical CO₂ Store in South Africa late 2019. The food retailer scrapped its existing premises and R22/R404A refrigeration system to invest in a more future-proof, energy efficient solution for its Middelburg store.

“We were aware of the fast-growing increase in the price of synthetic refrigerants,” explained Firmino Patricio, Owner of SuperSPAR Wonderpark. “And by installing a CO₂ system, it would help us negate this future problem.”

“We have been monitoring the development of CO₂ refrigeration systems for some time, however prior to transcritical systems, the South African climate had a significant impact on the efficiencies of these systems,”

Wayne Dedekind, Group Development Manager for SPAR South Africa stated. “With the advancements in transcritical CO₂ refrigeration, we were confident that our retailers would eventually be able to combat not only the environmental issues surrounding HFCs, but also be able to surpass the energy efficiencies of HFC plants.”

“Mr. Patricio was the first of our independent retailers to acknowledge the inevitable future of refrigeration for The SPAR Group South Africa, and we have since opened a second CO₂ site, with the objective to open another 10 sites for 2020,” said Dedekind.

Food Lovers Market³

In 2019, Food Lovers Market (FLM), a franchised supermarket and convenience store chain serving Southern Africa, installed its first transcritical CO₂ booster system in a new store in Ferndale, a suburb of Johannesburg.

“The system is quiet, manageable from a central point, and all data can be easily collated,” said Arthur Woest, project manager for FLM. “Therefore, feedback collected can assist with preventing any potential liabilities that can result in stock loss.”



U.S.

Seed to Table Market, Florida⁴

The 75,000ft² [6,968m²] Seed to Table Market, a refurbished Albertsons store that opened in December, is located in North Naples, Florida, the most south-eastern state in the U.S. The system includes three rooftop adiabatic gas coolers which helps the system function efficiently in the balmy climes of southwest Florida.

The high ambient of North Naples, the energy consumption of the system as compared to that of a traditional DX system is “parity, probably using a little more,” said Glenn Williams, sales manager, Supermarket Source, a Hialeah, Florida (U.S.)-based distributor of supermarket equipment, which arranged the purchase of the transcritical system for Seed to Table.

Williams suggested to Seed to Table’s owner, Alfie Oakes, that he should use CO₂ refrigeration if he “wanted to go all natural,” though it would cost more up front. “But he was happy that CO₂ was only 10% the cost of R448A refrigerant,” Williams said.

Weis Markets, New Jersey⁵

“Remarkable,” said Paul Burd, manager of refrigeration engineering for Weis Markets, a Mid-Atlantic chain of 204 grocery stores. He was referring to a chart comparing the energy usage of four refrigeration systems used by Weis stores between August 2018 and May 2019, as he stood before about 400 attendees of the ATMOSphere America conference in Atlanta, Ga., in June. All four systems are located in stores of similar size and refrigeration load.

What was remarkable to Burd was the energy savings demonstrated by Weis’s transcritical CO₂ refrigeration system, installed at a 54,000ft² [5,017m²] store in Randolph, N.J., in July 2018, the chain’s first such system. Its energy usage during that period was 250,790 kWh [71,654RTh], substantially below the energy consumed by the other systems, all based on HFC or HFO refrigerants: 32% less than a 1.5-year-old secondary glycol/DX system, 39% less than a seven-year-old distributed rack system, and 86% below a 23-year-old centralized DX system.

The transcritical system, Burd said, “has really been a win for us.”

AUSTRALIA

IGA, Cranbourne⁶

In 2018, the new Independent Grocers of Australia (IGA) supermarket at Clarinda Village in Cranbourne, Victoria opened boasting a transcritical CO₂ rack made in South Africa.

The client was very happy with their decision to try out this option. "When MB Refrigeration (the contractor) told me about the refrigerant changes and environmental impact of the new system along with long term cost of ownership with CO₂ gas, I could see that it was important to embrace the new system for my latest store," said Salam Rasool of IGA. "I am delighted with the result."

ALDI, Melbourne⁷

In September 2018, ALDI Australia began testing a CO₂ water-loop refrigeration system at a central Melbourne supermarket. The system is used in self-contained, plug-in cabinets, with heat withdrawn by the water loop.

After several months of operation, Marcus Meier, ALDI Australia's property director, revealed some conclusions from this test at ATMosphere Australia 2019. The advantages of the system, Meier said, lay in three areas. First, the CO₂ plug-in units "provided excellent case temperature control," he said.

Second, the solution makes sense for sites with engine-room space constraints, which was one of the original motivations to trial the system. "It's a good solution if you are in a mixed-use development where you don't have a plant room or you don't have a lot of space," Meier said.

In this case, the system was installed as a refurbishment in a multi-story high-rise building in Melbourne's space-constrained central business district. Finally, the units are "ideal for sites with sensitive noise restrictions," he said.

Woolworths, NSW⁸, Sydney⁹

Australian retailer Woolworths commissioned its first transcritical CO₂ system that fully integrates the store's HVAC&R systems on December 6, 2018. The store is located in Prestons, New South Wales.

Notably, the transcritical CO₂ system has been "completely locally designed, manufactured and installed for 45°C [113°F] ambient," according to Woolworths Sustainable Innovations Engineer Dario Ferlin.

The company states that, "by 2020 we will install ten natural systems employing technologies such as transcritical CO₂ or water loop," in its 'Corporate Responsibility Strategy 2020' report. This is a number that has since been exceeded.

Initially due for opening in March 2020, Eastern Creek is Woolworths' 13th store in Australia with a transcritical CO₂ system. The opening has been delayed however because of the COVID-19 pandemic. Ferlin said that, despite the current difficulties, the store is "an example of how transcritical CO₂ is quickly becoming the Woolworths norm."

EUROPE

Migros, Switzerland¹⁰

Swiss retailer Migros expects the vast majority of its supermarkets to use natural refrigerants by 2030 – and especially CO₂.

"In supermarket refrigeration, it's important to have efficient and reliable refrigeration production," says Urs Berger, who heads the Energy and Building Technology department at Migros Engineering Solutions (MES). "In our experience, CO₂ covers those two aspects very well," he adds.

In 2002, Migros opened its first supermarket to use CO₂, in a low-temperature subcritical system. It installed its first CO₂ transcritical system in 2005. "We decided in 2010 to make CO₂ our standard refrigerant," says Berger.

For supermarket refrigeration, all Migros's new and retrofitted installations use CO₂ transcritical systems as standard since that year.

"By 2030, the vast majority of our supermarkets will be with natural refrigerants – and especially CO₂ transcritical."

Of the 700 supermarkets in Migros's portfolio, 411 were equipped with CO₂ transcritical systems by the end of 2017 already.

Metro and Globus, Russia¹¹

In 2019, German retailers Globus and Metro AG opened new transcritical CO₂ stores in Russia.

As of January 2020, Metro AG has converted all of its R22 stores in Russia to CO₂ refrigeration, the final one located in Lipetsk, western Russia. Next on Metro's to-do list is the conversion of all of its R404A stores to CO₂.

"Talking about the large hypermarkets format, we don't see any other alternatives to CO₂ transcritical systems, as one of our top priorities is to increase the efficiency of refrigeration systems,"

said Vitaly Belozertsev, lead engineer for energy efficiency and refrigeration at Globus.

"In Russia we have now well performing installer partners, so that transcritical could be the standard. For us in Metro we will only install without exemptions transcritical systems, so far as technically possible," said Olaf Schulze, director – energy, facility and resource management, Metro AG.

"Natural refrigerants are a must for our climate, for our future as a wholesaler, and we will consequently follow this path," said Schulze, adding, "We are sure also the customers will recognize it."

Cementing the Group's reputation is its F-Gas Exit Program. A cornerstone of the firm's emissions reduction strategy, it will see Metro AG phase out f-gases by 2030, replacing them with natural refrigerants in all store locations worldwide – where it is technically feasible and economically reasonable to do so.

Mega Image (Ahold Delhaize), Romania¹²

As one of 22 local supermarket companies belonging to Ahold Delhaize, Mega Image SRL, the largest supermarket chain in Romania, shares its parent group's dedication to reducing the environmental footprint of its activities.

"Mega Image is part of the Ahold Delhaize group and all its actions are aligned to those of the group," said Vasile Casian, Technical Manager at Mega Image. "Our commitment is to have as little an impact on the environment as possible, and to make our actions more sustainable."

"Our targets refer to reaching a certain level of GWP and reducing our CO₂ emissions," he added. "To reach these targets, natural refrigerants are the best choice and the long-term solution."

MEXICO

Casa Ley, Culiacán¹³

In 2018, Casa Ley, a major food retailer in Northwest Mexico was the first supermarket operator in Mexico to install a climate-friendly transcritical CO₂ refrigeration system in one of its stores, a new 75,347 ft² [7,000m²] supercenter in Culiacán.

"We were surprised to be the first," said Juan Manuel Ley-Bastidas, son of Ley and current CEO and chairman of Casa Ley. "But we're proud of that. It validates the work we're doing."

"We believe as a company we have to be very responsible to our communities and our customers and employees, said Ley-Bastidas, who became CEO of Casa Ley in 2008 and chairman this year. "And a big part of that is taking care of the environment."

"It's not just for publicity or for marketing," he added. "It's really caring about our kids and communities."

In addition, from their analysis of market and policy trends in Mexico and other countries around the world, Casa Ley executives could see that refrigeration technology was moving toward using "less polluting gases," he said. In selecting a transcritical system, "we wanted to get ahead of legislation and stay ahead of the curve."

CHINA

Metro, China¹⁴

Metro China's Chongqing store is located in the Nan'an district and originally opened in 2001. The store building area measures 15,536 m² [167,228 ft²] and has a sales area of 8,597 m² [92,537 ft²].

The store's transcritical CO₂ system replaced an existing R22 system. "Due to the high temperature of Chongqing in the summer, we chose to use the ejector system" – a first for China – "as a solution for this store," according to a statement from the company. Energy savings compared to the previous system is estimated to be 25%. Carbon emissions are expected to be reduced by around 917 metric tons [903 imperial tons] of CO₂e per year.

* This is by no means a comprehensive list of available end user case studies. For plenty more transcritical CO₂ success stories – within commercial refrigeration and beyond – visit www.r744.com.

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INDUSTRIAL APPLICATIONS



An overview

Initially, transcritical CO₂ was often only considered for installations up to certain capacities i.e. commercial installations. Larger installations for industrial applications were perceived as too expensive and inefficient to motivate the premium cost over other solutions.

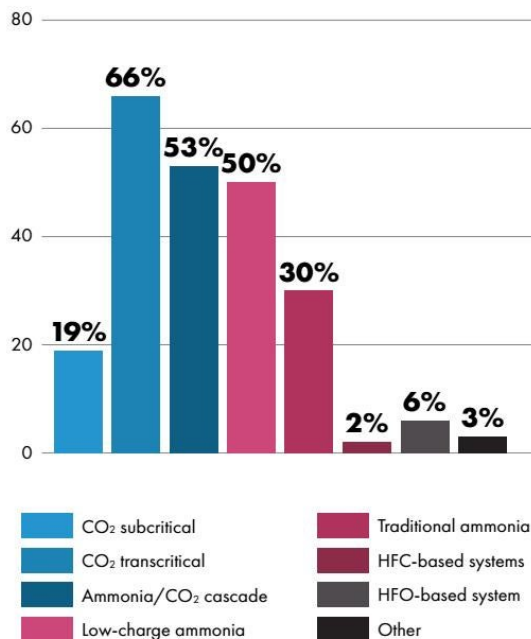
Today, this perception is rapidly changing as new innovations in transcritical CO₂ have made it a more viable solution for installations of any type. As such, the industrial market has been experiencing rapid growth with more and more transcritical CO₂ solutions emerging for large capacity projects too.

This chapter investigates the current market for transcritical CO₂ in industrial applications, specifically looking into global market trends and survey results relating to this. It also shares experiences from end users who opted for this solution and features partner case studies and interviews to show real-life applications.

TRANSCRITICAL CO₂ IN INDUSTRIAL APPLICATIONS AROUND THE WORLD – A SURVEY

TRANSCRITICAL CO₂ SEEN AS THE FUTURE CHOICE IN INDUSTRIAL REFRIGERATION

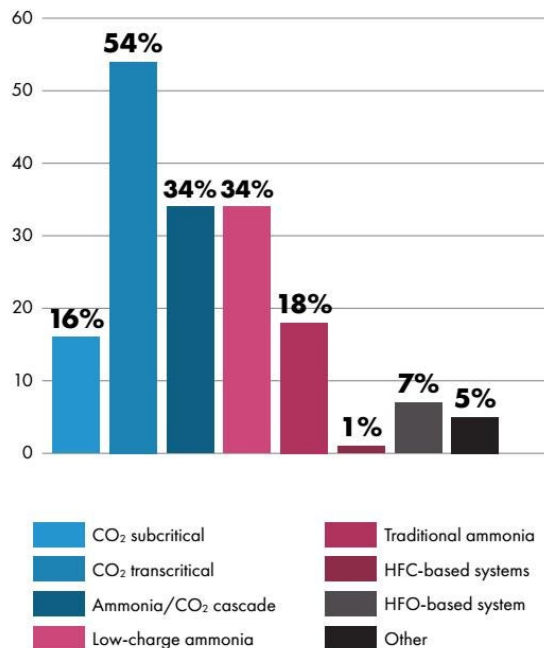
When respondents were asked which technology they expected to dominate new installations in industrial refrigeration 10 years from now, the majority were in favor of transcritical CO₂ (66%), followed by ammonia/CO₂ cascades (53%) and low-charge ammonia (50%). Traditional ammonia received 30% of all responses. This shows that the traditional use of ammonia in this sector is expected to prevail while there is also great interest in CO₂, whether in direct/transcritical systems or in indirect systems – such as ammonia/CO₂ cascades.



Number of responses: 462 [multiple answers possible]

TRANSCRITICAL CO₂ FIRST CHOICE FOR FUTURE ICE RINKS

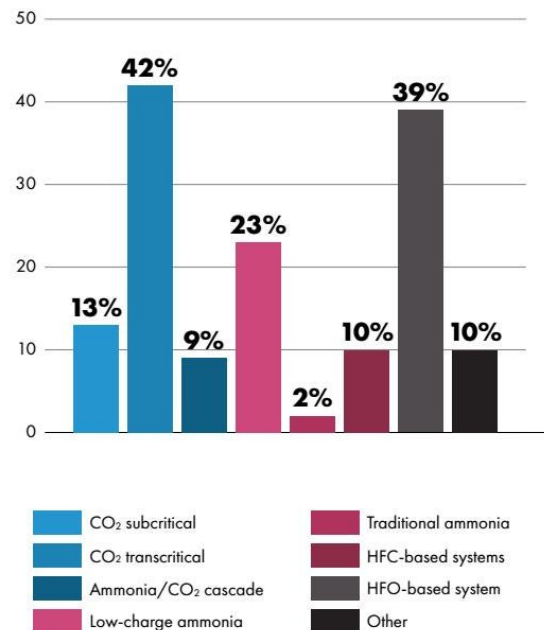
For ice rinks, survey respondents estimate that transcritical CO₂ will dominate this sector in 10 years' time, topping out with 54% of the responses. Next in line was ammonia, with ammonia/CO₂ cascades and low-charge ammonia each taking 34% respectively. Traditional ammonia scored 18%. This shows great potential for transcritical CO₂ in this sector in the future.



Number of responses: 334 [multiple answers possible]

TRANSCRITICAL CO₂ EXPECTED TO DOMINATE MARKET SHARE IN NEW DATA CENTER INSTALLATIONS

Still greatly dominated by the synthetic refrigerant market, HFOs in particular, even data centers show potential for transcritical CO₂ in the future. The majority of survey respondents (42%) expect transcritical CO₂ to dominate new data center installations in the future while HFO-based systems came in at a close second (39%). Next is low-charge ammonia with 23% of the answers.



Number of responses: 288 [multiple answers possible]

WHY USE (TRANSCRITICAL) CO₂ IN INDUSTRIAL APPLICATIONS?

USING TRANSCRITICAL CO₂ IN INDUSTRIAL APPLICATIONS – USERS EXPLAIN WHY



The use of CO₂ is enjoying rapid growth in industrial applications, taking market share in an area where it was previously considered unsuitable.

- by sheccoBase and sheccoMedia

The data collection for this guide has shown a clear increase in transcritical CO₂ installations in the industrial refrigeration sector – not only in the number of installations, but also compared to the overall share as compared to convenience store and commercial installations. sheccoBase estimates that there are around 2,200 industrial sites using transcritical CO₂ refrigeration systems, most of which are in Europe.

