

## Briefing Paper

# Availability of alternatives to HFCs in commercial refrigeration in the EU

## Context & Methodology

Regulation (EU) No 517/2014 (F-gas Regulation) in its Annex III introduced the following placing on the market prohibition, to take effect 1 January 2022, on the use of F-gases in some centralised large-scale commercial refrigeration systems:

*Multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1500 may be used.*

Ahead of this requirement taking effect, the European Commission is required by Article 21(3) of the F-gas Regulation to provide an assessment, no later than 1 July 2017, of the availability of cost-effective, technically feasible, energy-efficient and reliable alternatives in this sector.

Öko-Recherche and Prof. Kauffeld have been tasked by the European Commission to carry out technical work as input to the Commission's report. The preliminary findings summarized in this document are based on extensive consultations of the commercial refrigeration industry in Europe with a strong focus on Southern European manufacturers, service companies and operators.

The project team reached out to at least 143 organisations in 19 European countries via a questionnaire, included member state authorities and major associations in the discussion and engaged in numerous expert interviews. 39 responses to the questionnaire were received. They represent a mix of respondents