Various case studies in a multitude of industrial applications have been shared from around the world, showing why transcritical CO₂ should not be ruled out for larger installations. Here are a few key examples* from end users and other stakeholders sharing their experiences of working with transcritical CO₂ in industrial refrigeration applications and why it was the right system for the job.

U.S.

Yosemite, California¹

In 2018, five transcritical refrigeration racks amounting to 4MW [1.1TR] of cooling were installed Yosemite Meat Co., a meat processing facility in California, U.S.

The old facility had an ammonia 1970s semi-disconnected plant that could no longer keep up with the ever-growing refrigeration demand.

"We researched all different refrigerant systems and decided on CO₂ based on the evaluation of many factors," explained Michael Lau, Owner of Yosemite. "Our company saw benefits in choosing CO₂ with the tightening regulatory environment in California. Additionally, CO₂ provides a story to incorporate into our future path as a leader among energy efficiency and as a low GHG food processing facility."

The client has stated that they are happy with the way the new system is running as it is a lot quieter and is showing signs of being more energy efficient. "So far, the system has performed to expectations providing refrigerated cooling for product storage and hot water through heat recovery," said Lau.

(Read more on page 126 – Sphere case study)

Hannaford, Maine²

Hannaford was one of the first U.S. grocers to employ a transcritical CO₂ system in a refrigerated warehouse. Hannaford's CO₂ warehouse, located in Schodack Landing, New York (U.S.) also contains one of the world's largest refrigerated spaces [250,000ft²/23,226m²] to use a transcritical system.

The CO₂ system "seemed to be the safer overall alternative," said Dave DeLong, Director of Distribution operations at the warehouse. Moreover, he added, the cost of the system wasn't too different from that of other systems considered, and the long-term costs looked attractive.

"Environmentally, it's really hard to make any argument against CO₂ [refrigeration]," said Jim Baisley, Facility Manager at the Schodack Landing. Still, noted Baisley, there are some "perceptions of CO₂" that can be problematic. "It operates at a higher pressure, so right away people become nervous of those numbers," he said. "But it's a relative number. Your forklift carries a lot more pressure just in the hydraulic system, and nobody's worried about that."

Another issue, acknowledged DeLong, is the relative scarcity of technicians with CO₂ expertise, especially for a system as large and untested as the one at Schodack Landing. To address that, Hannaford has sent two of its in-house technicians for CO₂ training.

In transitioning from R22 to CO₂, Hannaford used the same two engine rooms occupied by the original R22 system, which consisted of a series of screw compressors that were removed a few at a time. "We needed to remove some of it to make room for the CO₂ system, but leave enough to keep our operations running," explained Baisley.

The process began last summer (2019), when the transcritical rack for the freezer room was installed during one of the hottest weeks of the year, recalled DeLong. "We've had zero problems out of the freezer since."



South Africa

Meat World³

The upgraded Meat World processing facility in Springs, South Africa boasts an energy efficient, state-of-the-art transcritical CO₂ refrigeration system. The new facility employs an impressive 370 staff, almost doubling the 180 in number at the previous facility. It also drastically increased in floor size, from 3,000m² to 7,000m² [32,292ft² to 75,347ft²].

The previous Meat World facility had a multiplex refrigeration system with synthetic refrigerants. The new CO₂ system is currently realizing energy savings of about 30% compared to the old plant, which the client is very happy about. The topping up of refrigerants is also significantly cheaper than the old system.

"The system is working very well, and I have no complaints," says Meat World CEO, Angelino Pereira. "If you're going to do something, do it properly," adds Pereira. "You have to keep up standards and work on uplifting the meat industry." Meat World places very high value on quality and not only are their own quality control processes very stringent, they also expect their entire supply chain to deliver to the same standard. It is no surprise then that they held the construction team to the same standard, expecting only the best. No shortcuts were taken, especially not with the refrigeration system.



Australia

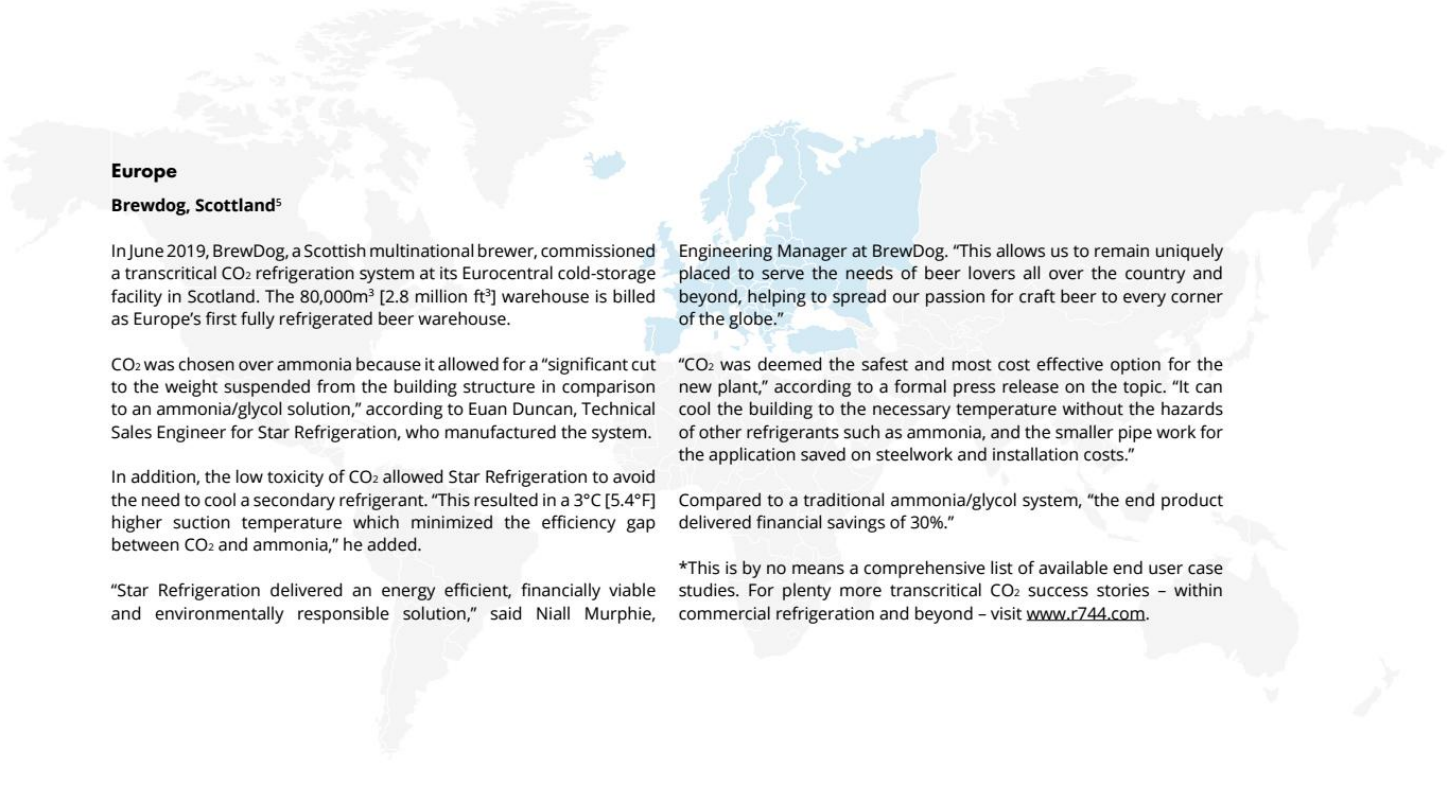
South Coast Stores⁴

South Coast Stores, an Australian wholesaler in the remote town of Nowra, New South Wales, has opted for a transcritical CO₂ system that uses solar energy and employs the waste heat from the refrigeration system for hot water and heating requirements.

South Coast Stores is a joint venture between V&C Food Distributors, and Cream of the Coast, the Streets Ice Cream distributor in Nowra. The aim of the venture was to replace the aging facilities of these two companies, both of which were nearing the end of their lives, with a new, modern building.

"The commercial viability of an ammonia plant versus a CO₂ plant with solar PV was found to be unattractive, and therefore a full CO₂ plant with booster and parallel compressors and an adiabatic gas cooler was chosen as the lowest-cost option," said Michael Bellstedt, Managing Director of Minus40 engineering consultants.

"Transcritical CO₂ in this application made sense over freon for obvious reasons and is far more cost effective over ammonia in this application," noted Shaun Davis of MB Refrigeration, the refrigeration contractor for the project. The CO₂ system had a "negligible incremental upfront investment cost relative to a freon system," added Mark Brennan, Director of Cream of the Coast.



Europe

Brewdog, Scotland⁵

In June 2019, BrewDog, a Scottish multinational brewer, commissioned a transcritical CO₂ refrigeration system at its Eurocentral cold-storage facility in Scotland. The 80,000m³ [2.8 million ft³] warehouse is billed as Europe's first fully refrigerated beer warehouse.

CO₂ was chosen over ammonia because it allowed for a "significant cut to the weight suspended from the building structure in comparison to an ammonia/glycol solution," according to Euan Duncan, Technical Sales Engineer for Star Refrigeration, who manufactured the system.

In addition, the low toxicity of CO₂ allowed Star Refrigeration to avoid the need to cool a secondary refrigerant. "This resulted in a 3°C [5.4°F] higher suction temperature which minimized the efficiency gap between CO₂ and ammonia," he added.

"Star Refrigeration delivered an energy efficient, financially viable and environmentally responsible solution," said Niall Murphie,

Engineering Manager at BrewDog. "This allows us to remain uniquely placed to serve the needs of beer lovers all over the country and beyond, helping to spread our passion for craft beer to every corner of the globe."

"CO₂ was deemed the safest and most cost effective option for the new plant," according to a formal press release on the topic. "It can cool the building to the necessary temperature without the hazards of other refrigerants such as ammonia, and the smaller pipe work for the application saved on steelwork and installation costs."

Compared to a traditional ammonia/glycol system, "the end product delivered financial savings of 30%."

*This is by no means a comprehensive list of available end user case studies. For plenty more transcritical CO₂ success stories – within commercial refrigeration and beyond – visit www.r744.com.

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NEW GERMAN UNIVERSITY'S CAMPUS CANTEEN COOLED BY TEKÖ'S CO₂ ROXSTAIN INDUSTRIAL



Made in Germany.

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ABOUT THE COMPANY

Established in 1982, TEKÖ designs and manufactures industrial and commercial heating and cooling solutions using natural refrigerants CO₂ (R744), ammonia (NH₃, R717) and hydrocarbons (R290). TEKÖ offers tried-and-tested, tailored solutions for tens of thousands of applications in the areas of:

- Food retail
- Food production
- Commercial refrigeration
- Industrial refrigeration
- Medical refrigeration
- Transport refrigeration
- Warehouses

The company is headquartered in Altenstadt, Germany. As an internationally active company, TEKÖ is represented by subsidiaries and affiliates in Europe and Asia and also delivers to South America.

INTRO

After almost 40 years, the technology and building of the canteen on the Garching Campus (Munich, Germany) exceeded its expected lifespan. Currently, around 17,000 students and about 7,000 employees are on campus every day – a number that is growing every year. To supply the largest campus of the Technical University of Munich (TUM), a new building was constructed in which the Free State of Bavaria invested around EUR44.5 million [USD48.1million].

With a usable area of 5,300m² [57,049ft²], the new building is designed to provide a total capacity of around 7,300 meals and handle 5,400 guests a day. The dining room alone measures 2,200m² [23,681ft²] and has 1,500 seats. Since September 11, 2019, students have been able to enjoy freshly prepared meals, served daily by the canteen staff.

The Garching canteen was in urgent need of modernizing since the building had long been unable to meet the required standards of capacity, technology and energy efficiency. Because of the state-of-the-art technology used, the new canteen will not only consume significantly less energy but will also offer long-term, sustainable, future-proof cooling with the natural refrigerant CO₂.

REFRIGERATION SOLUTION

The refrigeration equipment installation was designed by the engineering office Schmid+Partner from Erlangen (Germany) and installed by K.E.D. Kälte- & Klimatechnik GmbH from Bischofsmais. Beginning of 2022, a 40kW [11.4TR] limit will apply to synthetic refrigerants, and Hendrik Schmid (Engineering Office Schmid+Partner) immediately realised that their only option was a refrigeration system that uses CO₂ for this application.

At Chillventa 2018, Simon Ahlers, the CO₂ Systems Product Manager at TEKO, learned of the project and presented a perfect complete solution using CO₂. The refrigeration equipment was then redesigned to incorporate TEKO's ROXSTAindustrial CO₂ solution.

The whole project was carried out within a very short timeframe and was completed in November 2018. With a gross value of EUR1 million [USD1.1 million], the project is one of the largest individual projects ever undertaken by K.E.D.

The 5,300m² [57,049ft²] area required correspondingly long pipelines. In total, 1,750m [5,741ft] of K65 pipes up to 1 5/8" [41mm] in diameter and approximately 18.5km [61kft] of electrical cabling were laid.

What is cooled by the ROXSTA?

- 9 cold storage rooms – total area 185 m² [1991ft²]
- 4 deep-freeze rooms – total area 105 m² [1130ft²]
- 36 small refrigeration units – refrigerated display cases, tanks, refrigerators, refrigerated tables
- 4 blast chillers/blast freezers

THE RIGHT EQUIPMENT FOR THE JOB

The ROXSTA's modular design meant that the unit and intermediate pressure station could be installed separately, which is an enormous advantage in an installation of this size. And as the machine room is not large, the two units were installed separately, which economized the use of the available space.

Also, the waste heat from the refrigeration system is used to preheat the dishwasher water. The heat goes to two 500L [110gal] DK storage tanks with an integrated legionella circuit via an intermediate circuit fitted with a pump. In the storage tanks, the water is heated up to as much as 80°C [176°F], depending on the dwell time. If the capacity of the heat recovery unit is insufficient for a required temperature level, further heating is done inside the dishwashers. This special heat recovery application made it possible for planners to combine the refrigeration and dishwashing maintenance groups very effectively.

To provide the electronic controls in the Garching canteen, K.E.D. worked with TEKO's partner Wurm Systeme from Remscheid. Eight main modules with 56 refrigeration modules have been installed. These control medium temperature and low temperature cooling, as well as the blast freezers. The main HCO₂ G4 CO₂ module – jointly developed by TEKO and Wurm – is used to control the medium- and high-pressure valves, gas cooler control, heat recovery requirement and parallel compression. They also rely on control electronics from Wurm for CO₂ gas alerting system and remote data transmission.

TEKO also supplied a CO₂ gas cooler and 13 Whiteline CO₂ evaporators. Because the capacities of the refrigeration rooms vary widely, each cold room was equipped with an evaporator specifically adapted to the surroundings and the temperatures required.



ROXSTAindustrial

• Medium temperature cooling

5x Bitzer compressors

117kW (t₀ -11°C / t_{0c} 37°C) [33.4TR (12°F / 99°F)]

• Low temperature cooling

6x Bitzer compressors

13kW (t₀ -32°C / t_c -11°C) [3.7TR (-26°F / 12°F)]

• Blast chiller/blast freezer

4 x 12.4kW (t₀ -25°C) [4 x 3.5TR (-13°F)]

COLOSSAL 4MW INDUSTRIAL TRANSCRITICAL CO₂ SYSTEM CUSTOM-MADE FOR YOSEMITE

Sphere.

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ABOUT THE COMPANY

For over 10 years now, the Sphere group of companies has equipped more than 150 stores with transcritical CO₂ refrigeration, helping its clients save over 150,000MWh [42,857RTh] of energy, over 3,500,000 metric tons [3,444,723 imperial tons] of CO₂e, and over 320,000Mℓ [84,535 Mgal] of water.

The group includes Commercial Refrigeration Services (CRS), a Sphere company for over five years now, and celebrating 45 years of service to its customers. CRS has been a pioneer for developing CO₂ technology in Africa. Matador Refrigeration, founded in May 1958, also became part of the Sphere Group in 2017. Over the past 60 years, the company has grown into a national operation specializing in installation and servicing of supermarket refrigeration as well as cold storage and industrial refrigeration.

ABOUT THE PROJECT

In 2018, CRS/Sphere designed, manufactured and shipped five refrigeration racks amounting to 4MW [1.1TR] of cooling to Yosemite Meat Co., a meat processing facility in California, U.S. The project was handled by California (U.S.)-based contractor, Coolsys and at the time, it was the largest installation of this kind in the world.

In 2017, Michael Lau and his team at Yosemite Meat Co. had a vision of expanding this family-owned pork processing plant into a larger, state-of-the-art facility, allowing space for business growth, improved efficiency and the ability to have future capacity available. As such, an abandoned facility in Stockton, California, U.S. was chosen as the location.

CHOOSING CO₂ AS REFRIGERANT

Once the location was sorted, the next step was to determine what the best way was to refrigerate this new operation. The old facility had an ammonia 1970s semi-disconnected plant that could no longer keep up with the ever-growing refrigeration demand.

"We researched all different refrigerant systems and decided on CO₂ based on the evaluation of many factors," explained Lau, Owner of Yosemite. "Our company saw benefits in choosing CO₂ with the tightening regulatory environment in California. Additionally, CO₂ provides a story to incorporate into our future path as a leader among energy efficiency and as a low-GHG food processing facility."

"Although CO₂ is often more expensive than conventional synthetic refrigerant systems on smaller scales, the CO₂ solution becomes financially acceptable when implemented on larger scales, as in this case," explained Shaun Hadfield, CRS Managing Director.

Another benefit of CO₂ over other natural refrigerants is that it is a non-toxic substance that is safe for use in the food industry, thus an intermediate glycol system is not required between the CO₂ and the refrigeration coils, explained Hadfield. "The other added saving, to the client for this project was the reduction of space required for the refrigeration racks, the plant room area was made smaller enabling the client to maximize on his production area," he said.



One of the CRS racks from Sphere Solutions up close.



Inside the 4MW Yosemite refrigeration machine room.

STATE-OF-THE-ART REFRIGERATION

The entire facility is 199,993ft² [18,580m²] in size, of which 110,000ft² [10,219m²] comprises refrigerated space. These are divided up in many different dedicated areas as a production plant dictates and includes processing areas, cold rooms, freezer rooms, and snap chills.

The heart of the system consists of five CRS/Sphere parallel compressor rack systems, each with 13 semi-hermetic compressors. Each rack is split up into three separate suction groups; one designed at -13°F [-25°C] for freezer space and chill tunnels; one at 20°F [-7°C] for processing spaces, cooler storage and shipping and receiving; and one at 38°F [3°C] for parallel compression, required during transcritical operation. Each rack operates independently from the others, and loads are dispersed between the racks so that each space has redundancy in mind.

To efficiently operate a system such as this, key elements of consideration were the use of electronic expansion valves for each evaporator (required in a CO₂ system), distributed controls allowing plant operators visual indication of system operation features (refrigeration, defrost, alarm, cleaning, etc.), and distributed smart controls which enabled “zone-like” control strategies for temperature monitoring, leak detection, defrost and refrigeration control, as well as electronic valve control.

Remote defrost panels were located near the evaporator loads, minimizing wiring requirements for high- and low-voltage needs. Variable speed evaporator fan controls were included, following California’s Title 24 requirements for a refrigerated warehouse such as this.

Controls allow the fan speed to vary during certain times, minimizing fan input kW (TR), and saving energy. A Danfoss control system was selected as the controls of choice, allowing central oversight, but “smart” local independent controllers not requiring a host central processor.

“In selecting CO₂ as the refrigerant of choice, this enabled the design to take in a more ‘commercial’ approach in an ‘Industrial’ setting,” explained Bryan Beitler, Vice President Special Projects, CoolSys.

The inclusion of hybrid gas coolers on this system enables the system to function in transcritical mode, in a high ambient environment. The dry bulb design for the plant is 103°F [39°C], and with the addition of a wetted pad upstream of the gas cooler coils, ambient temperatures are dropped to a significantly lower level, facilitating as efficient as transcritical operation as possible. When ambient temperatures are low enough, the system will automatically shift to sub-critical mode, disabling the parallel compressor function. The booster system design is built to take full advantage of every possible opportunity to run as efficiently as possible.

INDUSTRIAL TRANSCRITICAL CO₂ SYSTEM FOR SWEDISH ICE RINK IMPROVES ENERGY SAVINGS



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ABOUT THE COMPANY

EKA, Energi & Kylanalys AB, is a company with a true passion for natural refrigerants and energy saving. EKA offers qualified engineering services in the field of energy and refrigeration applications with a specialization in Combined Cooling and Heating (CCH). As an impartial consultant, our services are always based on the latest scientifically available knowledge. We have a close collaboration with research institutes, universities and other specialists in the energy field to always be in the technical forefront. Today, EKA plays a leading role in the field of ice rink consultancy with a worldwide presence.

INTRODUCTION

Ice rinks are energy-intensive facilities and statistics from Sweden show that a typical single sheet indoor ice rink with conventional technologies uses about 1,000MWh [286RTh] purchased energy annually.

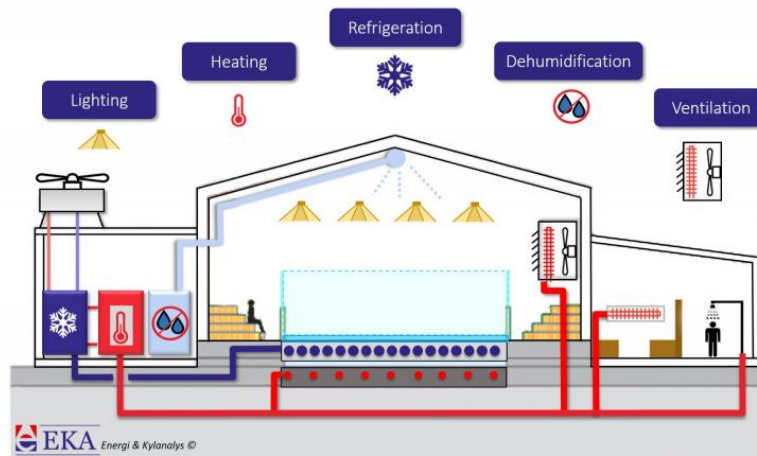


Figure 1: The general "Big five" energy system layout of an ice rink with optimized heat recovery.

Operating an ice rink involves several energy systems such as the following: refrigeration, heating, dehumidification, lighting, and ventilation. These "Big five" systems, seen in Figure 1, normally account for more than 90% of the energy used (Rogstam et al., 2014).

To maintain the desired ice temperature, the refrigeration system extracts heat from the ice.

This heat together with the added energy from the compression work is eventually rejected on the warm side of the refrigeration system. Optimizing the heat recovery process is by far the best energy-saving measure that can be done in an ice rink. It has been shown that when the heat recovery system is well-designed, the ice rink may be self-sufficient with heat (Rogstam and Bolteau, 2015).

CO₂ has very good thermodynamic properties in terms of heat recovery. This is mainly due to the possibility of operating in so-called transcritical mode. When a CO₂ refrigeration system operates in transcritical mode, as much as 50% of the rejected heat is available at a temperature higher than 38°C [100°F], as shown in Figure 2. This advantage allows the CO₂ heat recovery system to potentially cover all heating demands in a heated ice rink, thus considerably reducing the cost of operation.

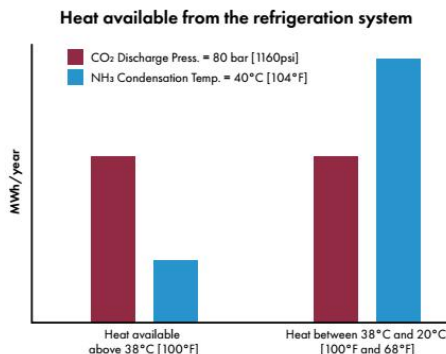


Figure 2: Comparison of the heat available between CO₂ and NH₃. (Rogstam et al., 2017)

Using CO₂ also in the distribution system (in the rink floor) brings several advantages over traditional secondary refrigerants, e.g. calcium chloride or ethylene glycol. This type of solution enables the system to run at a higher evaporation temperature, increasing the efficiency of the refrigeration process. Other prominent advantages are that CO₂ utilizes a phase change (evaporation) and has a low viscosity which leads to a considerably lower pumping power. By applying CO₂ as the secondary refrigerant in a rink floor the pumping power can be reduced to about 1kW

[0.3TR], a considerable improvement when compared with traditional fluids which require 5-15kW [1.5-4.3TR]. In a retrofit project where the rink floor is not affected, very good results can also be achieved by installing an indirect CO₂-system that uses aqua-ammonia as the secondary refrigerant in the existing plastic pipes.

ABOUT THE SYSTEM

Bahochallen is an average-sized ice rink, located in Enköpings municipality, Sweden. The facility used to be a single sheet ice rink, with a heated arena room. An ammonia refrigeration unit was connected to a brine circuit in the rink floor. Its heat recovery function provided a maximum of 28°C [82°F] fluid temperature which was mainly used for preheating air in an air handling unit.

In 2016, a new CO₂ system was installed with direct expansion into new copper pipes embedded in a layer of concrete on top of the existing rink floor. An additional indoor ice surface, located in a brand-new building adjacent to the existing ice rink, was included in the renovation project in 2017, bringing the total heated building surface to ca. 8,000m² [86,111ft²]. Moreover, an optimized heat recovery system connected to the CO₂ unit was designed to cover the heating demands of both ice rinks.

RESULTS

The second ice sheet was connected to the unit at the beginning of the season 2017-2018. The CO₂ system is now able to support two ice sheets, with a total energy consumption that is only 10% higher than what the previous energy systems needed when running only one rink. Such an improvement is mainly possible due to the high performance of the modern heat recovery system. As can be seen in Figure 3, almost no district heating is utilized today.

2 for 1: Two ice rinks with the consumption of one

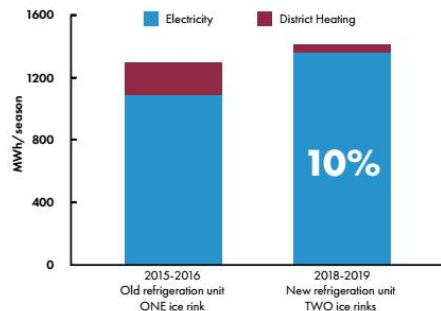


Figure 3: Energy consumption of the facility before and after renovating the refrigeration unit.

SUMMARY

This project demonstrates the great potential for energy savings when retrofitting an old ammonia-based refrigeration system with a modern CO₂ unit including an optimized heat recovery solution. Today, the facility in total consumes only 10% more energy with one additional indoor ice rink. The specific consumption has been cut by almost 50% and the heat recovery system provides almost all the necessary heat. Thanks to the good performance of this modern system solution, the municipality has decided to extend the season of one rink to full year operation. Finally, a swimming pool is currently being built adjacent to the ice rinks to which the remaining heat will soon be exported.

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THE BENEFIT OF TRANSCRITICAL CO₂ FOR INDUSTRIAL REFRIGERATION SECTOR



CO₂ offers a number of benefits for industrial refrigeration as a result of its physical properties and environmental credentials.

– By Stuart R Webb (BSc. MInstR), CO₂ Market Manager, Star Refrigeration

Carbon dioxide (CO₂) has taken great strides as a refrigerant in recent decades, to the point where it now represents a well-established, mainstream refrigeration solution. The year-on-year uptake of CO₂ systems in the commercial sector has been considerable, with total transcritical installations numbering in the tens of thousands. However, CO₂ is also an invaluable refrigerant for the industrial sector, where it can be used to great effect in a variety of applications and system architectures.

CO₂ offers a number of benefits for industrial refrigeration as a result of its physical properties and environmental credentials. For operators of industrial systems, it is important to know that the refrigerant they choose will be future proof and viable for the entire lifespan of the system; a period that is typically measured in decades

in industrial applications. With a Global Warming Potential (GWP) of one and Ozone Depletion Potential (ODP) of zero, CO₂ is not affected by the increasingly stringent legislation surrounding synthetic chemical refrigerants. As a result, operators are able to invest in CO₂ with confidence, without worrying about upcoming refrigerant bans, phase downs and associated pricing volatility. CO₂ is non-patented and freely available worldwide, at a cost that is both low and stable – a crucial factor when installed refrigerant quantities are high, as is the case with industrial systems.

Furthermore, CO₂ has the benefit of an A1 safety classification (non-flammable with low toxicity), which is an attractive feature for operators concerned about the use of flammable or toxic refrigerants on their site, for example where facilities are located in populous or residential areas. Of course, it would be impossible to discuss industrial refrigerants without mentioning one such refrigerant in particular – ammonia (NH₃). Ammonia is a standard refrigerant in industrial applications and for good reason. It too boasts impressive environmental credentials (GWP = 0, ODP = 0), has attractive thermodynamic properties and delivers highly efficient cooling. However, being classified as toxic and mildly flammable, NH₃ comes with some extra technical and safety considerations which mean that CO₂ can be a more cost-effective solution for small to medium

industrial sites. Every industrial refrigeration project has a specific list of considerations and requirements and it is important to select the optimal solution for the project at hand.

At Star Refrigeration (the UK's largest independent industrial refrigeration engineering company), CO₂ has been employed in a variety of applications over the last thirty years; from temperature-controlled storage and distribution to blast and spiral freezing. Depending on the site, CO₂ can be used in pumped, LPR or DX configurations, or as a volatile secondary refrigerant, and may be used either sub-critically or trans-critically.

Subcritical CO₂ systems present a very effective solution for industrial applications, for example in combination with a site glycol loop and / or high stage NH₃ circuit. By using CO₂ sub-critically, system pressures and complexity are reduced, and supercritical operation is avoided. Fewer, larger compressors can also be used, however there is of course the need for an intermediate heat exchanger and a separate high stage system. These types of cascade systems can deliver impressive performance and are typically installed on larger industrial sites.

Transcritical CO₂ systems, on the other hand, are well suited to small- and medium-capacity industrial applications, up to five or six hundred kilowatts (although this will vary). An example of a typical transcritical system would be one recently delivered by Star for a pizza manufacturer in Glasgow, UK, where a two stage transcritical booster CO₂ system was selected to fulfil the customer's low carbon and energy efficiency requirements. A single packaged unit was installed, delivering 200kW [56.9TR] of capacity to a spiral freezer operating at -40°C/-40°F. The system was equipped with multiple semi-hermetic reciprocating compressors and was designed for flexibility, with the ability to operate at two different temperature levels whilst achieving a small site footprint.

Other examples of recent transcritical systems include a 480kW [136.5TR] chilled distribution warehouse as well as a meat processing facility delivering 70kW [20TR] of low stage duty and 185kW [52.6TR]



Stuart R Webb

of high stage duty to various processes, including blast freezing, cold storage, inline chilling and chill storage.

It is clear that CO₂ systems will continue to be used in industrial refrigeration, with their deployment being seen on an increasingly frequent basis. However, with transcritical CO₂ systems becoming ever more popular, it will be important that these systems are developed, designed and manufactured to suit the demands and rigors of industrial (as opposed to commercial) settings. Controls, components, industrial build quality and dynamism in design are all key to ensuring that transcritical CO₂ continues to progress within the sector. The availability of larger, and appropriately rated, CO₂ compressors, high strength copper pipe work and associated components will also serve to advance the technology in this field.

SUPERMARKET SAVES UP TO 25% ON ENERGY, SPACE, AND MAINTENANCE WITH TRANSCRITICAL CO₂ HVAC&R INTEGRATION



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ABOUT THE COMPANY

Eliwell has been developing and producing control systems and services for commercial and industrial refrigeration since 1980. It embodies the success story of an Italian company that has been bringing Italian-made technological development to the world for 40 years. It has been part of the Schneider Electric group since 2014 and represents its center of excellence for HVACR applications. Today Eliwell, together with Schneider Electric, is the global partner providing efficient and sustainable solutions and services for food storage and distribution systems, as well as for systems dedicated to ambient comfort, for the integrated control of resources.

INTRODUCTION

Looking at efficiency through the eyes of a supermarket owner means identifying solutions to optimize the whole building and not just each individual part.

While history shows many examples of systems designed and built separately and only later connected and optimized, this case study shows how to start with a native optimized solution from the very beginning.

Thanks to the contribution of Biaggini Frigoriferi, Migros Riazino, a supermarket in southern Switzerland, is an example of a CO₂ transcritical system with integrated HVAC and refrigeration control systems that maximize energy efficiency while minimizing space occupation and maintenance.

The comprehensive solution benefits from one of Eliwell's latest releases within the RTX Domino Zero series of controllers, designed to grant optimal superheat control. The new solution can manage the superheat in evaporators at the lowest stable value in adaptive mode; this maximizes the heat exchange in the unit and allows for smooth operation of the compressor rack, thus reducing the need for maintenance.

The Migros Riazino supermarket is also a good example of a holistic approach to the design of the core control systems of the store, shifting from multiple suppliers to a single point of contact for the design and maintenance of all sub-systems: refrigeration, space heating and space cooling.



Migros Riazino Supermarket

ABOUT THE PROJECT

The collaboration between Migros, Biaggini Frigoriferi and Eliwell has already seen several sustainable and efficient CO₂ transcritical systems installed in the Ticino region; the introduction of the new Domino Zero offered the opportunity to go beyond refrigeration to design a completely HFCs-free supermarket.

The new integrated HVAC&R system has been designed as a CO₂ booster rack for 60kW [17TR] medium temperature (MT) and 15kW [4.3TR] low temperature (LT) refrigeration with auxiliary compressors that can deliver 55kW [15.7TR] heating in winter and 70kW [19.9TR] cooling in summer, while delivering hot water for space heating thanks to a dedicated plate heat exchanger.

The overall efficiency of the system is managed by:

- optimization of the suction pressure of the positive line through an optimal superheat control performed by the Eliwell RTX 600 /V Domino Zero with pulse EEV in each piece of equipment
- the RTX600 /VS Domino Zero controlling the motorized EEV for the chiller in nearly flooded evaporator mode. This is connected to the gas cooler outlet, avoiding a dedicated liquid line and additional costs
- sub-cooling plate exchanger with EEV controlled by RTX600 /VS Domino Zero to manage critical external conditions. As an example, with 37°C [98°F] external temperature, the EEV opens by 60% thus feeding CO₂ at 25-27°C [77-81°F] to the liquid receiver
- the EWCM 9000 PRO-HF Domino controller, that manages the compressor rack including the gas cooler, high pressure and flash gas valves and, thanks to the open programmability, the auxiliary line with chiller and heat pump coordination.

Even though the machine combines three traditional machines, the integrated CO₂ transcritical solution has been designed using standard components and an architecture based on a CO₂ booster with parallel compression. This means that, in terms of dimensions, the layout of the compressor rack is still as compact, clean and lean as a booster dedicated to refrigeration only.

Cold and hot water for space heating has been designed using plate exchangers and motorized EEVs. Those are reliable components and strengthened technologies well known in the refrigeration technician's world.

RESULTS

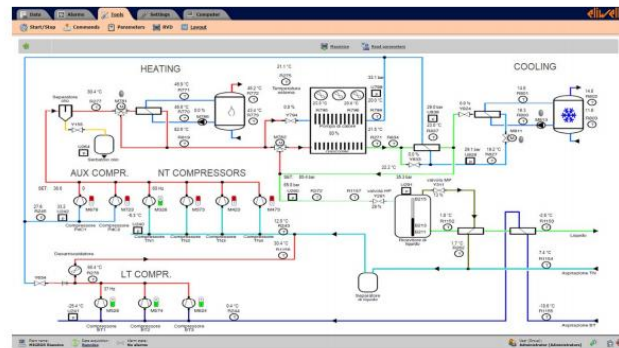
The benefit of an integrated machine with a controller programmed to optimize the working parameters depending on seasonal and load conditions has led to a compact and efficient system capable of covering a greater demand for space cooling – on average 25% to 30% increase in cooling capacity in summer – with lower total energy consumption compared to previously.

Increased energy efficiency is not the only good news for the supermarket chain. It has also boosted its environmental sustainability: A unique integrated system with CO₂ natural refrigerant has made it possible to eliminate 100% of HFCs from the HVAC&R equipment.

The new design has also completely changed the layout compared to the traditional design. The compressor rack is roughly 20% bigger than a traditional booster but the solution does not need a separate heat pump and chiller, leaving more available space and reducing the complexity of installation and piping.

Similarly, the investment for the new equipment benefits from the integration of the three HVAC&R machines into one compressor rack and from the easy replacement of superheat controls with Domino Zero in cabinets and cold rooms, reusing most of the existing equipment and piping.

In addition, operative costs are reduced due to the integration; with service and maintenance contracts decreased from three to one and Building Management System (BMS) integration with remote maintenance delivering the highest system reliability and level of service.



CO₂ HVAC&R machine room live data from TelevisGo monitoring system.

SUMMARY

After 12 months and four seasons of operation, the results are more than positive in all critical aspects:

- 25% more cooling capacity with reduced energy consumption
- 25% reduction in machine room space occupation vs. rack plus heat pump and chiller
- 25% reduction in initial investment vs. traditional systems
- 100% natural refrigerant supermarket for HVAC&R
- Single maintenance contract for all the HVAC&R sub-systems
- All HVAC&R systems connected to BMS and remotely monitored 24/7

The Domino Zero solution proved to be efficient and sustainable; minimal changes to the equipment were required and an optimal ROI was obtained and finally applicable to new supermarkets and retrofits.

LOOKING AT CO₂ REFRIGERATION TECHNOLOGY – TODAY AND IN THE FUTURE

Partner interview with Enrico Zambotto, Refrigeration Director at Arneg



DOES THE USE OF CO₂ ENTAIL PARTICULARLY HIGH COSTS FOR REFRIGERATION SYSTEMS?

In commercial refrigeration, there are a series of applications for which R744/CO₂ refrigerant is convenient and can be used with very favorable ecological efficiency. In the field of applications for supermarkets and small industrial plants, there are currently highly competitive refrigeration systems whose investment costs are similar to those of conventional systems but whose environmental impact is extremely limited considering both direct pollution, loss of refrigerant fluid in the environment, and indirect pollution generated by electricity production.

If in addition to the reduced ecological footprint and the investment safety guaranteed by CO₂ systems, life cycle costs are also considered, in our opinion, CO₂ systems can be even more convenient than conventional equivalent systems; particularly so considering the increase in the prices of HFC refrigerants and the uncertainty about their future availability (due to the EU F-Gas Regulation). Our innovations also contribute to this competitiveness, such as the parallel compressor system, the use of inverters for each compression stage and the use of ejector technology.



Enrico Zambotto

The system setup is fundamental: the measurement of consumption paired with the verification of the optimal coefficient of performance (COP) through continuous analysis is a must. To have all the information available, we have equipped all our compressor rack units with an energy meter, which can be connected via Modbus directly to the supervision system. These are “devices” that increase energy efficiency without increasing the cost of the system.

WHICH OF THE AFOREMENTIONED TECHNICAL MEASURES DO YOU CONSIDER PARTICULARLY SUITABLE TO SUPPORT THE NECESSARY EFFICIENCIES ECONOMICALLY?

Each of the proposed devices brings its useful contribution to increase performance. Some are already active at low ambient temperatures and are therefore now considered to be design standards; I am referring to the use of inverters and parallel compressors. Others can be used in harsh environmental conditions, such as high temperatures, in particular the ejector. Heat recovery, ideal for hot tap water or heating, can be used in any solution.

The continuous control of temperatures, operating pressures and electrical power supply is fundamental to containing energy consumption. System plant solutions with high added value are worthless if there is no continuous monitoring of system performance. Constant verification cannot be carried out by a human but must be performed by machines (machine to machine). They monitor the operating parameters and environmental variables to carry out a continuous analysis of the system, managing to predict the running performance of the system itself. We are now able to predict the consumption of the system according to the turnout of the shop and the internal and external temperatures (predictive analysis). By analyzing the data from various sources and cross-referencing them, interesting results can be obtained, which makes it possible to maximize performances in all conditions and carry out scheduled maintenance or urgent interventions at times of minimal impact for the customer.

I believe it is essential that the systems are simple to install, configure and maintain. For this reason, the training of designers is fundamental and at this start-up stage, it must be continuous and at a high level.

IS THE USE OF CARBON DIOXIDE A MATURE SOLUTION OR DO YOU SEE SPACES FOR DEVELOPMENT AND INNOVATION?

Although the technology of CO₂ systems may seem to have reached a mature stage of development, I believe there is still much to be done in terms of research, rationalization, industrialization and optimization; not major innovations but many small developments that can still lead to important results. We must not mistakenly consider that only a modification of the thermodynamic circuit can lead to improvements in performance. Too often we find sizeable systems running by themselves with consumption and temperatures far from their optimal design.

Research should not only be aimed at finding performing solutions but at ensuring that these are maintained for a long time. It has to be possible to constantly check that the operating values remain within what had been the design values. The boundary conditions established during the design phase must be constantly verified.

In the coming years we will see significant improvements in products, performances and consumption, which will lead to a significant reduction in the footprint of the plants, significantly reducing both direct and especially indirect CO₂ emissions.

THE FUTURE OF TRANSCRITICAL CO₂ REFRIGERATION



KYSOR WARREN
eptarefrigeration

There are various drivers and barriers that are influencing the uptake of transcritical CO₂ systems in the refrigeration sector. Where do the opportunities really lie with these systems?

– By Conner Meadows, Systems Product Manager at Kysor Warren (part of the Epta Group)

WHAT ADVANTAGES DO TRANSCRITICAL CO₂ REFRIGERATION SYSTEMS PROVIDE?

Transcritical CO₂ provides many advantages in terms of environmental sustainability, safety, and energy efficiency. CO₂ has a global warming potential (GWP) of 1 which means it is the baseline used to quantify the impact that a greenhouse gas has on global warming. Being that CO₂ is non-flammable and non-toxic, it is an ideal refrigerant to aid in the advancement of natural refrigerant solutions around the globe.

The thermodynamic characteristics of CO₂ also make it an efficient refrigerant in terms of capacity and as a result the line sizes are reduced one to two sizes compared to that of an HFC system, which reduces the cost for the store piping. Also, the cost of refrigerant grade CO₂ is relatively cheap at US\$1-2/lb [EUR2-4/kg], compared to R407A



Conner Meadows

which is US\$7-8/lb [EUR14-16/kg]. With new enhancements like Epta's Full Transcritical Efficiency (FTE), the efficiencies of transcritical CO₂ systems continue to increase, and in many cases, out-performs the current HFC systems.

WHAT ARE THE MAJOR CONSTRAINTS OR BARRIERS TO THE MARKET FOR TRANSCRITICAL CO₂ SYSTEMS?

The three barriers that we find most prevalent amongst customers are defined as reduced efficiency in warmer climates, increased capital investment, and serviceability/industry knowledge. The relatively low critical point of CO₂ introduces challenges to the efficiency levels in high ambient conditions. There have been many advancements in

the technology aimed at helping mitigate this obstacle, which are showing positive results and improving the efficiency of transcritical CO₂ systems in hot climates. Another obstacle that is present in the U.S. market is the cost parity of the transcritical CO₂ system compared to an HFC system.

One influencing factor is that in the U.S. market the number of CO₂ systems is much lower than that of European countries where the cost of CO₂ systems is lower. The U.S. market also has certification requirements that drive up component pricing. As the adoption rate of transcritical CO₂ systems increases, component prices should decrease, thus reducing the cost parity. With the technology advancements also comes increased complexity in terms of serviceability, which must be managed with increased training opportunities and after sales support from the OEMs. Epta's innovative yet simplistic FTE enhancement mitigates the effect of these barriers by providing 10% energy savings in any climate region at a fraction of the cost of other seasonal efficiency enhancements available on the market. With the current technological advancements in combination with superior training and support the stage is set for future growth of transcritical CO₂ systems.

WHERE DO YOU THINK THE BIGGEST OPPORTUNITIES FOR TRANSCRITICAL CO₂ LIE?

The vast opportunities for transcritical CO₂ are in the commercial supermarkets, cold storage warehouses, convenience stores, and specialty markets such as ice rinks. With many retailers scaling back new brick and mortar stores and moving to online sales, self-pickup, and delivery options, the cold storage market and self-service grocery opportunities are predicted to be on the rise. Also, many retailers are scaling back the size of the stores, which also brings opportunities for smaller capacity transcritical CO₂ opportunities.

WHAT HAVE BEEN THE MOST INFLUENTIAL REGULATORY DEVELOPMENTS FOR TRANSCRITICAL CO₂?

There are many states taking the lead in implementing regulations introduced as part of the Environmental Protection Agency's (EPA) SNAP rules 20 and 21. For example, the California Air Resources Board (CARB) initial proposal included a GWP limit of 150 for commercial refrigeration systems containing more than 50lbs [22.7kg] of refrigerant, starting on January 1, 2022. Refrigerants such as isobutane (R600a), ammonia (R717), propane (R290), and CO₂ (R744) all have GWPs less than 150.

More recent proposals include goals of reducing retailers' weighted average GWP to 1,400, equating to a 55% reduction by 2030. Many other U.S. states including Washington, Vermont, New Jersey, Colorado, Oregon, and Hawaii have also announced that they too intend to adopt similar regulations. Also, there are some incentives to help offset higher upfront cost to end users for implementing systems utilizing natural refrigerants such as CO₂.

The North American Sustainable Refrigeration Council has launched an Aggregated Incentive Program (AIP) with the goal of accelerating and increasing the funding resources for natural refrigerant solutions. CO₂ meets all the criteria for a future proof refrigerant option, as it's non-flammable, non-toxic, and has a GWP of 1. Transcritical CO₂ systems will play a major role in the global effort to eliminate the use of high GWP refrigerants and the progression to more environmentally sustainable solutions.



THE FUTURE OF TRANSCRITICAL CO₂ REFRIGERATION



An overview

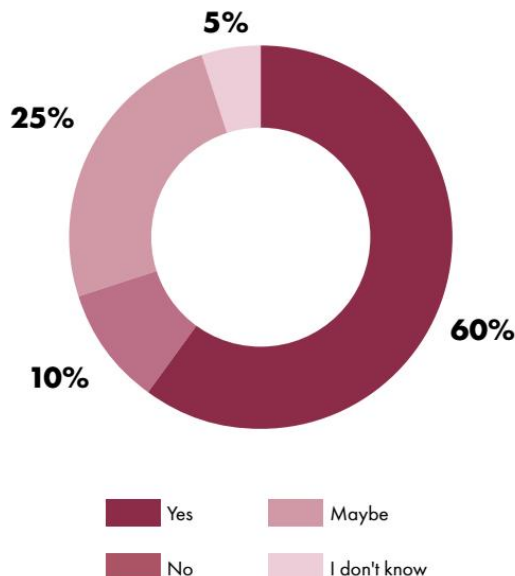
What does the future look like for transcritical CO₂ in refrigeration? Based on interviews, market research, and survey results, this chapter anticipates the global market potential for transcritical CO₂ technology, looking at its future uses and projected growth around the world.

It will also cover drivers and barriers for the uptake of this technology to show where more work is required to further mainstream the use of transcritical CO₂ globally. This chapter also includes various thought leader pieces from industry experts to discuss the potential of using transcritical CO₂ in the refrigeration sector.

THE FUTURE MARKET FOR TRANSCRITICAL CO₂ REFRIGERATION WORLDWIDE – SURVEY RESULTS

MANUFACTURERS AND CONTRACTORS: MAJORITY PLAN TO WORK WITH TRANSCRITICAL CO₂ IN THE FUTURE

Manufacturers, contractors, consultants/engineers and others who do not work with transcritical CO₂ currently were asked if they plan to do so in the future. The overwhelming majority answered with “Yes” (60%), followed by “Maybe” (25%), and only 10% said “No”. This positive response affirms the future potential for transcritical CO₂ in refrigeration applications far and wide.

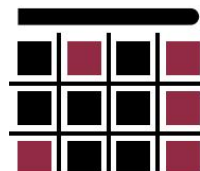


Number of respondents: 40

MANUFACTURERS AND CONTRACTORS: MAJORITY PLAN TO USE TRANSCRITICAL CO₂ WITHIN THE NEXT YEAR

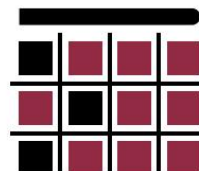
Manufacturers and contractors, who are planning to work with transcritical CO₂ in the future, plan to do so very soon, with the great majority of survey respondents (75%) estimating to start in 2020-2021. The other 25% plan to do so only slightly later – by 2022-2023.

75%
are planning to start working
with transcritical CO₂ in
2020-2021



Number of respondents: 24

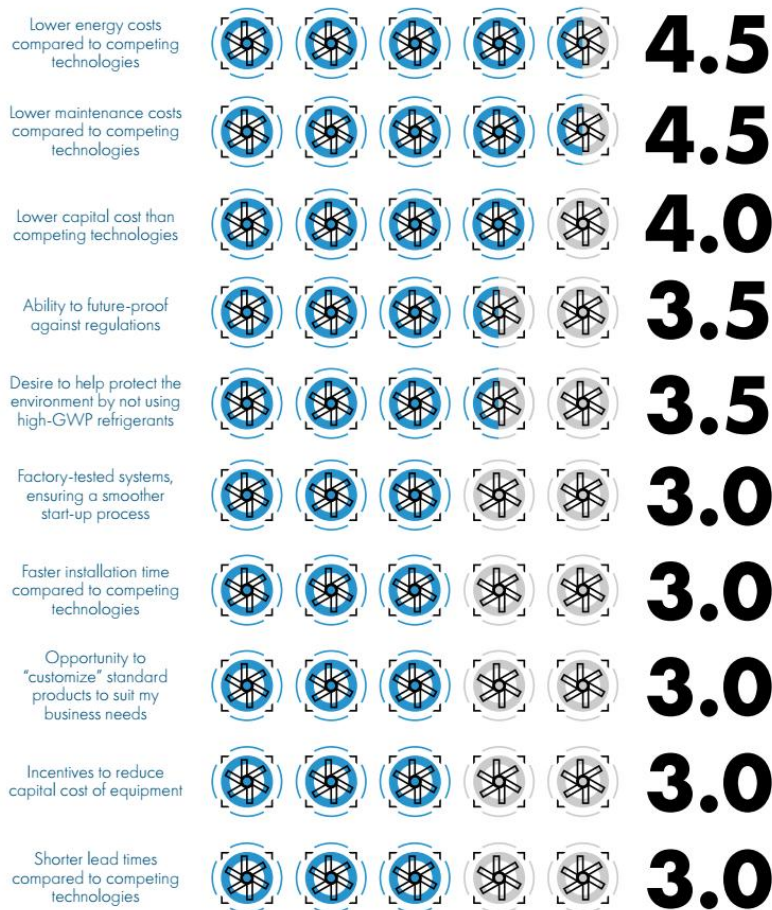
25%
are planning to start working
with transcritical CO₂ in
2022-2023



ENERGY COSTS AND MAINTENANCE COSTS THE MOST IMPORTANT FACTORS FOR NEW EQUIPMENT PURCHASES

Influencing factors for equipment purchases for end users (Ranking from 1 to 5 with 5 being the highest influencing factor)

End users who currently do not have any transcritical CO₂ installations were asked to rate how different factors would positively influence their decision to buy a transcritical CO₂ system. Lower energy and maintenance costs, as compared to competing technologies, were the most decisive factors. Another important driver was capital costs. This shows the importance of cost-competitiveness for transcritical CO₂ vs. other technologies – not only in terms of CAPEX, but also life cycle costing (LCC).

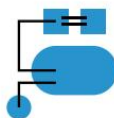


Number of respondents: 7

END USERS: TRANSCRITICAL CO₂ MOST POPULAR OPTION FOR FUTURE REFRIGERATION PROJECTS

End users who participated in the survey are most likely to consider transcritical CO₂ for future refrigeration projects with R290 self-contained cases also scoring high. There were 81 responses in total, and 76% went to transcritical CO₂, 52% to R290 self-contained cases, and 31% to subcritical CO₂. As the large majority of end users in this survey are active in commercial refrigeration and supermarkets in particular, these answers are in line with current global trends for this sector. In the category "Other", which scored 28% of the votes, indirect systems with R290 or other hydrocarbons were often mentioned.

24%



Traditional
ammonia
systems

24%



Low-charge
packaged
ammonia
system

14%



Optimized
centralized
ammonia
system

76%



Transcritical
CO₂

31%



Subcritical
CO₂

52%



R290
self-contained
cases

17%



Ammonia/CO₂
cascade

7%



HFC-based
systems

7%



HFO-based
systems

28%



Other

Number of responses: 81 [multiple answers possible]

TRANSCRITICAL CO₂ SHARE IN COMMERCIAL REFRIGERATION MARKET EXPECTED TO GROW IN NEXT FIVE YEARS

The survey respondents were asked to estimate the market share of transcritical CO₂ in its traditional sector, commercial refrigeration – now (in 2020) and five years from now (in 2025).

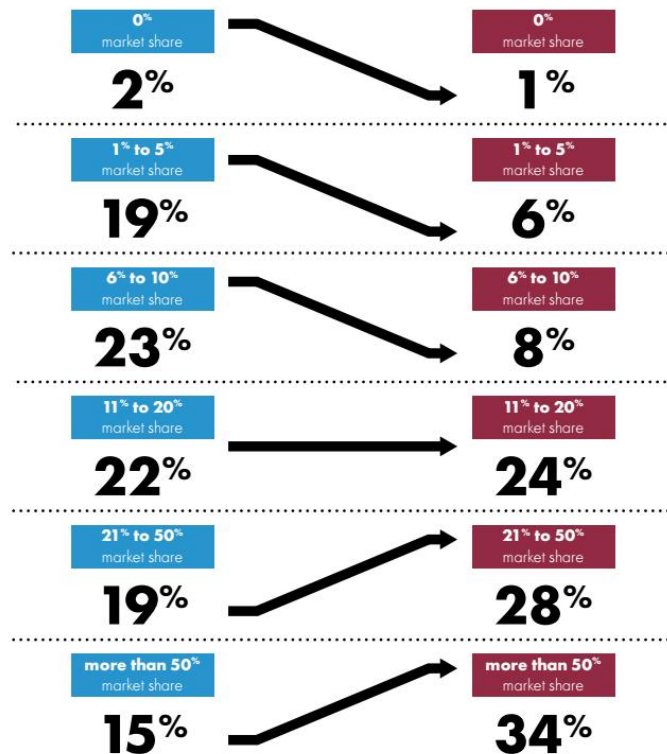
Responses for 2020 were varied and only moderately ambitious. Results were rather evenly split between the possible ranges. The greatest exception was those who believed the market share to be 0% – only 2% of the total respondents selected this option. More positively, 15% selected a market share of more than 50%.

For 2025, the results look different. The lower ranges received fewer responses. While for 2020, 66% of the respondents estimated a market share of 0-20%, only 39% of the respondents selected this lower range for 2025. The higher ranges received more responses, with 28% selecting a market share of 21-50%, and 34% opting for even more than 50% (compared to 19% and 15% of the respondents for this same question relating to 2020).

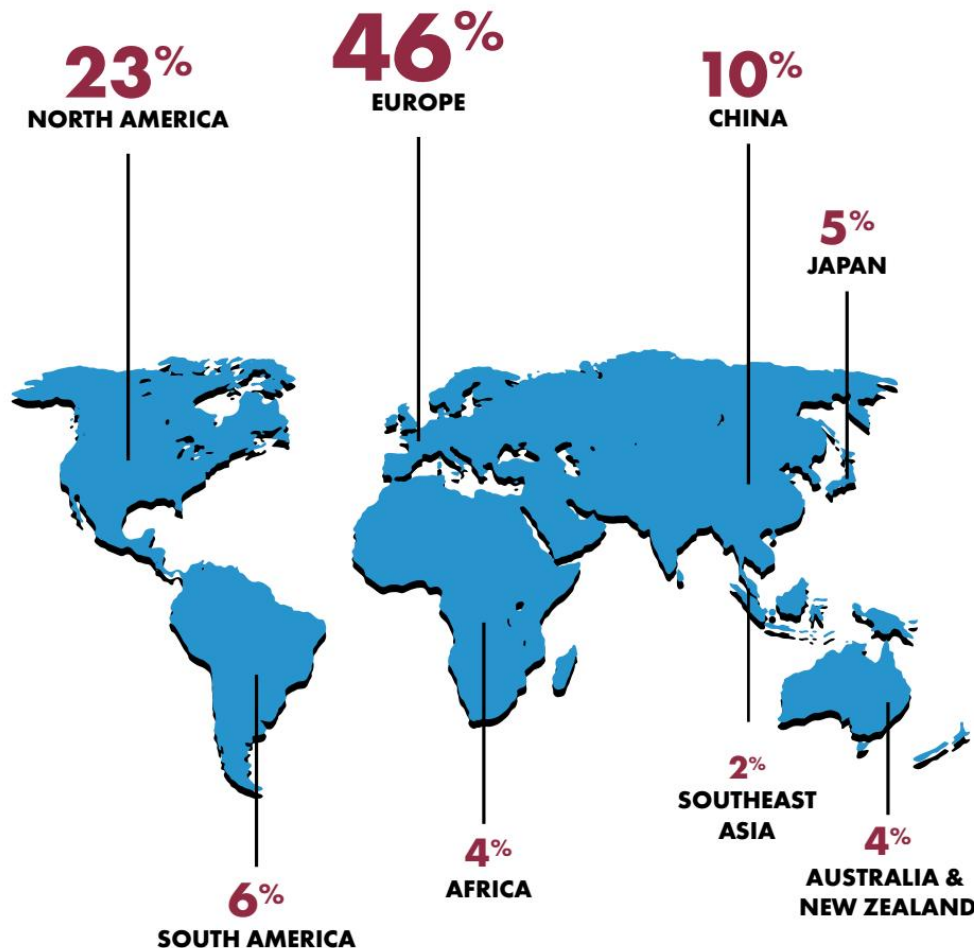
This result shows the market share of transcritical CO₂ in commercial refrigeration is expected to grow over the next five years.

2020 Current market share for new installations using transcritical CO₂ in commercial refrigeration

2025 Market share for new installations using transcritical CO₂ in commercial refrigeration 5 years from now



Number of respondents: 204 and 201



MAJORITY OF RESPONDENTS EXPECT FASTEST GROWTH OUTSIDE OF EUROPE

The relative majority of survey respondents (46%) still expect the fastest growth of transcritical CO₂ in commercial refrigeration to happen in Europe (traditionally the biggest market). However, it is positive to note that more than half now expect the fastest growth to happen outside of Europe. This includes North America (23%), China (10%), and South America (6%). Other global regions scored 5% or less, each.

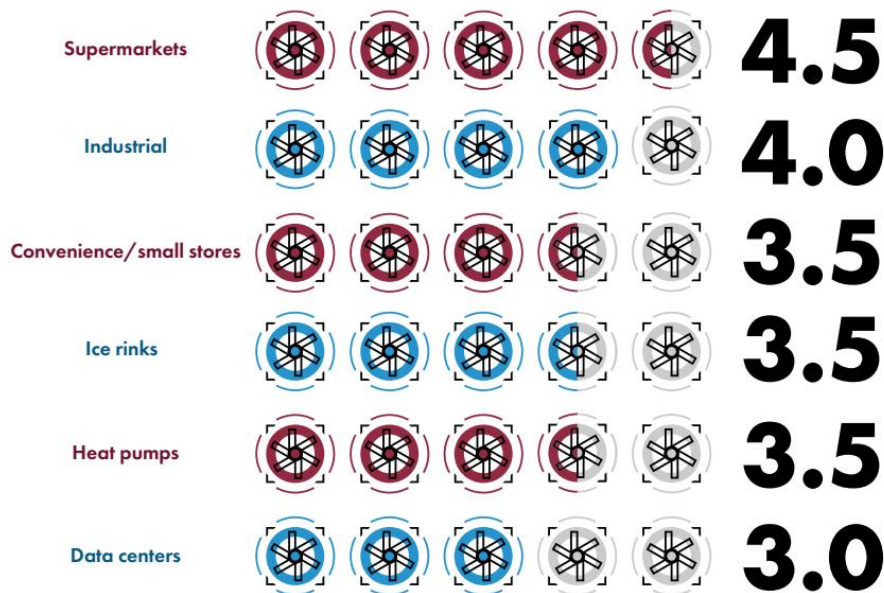
Number of respondents: 204

HOW WOULD YOU RATE THE POTENTIAL FOR GROWTH IN THE TRANSCRITICAL CO₂ MARKET?

(Rating each from 1 star for low potential to 5 stars for high potential)

The potential for growth in the transcritical CO₂ market was rated highest in the supermarkets sector with 4.5 stars (out of 5), followed by industrial refrigeration with 4 stars. Great potential was also noted for convenience/small stores, ice rinks, and heat pumps, with 3.5 stars each. Data centers were rated at a medium value, 3 stars. This shows that the greatest potential for growth is expected in supermarkets, similar to the expectation of growth in the commercial refrigeration sector indicated previously in the survey.

The next question related to additional areas of growth potential for transcritical CO₂ technology. Open comments were possible; and sectors that were often mentioned include: HVAC (such as air conditioning or chillers); heat pumps; mobile air conditioning in cars; transport refrigeration; food distribution centers; and logistics centers. It is exciting to note the wide range of potential applications for transcritical CO₂ technology, extending beyond just refrigeration.



Number of respondents: 185

DRIVERS AND BARRIERS

When it comes to the adoption of transcritical CO₂ refrigeration systems around the world, there are various drivers and barriers that influence this choice. Drivers will have a positive impact on the uptake of the technology, while barriers might hinder the progress of it.

When choosing an appropriate refrigeration system, it is important to compare key factors such as electric energy efficiency of the proposed system; GWP of the refrigerant; cost; toxicity and/or flammability of the refrigerant; regulatory incentives and constraints; and available skills and training (to name a few). Depending on the refrigerant, these characteristics could either be a driver or a barrier.

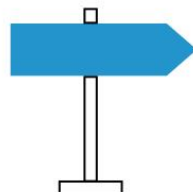
When comparing different refrigeration systems, it is important to understand what the most important criteria are – meeting as many of the end user's specifications as possible while also remaining compliant with standards and regulations. For example, some phased-out refrigerants might have certain favorable characteristics, such as being inexpensive or more easily available, but their impact on the environment makes them unsuitable to use.

Some of the key drivers and barriers were highlighted in the industry survey. Training was mentioned as a challenge regularly throughout the survey – often considered a key barrier. Other barriers highlighted included the higher first costs of transcritical CO₂ refrigeration systems and the challenges associated with working with high pressures.

The survey respondents also shared an overwhelmingly positive response in terms of drivers, the biggest of which being CO₂'s environmentally friendly properties, the limited regulatory constraints, and the increased energy efficiency. These make CO₂ the preferred choice for end users wanting to future proof their installations and be sustainable.

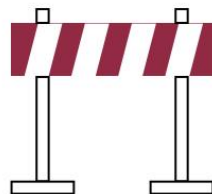
To assess the drivers and barriers properly, it is important to look at how transcritical CO₂ systems compare to other available options – such as traditional HFC systems, as well as HFO systems that are now gaining in popularity, and even natural refrigerants, such as ammonia (R717) and propane (R290).

The drivers and barriers will change depending on the region as some countries are more advanced in their CO₂ journey compared to others. In some regions, training is plentiful, for example, while other regions might still struggle with component availability. However, as regulatory pressure fast-tracks the move away from harmful synthetic refrigerants, many factors that were previously considered barriers are being addressed to increase the uptake of sustainable refrigeration solutions such as transcritical CO₂.



DRIVERS

- Lower lifetime (OPEX) cost
- Improved energy efficiency
- Extremely low GWP (environmentally friendly)
- Non-flammable
- Future proof
- Low refrigerant cost
- Less risk of leaks



BARRIERS

- Higher start up (CAPEX) cost
- Challenge in high ambient conditions
- Training and skills availability
- High pressures
- Toxicity at high concentrations
- Availability of components

TRAINING

SHORTAGE OF QUALIFIED TECHNICIANS STILL A CHALLENGE

Training was often mentioned as a challenge throughout the survey, for various world regions – making it one of the key barriers for the uptake of transcritical CO₂ technology.

The survey respondents estimate the percentage of outside technicians that have sufficient skills to work with (such as installing, maintaining) transcritical CO₂ systems in their region to be relatively low. The vast majority (51%) estimated it to be between 1% and 10% only, while 26% put this number between 11% and 20%. Only 20% estimated it at 21% or higher. It is important to note that this does not show the actual qualification of technicians but rather reflects perceptions of their skills.

An estimated
0%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

4%

An estimated
1% to 5%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

28%

An estimated
6% to 10%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

23%

An estimated
11% to 20%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

26%

An estimated
21% to 50%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

14%

An estimated
more than 50%
of outside technicians have sufficient skills
to work with CO₂ transcritical systems

6%

Number of respondents: 204

WHY ARE SKILLS AND TRAINING SO IMPORTANT?

Working with CO₂ requires a specialized technician to ensure a safe, compliant and optimized installation.

CO₂ is not flammable, but its higher operating pressures, toxicity in high concentrations and the potential for dry ice (solid CO₂) formation must be taken into account when applying and handling. Technicians need to follow strict safety procedures when handling, servicing and installing CO₂-based equipment. Prior to working or training on a system or handling refrigerant, technicians should be equipped with necessary safety equipment, and they should check the material safety data sheet regarding the refrigerant. Technicians should wear safety glasses and goggles at all times when handling the refrigerant and system. They should wear proper respiratory protection for any work on CO₂ equipment in a closed area where there is a suspected leak.¹

Compared to synthetic and other natural refrigerants, CO₂ operates at a higher pressure, especially when ambient temperatures cause the system to work in transcritical mode, meaning above the critical point. However, only in a few parts of a CO₂ system will the pressure be higher than in a conventional system, and special components are available and used for that purpose. Systems are typically designed to withstand the maximum working pressures of CO₂ of up to 73.6bar [1,067psi] in subcritical cycles and 140bar [2,031psi] in transcritical cycles (although such pressures are rarely reached). When working with a CO₂

system, personnel should always check the operating pressures of the refrigerant by using gauges to monitor the pressure. CO₂ system components, pipe work, tools and equipment must be rated to safely operate at a higher pressure. To make sure that the pressure does not reach the relief pressure in case of power failure or an unexpected shutdown, the systems can also be fitted with a small supporting cooling system.¹

CO₂ is an asphyxiant with a threshold limit value (TLV) of 5,000ppm [0.5%], beyond which CO₂ concentration might affect health. One must ensure that the facilities with CO₂ equipment are equipped with ventilators, as well as with gas sensors that will prompt an alarm when the CO₂ concentration reaches a specific limit.¹

Formation of dry ice can occur if a system is not handled properly. This happens when CO₂ pressure and temperature drop below the triple point if the refrigerant is vented during servicing or when a system below 5.2bar is charged. With significant increase in pressure, dry ice can block vent lines and care must be taken by servicing personnel to ensure this does not happen.¹

Technicians must also learn how to charge CO₂ systems safely. Some systems, such as cascade systems and parts of transcritical systems, have a lower maximum operating pressure than the CO₂ cylinder pressure. Therefore, to prevent pressure relief valves discharging, the systems must be charged slowly and carefully.¹

STATE OF TRAINING

A 2017 report by shecco on natural refrigerants training in Europe found that the uptake of training on natural refrigerants in Europe is progressing rapidly, mainly as a consequence of the F-Gas Regulation that drives the industry away from high-GWP HFCs, nevertheless there are still barriers to overcome. Among them, lack of awareness and investment costs related to both setting up training facilities and taking part in courses appear as the biggest ones. It is now up to all industry players as well as governments to work together to facilitate the wider uptake of natural refrigerant training as a prerequisite for the safe use of natural refrigerants on a broader scale.¹

According to Marco Buoni, president of AREA, the European association of refrigeration, air conditioning and heat pump (RACHP) contractors, demand for training for natural refrigerants is increasing in Europe. In India and China, the market is moving rapidly towards natural refrigerants. While manufacturers are ready for the change, technicians are lagging behind – thus training is a high priority in these countries, according to Buoni.²

The EU-funded REAL Alternatives 4 LIFE project has launched a free e-learning certificate, awarded to anyone who completes nine e-learning modules in an online course. The course covers basic knowledge of natural refrigerants, including safety-related issues, and also includes other low-GWP refrigerants. The course material is available in 15 languages.³

The ongoing Refrigerants, Naturally! For LIFE project (more info on [p.86](#)) prioritizes the building of capacities and raising of awareness among small store owners and the RACHP servicing sector by providing information and training needed to accelerate the shift to climate-friendly cooling. This will be done complementary to the Real Alternatives for LIFE project's online trainings. More about the trainings:

<https://www.realalternatives.eu/home>
<https://www.refnat4life.eu/english/training-guidance/>

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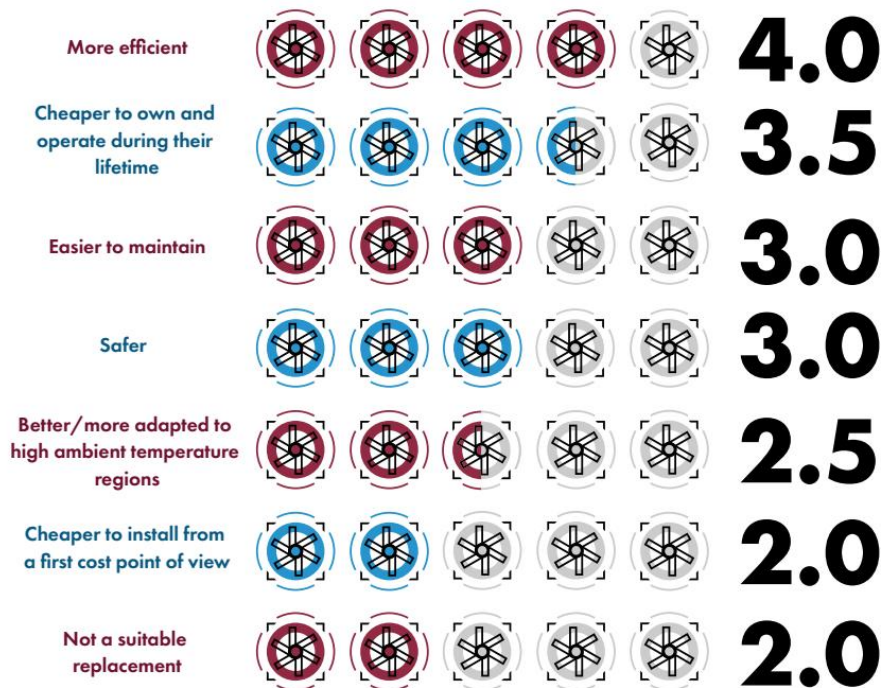
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COMPARISON TO HFC SYSTEMS

Compared to HFC systems, transcritical CO₂ systems are... (Rating each from 1 star for strongly disagree to 5 stars for strongly agree)

The respondents view transcritical CO₂ systems as more efficient and less expensive to own and operate during their lifetime than HFC systems. Another advantage listed was that it is easier to maintain, and safer. Adaptability to high ambient temperature regions of transcritical CO₂ systems was viewed as equal to the adaptability of HFC systems. Areas where transcritical CO₂ was seen less favorably related to installation costs. But, overall, transcritical CO₂ was seen as a suitable replacement for HFC systems in refrigeration.



Number of respondents: 188

HOW DO TRANSCRITICAL CO₂ SYSTEMS COMPARE TO HFC SYSTEMS? (OPEN COMMENTS)

As a summary, the survey comments on how transcritical CO₂ systems compare to HFC systems showing that transcritical CO₂ is considered more energy efficient than HFCs. It is seen as less efficient in hot climates, but there are solutions available. The investment costs for transcritical CO₂ were seen as higher, but the installation and operating costs were said to be lower. Furthermore, the GWP is lower. A challenge is the lack of skills. However, many respondents indicated that the comparison depends a lot on the application.

In the following, selected quotes from survey participants will be displayed, with their name, company and region of the company's headquarters.

Rafael Rau, Refrigeration And Consulting Eng.SA, North America

"Better if you understand your climate and applications, and use the right tools."

Cesar E. Berrios Eugarrrios, Hillphoenix, North America

"Its installation is cheaper, it is more reliable, requires less maintenance, has a lower operating cost. Its cooling effect achieves temperatures in a shorter time than an HFC."

Pier Zecchetto, Portan SA, South America

"CO₂ is more technologically advanced, energy efficient, has better installation and operational standards."

Mauro De Barba, Eliwell, Europe

"Enables system integration and forces to think greener. More complexity depending on the climate zones, but solutions are now available."

Ian Dickinson, MBA Consulting Engineers, Europe

"Much better. They may appear more complicated but once you grasp an understanding of the technology and the fluid behavior they are not overly complicated."

Ignacio Varela Chaparro, Kysor Warren Epta U.S., North America

"They are similar in construction and components; they use the same type except higher pressure rating. Both are direct expansion systems. An HFC technician can use 80% or more of his HFC knowledge in CO₂ transcritical systems."

Frédéric Lavallée-Trubiano, Systems LMP inc, North America

"Similar system, just higher pressure and electronic valves."

Dawie Kriel, Energy Partners Refrigeration, Africa

"Transcritical CO₂ is better for the environment, and can be as efficient when comparing like for like. It does however depend on climate and locality."

Brian Toulson, City Holdings, Australia/ New Zealand

"A refocus on design considerations is required for TC systems to meet the same safety standards as HFC systems, therefore CO₂ TC systems are generally built to a higher standard and should have a longer life span. They (TC) are better for the environment from both direct and indirect emissions standpoints. It is possible to have stable and safe transcritical systems providing all aspects from correct system selection for the application to design to best practice standards, component selection to standards, manufacture to best practices, site infrastructure considerations, installation best practices with attention to detail, optimum commissioning and correct preventative maintenance protocols."

Richard Taylor, Pic n Pay, Africa

"More energy efficient. A little more than high-end HFC systems in hotter areas. We do pay a premium compared to an HFC installation."

Rogério Marson, Eletrofrío Refrigeração Ltda, South America

"Here in South America, we need to reduce the cost to install and maintain the transcritical CO₂ systems."

Michael Riese, Cold Logic, Australia/ New Zealand

"It's always horses for courses. In high ambient temperature climates transcritical CO₂ struggles without additional adiabatic cooling. HFC doesn't."

Dario Ferlin, Woolworths Food Group, Australia/ New Zealand

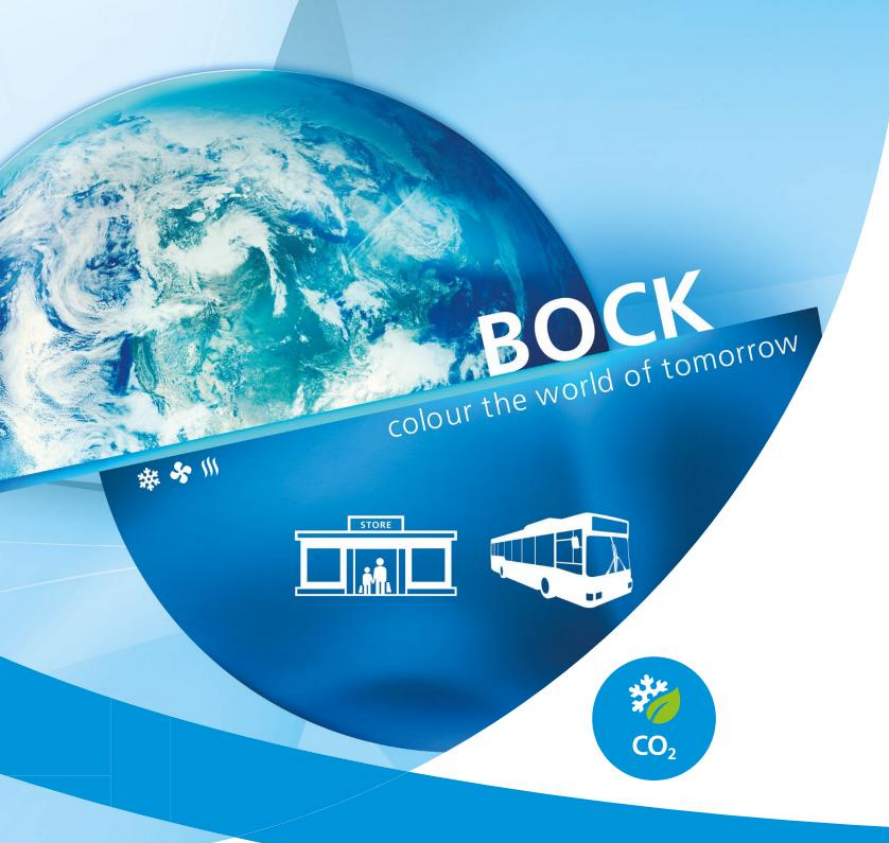
"HFC systems have very little scope for optimization. They are as good now as they will likely ever be in the future. T-CO₂ is, however, still an evolving technology and we are likely, in time, to continue to see efficiency, reliability and cost improvements."

Pablo Francisco Buchko, Arneg Central America, Europe

"Due to the possibility of using smaller compressors with less energy consumption, added to the lower cost of CO₂ as a refrigerant compared to the traditional ones, CO₂ is positioned as the best alternative in regions where the cost of energy is high. That is regardless of the fact that it is the most environmentally friendly option and that in the long term it will suffer less due to F-Gas regulations."

Mauricio Baena, Hillphoenix, North America

"Transcritical CO₂ is best suited to industrial applications. Especially on low temperature applications, and cold storage applications."



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COMPARISON TO HFO SYSTEMS

Compared to HFO systems, transcritical CO₂ systems are... (Rating each from 1 star for strongly disagree to 5 stars for strongly agree)

Compared to HFO systems, transcritical CO₂ systems are seen as more efficient, less expensive to own and operate during their lifetime, and safer. The following factors are rated approximately at the same level: ease of maintenance, adaptability to high ambient temperature regions, installation costs. The question as to whether transcritical CO₂ systems are a suitable replacement for HFO systems scored in the medium range.

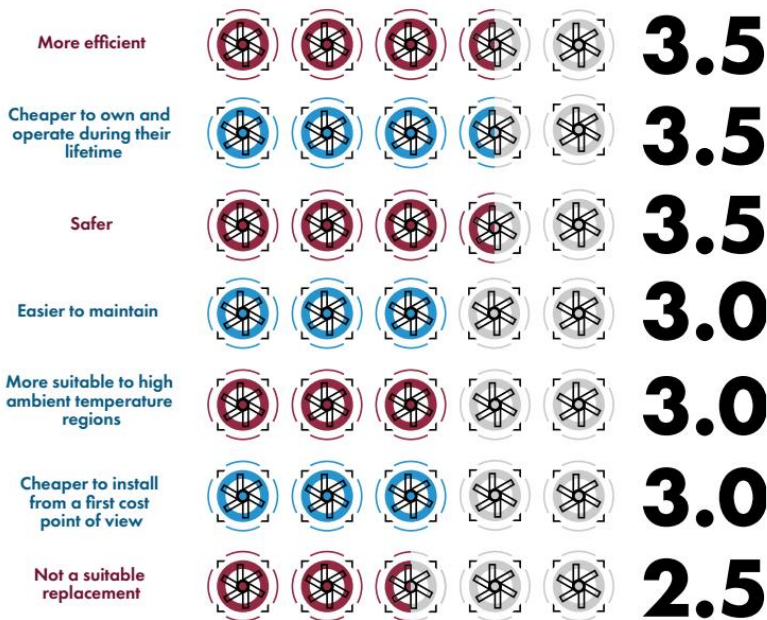
HFO SAFETY CONCERNS GROWING

HFO is often selected over CO₂ systems as these systems are seen as easier to retrofit. However, concerns over the long-term effect of HFOs are growing. This is because Canadian researchers found elevated levels of trifluoroacetic acid (TFA) in Arctic ice cores. TFA is a byproduct of HFC-134a and its replacement HFO-1234yf.⁴

TFA descends via rainfall as a form of "acid rain" to the earth; there it accumulates in various bodies of water, including rivers, streams, lakes and wetlands, as well as "terminal sinks" like salt lakes, playas and oceans. TFA occurs naturally in oceans but in freshwaters, it is thought to be solely man-made (anthropogenic).⁶

A 2017 study by the Norwegian Environment Agency, while noting that while the TFA produced by HFO-1234yf in the atmosphere is not considered an environmental threat in the foreseeable future, concluded that nature's ultimate tolerance to TFA accumulation – and its effect on human health – remain an open question.^{4,7}

Given the persistence of TFA, the risk it presents increases if emissions of HFO-1234yf to the environment grow, the Norwegian report said. With that in mind, it concluded that "phasing out HFOs (and consequently TFA), or emission reduction strategies along with best practice measures that help ensure efficient capturing of HFO/TFA during recycling operations, will help reduce the risk to human and environmental health."



Number of respondents: 180

HOW DO TRANSCRITICAL CO₂ SYSTEMS COMPARE TO HFO SYSTEMS? (OPEN COMMENTS)

Compared to HFOs, transcritical CO₂ has some advantages: the installation costs were seen as lower, refrigerant price lower, energy efficiency higher, and lifetime costs lower. CO₂ was evaluated as safer from a regulatory point of view because it is not likely to be phased out in the future. HFOs were called a “short-lived ‘solution’”. Other disadvantages of HFOs included the formation of TFA, and that the overall environmental impact is not completely known. Elsewhere, flammability was mentioned as an issue.

The disadvantages of CO₂ compared to HFOs are the availability of training and qualified technicians to work with high pressures. Especially in remote and high ambient temperature regions, there might be a lack of technicians qualified to work with equipment such as ejectors.

Dawie Kriel, Energy Partners Refrigeration, Africa

“I don’t see the point of using HFOs if there is a natural refrigerant option. The cost is high, HFOs are somewhat flammable and I am not sure they will be here in 10 years time.”

Rafael Rau, Refrigeration And Consulting Eng SA, North America

“Better if you understand your climate and applications, and use the right tools.”

Tony Deith, KB Refrigeration, Europe

“This is a pressure versus flammability issue. On transcritical systems, engineers deal with pressure and possible dry icing issues. HFO refrigerants are mildly flammable and still pose a risk under the right circumstances. This will also be down to training. I personally, would rather work with CO₂ rather than HFOs.”

Cesar E. Berrios Eugarríos, Hillphoenix, North America

“Today it is not common to use HFO because there are few suppliers of valves and components that facilitate its use. The cost of the refrigerant is more expensive compared to CO₂.”

Mauro De Barba, Eliwell, Europe

“Efficiency gap versus HFC shortened, therefore using a non-fully long term sustainable HFO solution could become a higher cost over time.”

Rogério Marson, Eletrofrio Refrigeração Ltda, South America

"I do not believe that HFOs will be a solution in commercial refrigeration in South America."

Dario Ferlin, Woolworths Food Group, Australia/New Zealand

"From a field technician's perspective a HFO system is not too dissimilar to a HFC system. So in remote regions where ambient temperatures can get very high, the pool of qualified technicians limited and reliability a priority, HFO systems may have advantages over T-CO₂."

Wynand Groenewald, independent consultant, Africa

"The same as compared to HFC, the difference is just that HFOs are more complicated and more expensive than HFC solutions. HFOs are a short-lived "solution"."

Nicolas Pondicq-Cassou, Carrier Commercial Refrigeration, Europe

"Direct stationary HFO refrigeration systems still have to face local regulations and building codes, making their usage at high scale complicated."

Simone Piovesan, SCM Frigo, Europe

"Maybe HFOs will last longer in air conditioning, but eventually CO₂ will come. Even though new synthetic refrigerants will always come up; nowadays a stronger green culture is present. Furthermore, from a technical point of view, it is simpler to improve the CO₂ technology and make it cheaper instead of struggling in finding the best synthetic refrigerant."

Julian Parker, Henry Group Industries LTD, Asia: China

"High pressure of CO₂ TC and oil control issues drive concerns versus HFOs. Lack of trained technicians is still a problem but is being addressed in some regions."

Pablo Francisco Buchko, Arneg Central America, Europe

"They have no comparison. If we analyze it at the cost of installation level, the CO₂ components have significantly reduced their price. If we analyze it at the cost level of the refrigerant, CO₂ is between 8 and 10 times cheaper than HFOs. If we analyze it for energy efficiency, even in hot weather with the incorporation of ejectors and parallel compression, CO₂ far exceeds HFOs. What are the points to improve:

- 1) Training
- 2) More efficient solutions for small shops (HVAC/REFRIGERATION integration is a great alternative)."

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GENERAL REMARKS ON TRANSCRITICAL CO₂ REFRIGERATION

WHAT ELSE DOES TRANSCRITICAL CO₂ REPRESENT FOR YOU? (OPEN COMMENTS)

In an open question, respondents were asked what else transcritical CO₂ technology represents for them. Overall, higher first costs of transcritical CO₂ compared to other refrigerant options were mentioned as a disadvantage. On the contrary, it was also pointed out that transcritical CO₂ requires less maintenance. It is seen as more energy-efficient than alternatives in mild climates. In hot climates, it is evaluated as less efficient than alternatives, but existing solutions are mentioned.

Mauricio Baena, Hillphoenix, North America

"The logic step on natural refrigerants."

Cesar E. Berrios Eugarríos, Hillphoenix, North America

"A simple and economical technology friendly to the planet. It is a reality that works in hot climates and if possible savings in kW vs. other refrigerants. Advanced technology making it possible to take advantage of this natural refrigerant."

Pier Zecchetto, Portan SA, South America

"A cost-competitive technology, an efficient technology, a safe and reliable technology."

Jim Hower, Danfoss, North America

"One option in the tool box. It is not the default future solution for all commercial and industrial applications."

Irving Grimaldo, Bitzer México, Europe

"Safety, state-of-the-art technology, investment, ROI, future-proof."

Mauro De Barba, Eliwell, Europe

"Business opportunity"

Sergio Maria Capanelli, Carel Industries Spa, Europe

"An interesting opportunity for the residential market also, probably more in the next 5-10 years."

Ian Dickinson, MBA Consulting Engineers, Europe

"Evolving technology. I think this is still only the start of modern CO₂ refrigeration. I am interested to see what the next generation will bring along, i.e. heating, cooling and power."

Stefan Jensen, Scantec Refrigeration Technologies, Australia/New Zealand

"TC CO₂ is justified within regions enjoying a temperate climate. The annual energy consumption of a TC CO₂ plant is 35-40% higher than low-charge ammonia in regions with subtropical/tropical climate. (T. Lund; M. Skovrup Danfoss ICR20 19 Montreal)."

Stefano Cosmi, HiRef Engineering, Europe

"The most credible solution for HVAC-R and data center systems for the future."

Massimo Pellizzari, Zanotti/member of Daikin Group, Europe

"A long-term solution for all refrigeration sectors."

Jörgen Rogstam, EKA, Europe

"A solution not attached to/dependent on producers of chemical/synthetical products."

Rogério Marson, Eletrofrío Refrigeração Ltda, South America

"I think that CO₂ and R290 will be the best solution for commercial refrigeration."

GENERAL OPEN COMMENTS

There was the possibility to submit additional comments at the end of the survey. The energy efficiency in regions with high ambient temperature is seen as a challenge, but there are some possible solutions available. Training for technicians is mentioned as a barrier to market entry, with the need to offer much more. Installation costs were often said to be relatively high.

Dawie Kriel, Energy Partners Refrigeration, Africa

"Regional skill levels and technical support as well as climatic conditions should be taken into account."

Rafael Rau, Refrigeration and Consulting Eng SA, North America

"Training for all who are involved in their presence in the market, not only for technicians."

Cesar E. Berrios Eugarrrios, Hillphoenix, North America

"CO₂ is a reality for hot climates if we use the right technology. We have installed several projects in supermarkets and industrial warehouses with excellent results."

Debray Xavier, Versan, Europe

"All documents online are mainly for people with f-gas, CO₂, understanding. Decision makers in the small manufacturer and small supermarket segment have difficulties to understand why they should carefully select a refrigerant and technology."

Mauro De Barba, Eliwell, Europe

"Expansion of CO₂ Systems is strictly dependent on the training of installers and ability of OEMs to provide solutions that are easy to commission and maintain."

Gregorz Toczek, Biuro Inżynierskie Grzegorz Toczek, Europe

"Small customers don't have money to buy CO₂ installations."

Olaf Schulze, Metro, Europe

"The technology should always be developed with the cooling equipment, means closed cooling furniture, eco fans, LED."

Michael Riese, Cold Logic, Australia/New Zealand

"Transcritical systems can be highly effective in areas where they operate in subcritical conditions for most of the year. High ambient temperatures like in South Australia make it hard to build a viable case. This is now being addressed by some contractors in a number of new supermarket projects, but the verdict is still out"

Stefan Jensen, Scantec Refrigeration Technologies, Australia/New Zealand

"If the objective is to maximize energy efficiency, transcritical CO₂ is not the answer. The answer is a well-designed centralized low-charge ammonia system and this is well documented. If the objective is to employ a natural refrigerant with lower toxicity and flammability levels than ammonia, then CO₂ is the answer, but the penalty will be elevated energy consumption in most cases."

Mack Hajjar, Tri Tech Refrigeration Australia, Australia/New Zealand

"Australia and NZ have vastly different climates which is driving opposing trends in the uptake of TC CO₂, NZ having the more suitable climate of the two."

"The uptake of industrial CO₂ refrigeration will be slow in regional areas given reliability issues when compared to conventional ammonia systems. This is due largely to Australia's population distribution where roughly a quarter of all industrial installations are in regional areas that are far from major population centers; this makes it difficult to tend to CO₂ issues fast enough, and slow any trends away from traditional ammonia."

"CO₂ will be an important option in the uptake of Natural Refrigerants in plants between 300kW and 1000kW, especially in rented buildings that do not have purpose built plant rooms. The main drivers will be cost, weight and footprint where CO₂ has an advantage over ammonia, as well as lower connected amps and power consumption where traditional air cooled HFC systems are at a disadvantage."

LOOKING AT DRIVERS AND BARRIERS WITHIN THE TRANSCRITICAL CO₂ REFRIGERATION SECTOR

"Despite a long absence, CO₂ as refrigerant is once again gaining in popularity thanks to its favorable properties. Where did this journey start and where are we today?"

- By Professor Michael Kauffeld of the Karlsruhe University of Applied Sciences of the Norwegian University of Science and Technology

Carbon dioxide was first proposed and patented as a refrigerant in 1850 by the American inventor Alexander Catlin Twining. After the first land-based CO₂ refrigeration plants by Thaddeus S.C. Lowe, Carl von Linde and Franz Windhausen, among others, in the 19th century, CO₂ became widely accepted, especially in ship refrigeration plants at the beginning of the 20th century. Due to its high pressures and comparatively low critical temperature of 31°C/34°F [at 74 bar/1,073psi], CO₂ had almost completely disappeared as a refrigerant for 50 years. The main reasons for its success in early marine refrigeration systems were its low toxicity¹ compared to sulphur dioxide and ammonia and the fact that CO₂ does not burn. Both properties are still today driving arguments for this refrigerant to be used again.

Due to the discussion about ozone depletion caused by CFCs and the high global warming potential of most halogenated hydrocarbons, CO₂ refrigeration systems are again being used in large quantities today. Its re-invention as one of the "natural champions" was initiated by Norwegian researchers around Professor Gustav Lorentzen in the late 1980s and early 1990s. Lorentzen remembered his early days in the refrigeration business when he worked with CO₂ refrigeration systems onboard Norwegian fishing vessels. The fact that the Norwegian University of Science and Technology (NTNU) still had an old CO₂



Professor Michael Kauffeld

compressor hidden in the basement made first tests with this high pressure refrigerant possible in Trondheim. Initial efforts focused on the car industry, but these are yet to prove fruitful. Instead, CO₂ for commercial refrigeration picked up quickly.

From around 1998, the first semihermetic high-pressure compressors for CO₂ were available in small quantities and the first supermarket refrigeration systems were built using carbon dioxide as the sole refrigerant – initially designed as cascade systems (CO₂/CO₂), as there were concerns about the oil balance in two-stage systems. For a little more than 15 years now, CO₂ supermarket refrigeration systems have been designed as two-stage systems, which increases their energy efficiency. The 30,000 systems worldwide, to date, operate transcritically in summer and rely on the control of high pressure depending on the outside air temperature. This is also where the disadvantage of CO₂ technology lies so far: with correspondingly high outside air temperatures (above approximately 22°C/72°F), the basic transcritical CO₂ plants need more energy than their counterparts with HFCs, which is why for years there was a CO₂ equator in Europe roughly at the latitude of the Alps. South of this equator, the ambient temperature was above this temperature too many hours a year and basic transcritical CO₂ systems were not really competitive in terms of energy consumption. The situation is different, however, for cascades with CO₂ only in the lower stage and a high efficiency refrigerant such as propane or ammonia in an upper stage, which achieve very good energy efficiency even at high ambient temperatures.

Recent developments in transcritical CO₂ systems rely on additional small external refrigeration systems to increase subcooling, on water humidified condensers/gas coolers known as adiabatic cooling, on additional parallel CO₂ compressors and, recently, increasingly on ejectors and flooded evaporators. If these measures are cleverly integrated into the transcritical CO₂ system, CO₂ refrigeration plants can also compete in terms of energy with HFC refrigeration plants in the southern part of Europe. However, for smaller supermarkets (less than approx. 2,000m²/ 21,528ft² sales area) the investment costs are approx. 10-20% higher than for a comparable HFC refrigeration system. For larger supermarkets, the higher volumetric refrigeration capacity and the associated more compact components provide cost advantages for CO₂.

Another application in which CO₂ offers clear advantages is that of tap water heat pumps or heat recovery from refrigeration systems. The reason for this is the very high desuperheating heat or the continuous temperature change of CO₂ during supercritical cooling. This is an excellent way of heating water from the lowest possible temperature (e.g. the 15°C/59°F coming from an underground water pipe) up to 70°C [158°F] or more, which is why many companies in Japan offer CO₂ tap water heat pumps known as EcoCute. According to the Association of Electric Utilities in Japan, by 2009 over two million such devices had already been installed, consuming only a quarter of the electricity used by electric water heaters.



Due to the discussion about ozone depletion caused by CFCs and the high global warming potential of most halogenated hydrocarbons, CO₂ refrigeration systems are again being used in large quantities today. Its re-invention as one of the “natural champions” was initiated by Norwegian researchers around Professor Gustav Lorentzen in the late 1980s and early 1990s.

Michael Kauffeld

¹ CFCs and HFCs are only hazardous to health at relatively high concentrations due to oxygen displacement, while CO₂ leads to corresponding impairments from as little as approx. 4 % in the air we breathe and even to death from approximately 10%.

LOOKING AT DRIVERS AND BARRIERS WITHIN THE TRANSCRITICAL CO₂ REFRIGERATION SECTOR

"Why is CO₂ a good refrigerant to use? Because we know it and nature can handle it."

-By Professor Armin Hafner, Professor of the Norwegian University of Science and Technology

What is the greatest barrier to the widespread adoption of transcritical CO₂ systems?

There are several barriers and they are very much dependent on the region. For example, there are awareness barriers in regions where we do not see many refrigeration systems with natural working fluids. Often vendors are not interested in changing to new technologies; business as usual is very convenient.

This relates closely to the knowledge barrier: because transcritical CO₂ refrigeration technology is not a standard option everywhere as it is in Europe, it can be hard to find local vendors able to implement and service such units. Often there are also organizational barriers amongst the different owners of the equipment and building infrastructure. If the first cost is the main focus, and the focus on the entire energy flow is divided between different actors, even within the same organization, sub-optimal solutions are sometimes implemented, resulting in a high total cost of ownership. If the entire energy flow is taken into consideration, integrated energy solutions based on CO₂ technology represent a very competitive solution, which are able to provide all capacities for the heating and cooling of buildings and industrial processes.



Professor Armin Hafner

Still, the greatest barrier on the global scale is training people involved in the different processes, from the development to the commissioning of CO₂ equipment. Therefore, we are working on platforms like this one, to disseminate knowledge and to encourage vendors and end users to enter into the arena of natural working fluid refrigeration and heat pumping technology.

What is the greatest driver for the widespread adoption of transcritical CO₂ systems?

The driver will be the cost of the entire installation; this also includes OPEX, i.e. the total cost of ownership. The end user requires, and deserves, quality related to the provided capacities. They also focus on the energy bill. Highly skilled vendors are able to meet the expectations of demanding customers and steadily increase their market share. The end users with an HFC exit strategy will not deviate from their path now, as they see on a daily basis how much better the new units are compared to those they are replacing.

How has the global market for transcritical CO₂ changed over the past decade?

There has been a significant change on the markets in Europe, Japan and Northern America in the past decade. CO₂ transcritical systems are built on an industrial level by several suppliers, able to serve the global commercial refrigeration sector. Industrial

refrigeration systems have been converted to CO₂ units, especially when low temperatures (lower than -40°C/104°F) are advantageous to the process plants. Sometimes a combination with Ammonia units is the best solution with respect to performance and high heat rejection temperatures.

On the other hand, if hot water production can be a side product or even the main product of the unit, CO₂ is superior for hot water production – as we can see from the several million hot water heat pumps installed across Japan.

What does the market look like today?

For commercial refrigeration systems CO₂ has become the standard choice in many regions. Other regions will follow as some barriers are removed. The next sector to follow will be hotels, due to their high demand for hot water and significant demand for chilled water – a perfect combination for CO₂ transcritical systems.

It will be interesting to see the development of mobile air conditioning and heat-pump systems for the next generation of vehicles. Here there is a close race between CO₂ and hydrocarbon-based units. CO₂ has been developed and is applied in a few serial production cars. There is a chance that non-fossil fuel driven vehicles will benefit from CO₂ units.



In combination with other natural working fluids, all current systems depending on HFC can be replaced by natural working fluid systems if the end user demands it.

Armin Hafner

What do you predict the global transcritical CO₂ market will look like 10 years from now?

Commercial refrigeration will be in a very strong position. There will also be very high growth in heat pump chiller units for hotels and high energy demanding buildings. Transport refrigeration for goods and cooling for passengers will be provided partly by CO₂ units.

R&D to watch includes thermal cold storage.

In combination with other natural working fluids, all current systems depending on HFC can be replaced by natural working fluid systems if the end user demands it.

FUTURE CO₂ TECHNOLOGY TRENDS – IN AFRICA AND BEYOND

"We should be focusing on making CO₂ delivery more industrial and not just for large-scale retail systems."

- By Wynand Groenewald, South-African based independent consultant

What is your personal history with CO₂ and natural refrigerants?

I studied Mechanical Engineering and came across a post graduate study on CO₂ heat pumps. From here, I started to learn about the refrigeration industry and fell in love with it. This was a good 15 years ago, and I have been pursuing to implement CO₂ into the industry ever since. My passion is to help the adoption of CO₂ as fast as possible by making these systems as simple as possible.

Why do you believe in CO₂ technology? Why CO₂ specifically?

I believe that the refrigeration industry not only has a considerable impact on the environment but also that it is an industry where we can make the biggest change in the shortest time. I believe CO₂ fills a large gap within the refrigeration industry where other natural refrigerants perhaps do not suit the application as well. Other than that, the properties and capabilities of CO₂ open a lot

of opportunity to achieve best working applications. There are limited constraints with implementing CO₂ in any environment and the technology has been tried and tested, therefore there is not a lot stopping us from implementing CO₂ into every refrigeration application where synthetic refrigerants have been used up until now.

What changes have you noticed in this market, both in South Africa and globally?

I would say in South Africa, over the last two years, we have definitely seen stronger move towards CO₂ as a refrigerant. People are finally seeing the future of natural refrigerants and this has sparked an uptake in interest towards using natural refrigerants. Globally, I suggest we are reaching a tipping point soon where people no longer argue about whether naturals are the right choice or not, but instead label synthetic refrigerants as old tech. Europe has proven that it is possible to change over completely and I think the world has stood up and took notice. I rarely have a conversation with someone that does not think naturals are here to stay and the future.

Where do you think we are heading with CO₂?

In terms of trends, I think we will see a slow-down in terms of "new" technology like ejectors, etc. I think the focus now will be, and should be, more on fine tuning current systems for optimization and also



We need to stand together and spread the knowledge and awareness of naturals – it's our duty. Chemical companies are spending millions on advocating against naturals and for the 'new' age HFO refrigerants. We need to see this as a fight and take up the challenge to fight back.

Wynand Groenewald



Wynand Groenewald

to reduce cost as the demand increases. In terms of sectors, I do foresee that CO₂ will start playing a much larger role in the industrial and cold chain sector. We should be focusing on CO₂ delivery into the industrial environment and not just to large-scale retail systems, here we need the help of suppliers to achieve this by getting more industrial products into the market. The drive behind CO₂ now will be to make the systems as simple and user friendly as synthetic refrigerants are perceived to be. Also, the internet of things will come into play more so within every industry.

Are you still involved with R&D? What are you currently focusing on?

I am still involved with R&D; I think anyone that is involved with CO₂ as a refrigerant is involved in R&D daily whether they like it or not. One can always improve, and I find it exciting to continue to see how systems can be optimized and made simple.

Currently, I am looking into how to make systems more industrialized, I am convinced that even with constraints of product supply that there is a way to design and implement a system which suit the industrial sector better than what we are currently using. Then on the opposite side of the spectrum I am continuously looking at how to make smaller retail systems more efficient but in a simplified manner and not with over complicated technology.

What do you see as the biggest barriers to the uptake of CO₂ globally?

For me, the biggest barrier is still awareness. If you are in the industry you know all about what is going on but as soon as you speak to someone outside of the industry, they have no clue what impact a refrigeration system has on the environment. This impact must be communicated to the consumer not closely related to the industry.

When it was announced globally that CFC in aerosols are creating a hole in the ozone, the product was changed overnight, otherwise it wouldn't have been bought by the consumer. The sad thing is that the public is not aware that the same compound is still being used within refrigeration systems all over the world.

We need to stand together and spread the knowledge and awareness of naturals – it's our duty. Chemical companies are spending millions on advocating against naturals and for the 'new' age HFO refrigerants. We need to see this as a fight and take up the challenge to fight back.

What is the biggest change that needs to happen globally in terms of mindset as well as policy to encourage the uptake of CO₂ on a large scale?

Sadly, most people do the right thing only when it suits their pocket. Therefore the mindset change should

be focused towards the consumer. If the consumer demands sustainable refrigeration the whole industry will change. It's a catch-22 situation, demand will reduce the cost of these systems, so we need people that are willing to invest now for the benefit the future will bring.

What new technology has had the greatest impact on CO₂ systems, particularly transcritical systems in what is traditionally considered "high ambient conditions"?

I would have to say that it is a combination. Depending on the requirement of a facility, size and location, every new technology has a part to play. I do however think that the design around the technology is what makes the biggest impact. You can achieve a 3% energy saving with a 1K higher suction temperature; and 15-20% energy savings when using parallel compression... all these add up and designing around them is what gives the ultimate success. Installation also plays a bigger role in energy saving and doesn't get enough credit. It is about understanding the technology and making it work for every type of application; in some cases the technologies can work against each other as well.

I do think that ejectors offer the biggest possibility to improve system efficiency in high ambient temperatures but also allow us to look at putting a system together in a different way, making it more simple by introducing new technology.

DEFINING 'CLEAN COOLING'

Comprehensive clean cooling – which will include standards by which to measure the impact of cooling systems – is a prerequisite for a sustainable and resilient future. Transcritical CO₂ installations are a great example of a clean cooling solution in the refrigeration sector.

- By Professor Toby Peters of the University of Birmingham and the Centre For Sustainable Cooling

“Cooling” refers to any human activity, design or technology that dissipates heat and reduces temperatures, typically including refrigeration and air conditioning. Cooling contributes, in both the built and transport environments, to achieving: (i) safe/adequate thermal comfort for people, or (ii) preservation of products (food, medicines, vaccines, etc.), or (iii) effective and efficient processes (for example, data centers, industrial or agricultural production, and mining).

Recognizing both the growth in demand for cooling and the paradigm shifts that are affecting both our communities and global markets, we developed the term “Clean Cooling” to take cooling to a much higher level, encompassing a portfolio of elements outlined below. “The Clean Cooling Landscape Assessment,” was published in 2018 and released at the 24th Conference

of the Parties to the United Nations Framework Convention on Climate Change (COP24), with support from the Kigali Cooling Efficiency Program (K-CEP) and endorsements from Mission Innovation and the U.K.’s Department of Business, Energy and Industrial Strategy (www.clean-cooling.ac.uk).

To build on the work to date, and to help accelerate the transition from traditional cooling to Clean Cooling, the Centre for Sustainable Cooling and shecco are, over the course of 2020, leading a new collaborative project to develop a set of measurable standards for Clean Cooling against which cooling innovation and projects can be assessed. These standards will help all stakeholders to properly understand and quantify the true sustainability (financial, social and environmental) of cooling technology, including CO₂e emissions reduction. Depending on market interest, this could become the basis for a first-of-its-kind formal Clean Cooling Audit-and-Certification Program.

We accept Clean Cooling is setting a very high bar when compared with the many incremental improvements being rolled-out – and we absolutely recognize the value of every efficiency improvement, every use of lower GWP refrigerants. But given the size of both the societal and climate challenges we face, we need to go further, faster. We have to deliver the ambition of Clean Cooling. To achieve this, we have to properly define and quantify what that means and be able to assess the extent to which new cooling systems meet the challenge. As we create the framework for the definition and measurement of Clean Cooling, we welcome comments from all stakeholders.



Professor Toby Peters

Current definition of Clean Cooling

Clean Cooling provides resilient cooling for all who need it without environmental damage and climate impact. It incorporates smart thinking to mitigate demand for active cooling where possible, minimized and optimal use of natural resources, and a circular-economy design that includes repurposing of waste heat and cold (thermal symbiosis) throughout the lifespan of the cooling system.

Clean Cooling meets cooling needs while contributing towards achieving society's goals for greenhouse gas (GHG) emissions reduction, climate change mitigation, natural resource conservation and air quality improvement. It necessarily must be accessible, affordable, financially sustainable, scalable, safe, and reliable to help deliver societal, economic and health goals as defined by the United Nation's Sustainable Development Goals (SDGs).

In short, Clean Cooling is the benchmark at the intersection of the Paris Climate Agreement, the Kigali Amendment, the Montreal Protocol and the SDGs. It is environmentally, socially and economically sustainable cooling that helps the global community adapt to and thrive in – but also mitigate the impacts and risks of – a warming world.

A radical reshaping of cooling Clean Cooling starts with what we can do today to reduce demand for cooling and deliver incremental efficiency improvements in cooling systems, while providing access to cooling for all. This includes, among other things, behavioral change; more effective use of passive design elements such as shade and natural ventilation in building

design; cool roofs; doors on chilled display cases in supermarkets; best-in-class, very low global warming potential (GWP), high efficiency refrigeration and air-conditioning equipment; district cooling systems where possible; and the use of waste heat in parallel thermal processes. Clean Cooling also requires regular preventive and predictive maintenance to ensure optimal operating performance.

These interventions are essential, but, given the growth in cooling demand, they will not deliver the required reductions in energy usage, emissions and pollution, nor will they adequately increase resource productivity, or deliver access to cooling for all who need it.

Delivering Clean Cooling is, therefore, also about investing in a radical reshaping of cooling provision to design more ambitious routes to mitigation and management of energy use and cooling demand. This will include:

- Starting with understanding the first principles of “what we are trying to do” to meet the cooling needs for all;
- Prioritizing how to mitigate cooling demand and meet it through behavior change and design;
- Recognizing the portfolio of free, natural and energy-waste resources to help meet demand;
- Defining the right mix of energy sources, natural refrigerants*, thermal energy storage, cooling technologies, business models, manufacturing, maintenance regimes, end-of-life management and

policy interventions – and then to optimally, and safely, integrate all available energy resources through complete system approaches;

- In short, thinking thermally, which means, among other things, defining a new set of incentives and behavior changes that impact individual and organizational decisions – how we mitigate cooling demand; de-electrify cooling where possible; store energy for use on-demand; balance heating and cooling; and transition fully from fluorinated to natural refrigerants;
- Also ensuring that we have an adequate skilled workforce to design, install and maintain Clean Cooling systems;
- Finally, in delivering the above, driving inclusive and sustainable industrialization in a holistic approach to create resilient and future-proof communities.

By pooling demands and fully understanding the portfolio of resources available, Clean Cooling can facilitate a re-mapping and integration of processes, thermal energy storage and technology to achieve efficiencies and harness all resources; and it will enable new business models to make cooling affordable and accessible to all. This would not be possible with a siloed or sub-system approach.

Deploying such integrated solutions will require smart coordination among many actors and industry sectors in planning, implementation, business models and systems management. In addition, to ensure that the cooling needs of their people are met equitably

and sustainably – including for the most vulnerable – governments must understand what these needs are for health, food, productivity and safety across the built environment, logistics and transport, etc. In short governments must determine how much cooling is actually required to meet societal, environmental, health, well-being, economic and adaptation goals, with no one left behind in a warming world?

There is a significant probability that if countries fail to answer these questions, any thermal planning will be inadequate, and they risk contributing to a lack of ambition in policy, infrastructure and technology development; this could ultimately have far-reaching social, economic and environmental consequences, with both SDGs and climate targets not being achieved.

Clean Cooling specifically demands clean cold chains for food and medical needs. This means integrated, seamless and resilient networks of interconnected refrigerated and temperature-controlled storage, aggregation, distribution and process points, and transport modes. The objective is to maintain the safety, quality and quantity of food, medicines, vaccines, blood, etc. while moving them swiftly from source to point and time of use. This is especially true for health-related cold chains in times of peak demand that are responding to natural disasters or epidemics/pandemics.

Clean Cooling strategies also need to consider the unique challenges of cooling in passenger transport

and logistics as we see a significant increase in vehicles on the road and aspire to move away from diesel. Alongside the transition to electric vehicles, thermal management interventions will be needed; otherwise, the rapid growth in energy demand for passenger transport cooling will complicate both grid resilience and managing peak energy demands.

Clean Cooling is, ultimately, about future-proofing society and ensuring a more sustainable relationship between humans and the planet we live on, we hope, thrive on. Today, our urgent goal is to ensure basic needs are met for all people in a warming world, while living within our natural resource limitations and mitigating future risks to our survival on the planet. But equally, we need to improve the quality of life for all, while simultaneously delivering environmental growth in collaboration with the global and local ecosystems that provide the resources upon which we depend to survive and thrive.

Rising ambient temperatures and the increasing frequency and severity of heat waves will demand more cooling for health, food, productivity, data and, increasingly, safe living. Thus, the provision of comprehensive Clean Cooling is a prerequisite for a sustainable and resilient future. The sooner we recognise this fully and invest accordingly in the step-change interventions required to deliver access to environmentally and socially sustainable cooling for all who need it, the better the outcome for humans in the 21st Century.

*Refrigerants endnote

Clean Cooling by definition includes the complete transition from fluorinated refrigerants to natural refrigerants, including CO₂, ammonia, hydrocarbons, water and air.

However, there are circumstances in which a particular societal need for cooling – often with life-and-death implications – is not aligned with the use of natural refrigerants. In these cases, natural refrigerants and related technology – as well as skilled technicians who can address the safety and technical challenges associated with natural refrigerants – may not be available in the short term. Thus, alternatives may need to be employed to support critical cooling of foods and medicines, particularly in developing countries.

In these exceptional cases, we should still be targeting ultra-low-GWP refrigerants – i.e. with a GWP of less than 30 – if a system is still to be regarded as representing Clean Cooling. But this could be lifted to a maximum GWP of 250 where there is supporting Total Equivalent Warming Impact (TEWI) or Lifecycle Assessment (LCA) data or safety assessments to justify not using natural or ultra-low-GWP refrigerants; there must also be maintenance program in place to minimize leakage and facilitate end-of-life management. This maximum GWP should be regularly reviewed based on available technology, system enhancements and skills development.

The use of fluorinated rather than natural refrigerants in Clean Cooling systems must never be viewed as anything other than a short-term expedient measure needed to address particular exigencies, with a clear eye to transitioning to naturals as soon as possible.

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CONCLUSION

The use of CO₂ as a refrigerant began in early industrial times and today it is once more becoming the refrigerant of choice in a world where the harmful effects of synthetic refrigerants are becoming ever-more apparent. Just like other natural refrigerants, it neither contributes to ozone depletion nor to global warming and offers great wins in terms of energy efficiency and future-proofing installations.

It is exciting to note the rapid rate at which transcritical CO₂ refrigeration installations are increasing globally – no longer just in Europe alone. By means of an extensive global data collection from manufacturers, the amount of installations is estimated at more than 35,500 systems today. This is an exponential increase from the mere 140 installations counted in 2008 (all of which were in Europe). This growth is most noticeable within regions such as Europe, the U.S., Canada, Japan, Australia, New Zealand, and South Africa.

Together with an extensive industrywide survey, the data has highlighted various key industry trends – not only today, but also anticipated in future. The most noticeable trend is the expansion of suitable applications beyond the traditional commercial food retail industry (where today, especially in Europe, transcritical CO₂ has become almost a “no-brainer” for both new and retrofit installations).

The versatility of transcritical CO₂ systems is clear in the various case studies highlighted in this guide. Even smaller convenience store end users are now seeing the benefit of going the transcritical CO₂ route and despite a widespread belief that industrial systems are more the domain of ammonia, there is a clear rise in industrial CO₂ applications around the world. Today there are an estimated 2,200 industrial sites already using transcritical CO₂ refrigeration systems, most of which are in Europe.

With the help of extensive research, the “World Guide to Transcritical CO₂ Refrigeration” has highlighted the great potential of CO₂ for the use in refrigeration installations of any size. Although it may not always be the most suitable solution for a particular installation in a particular geographical region, it is certainly worth considering as it often brings great environmental and efficiency gains.

With increasing regulatory pressures to phase down harmful refrigerants and even the low-GWP synthetic refrigerants starting to show warning signs, the future is clearly natural.



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Get in touch with shecco's market development team to learn more about the market for natural refrigerants or find out how we can help you in gathering market intelligence and proactively building your business with our tailored market development services, to get your technology faster to market.

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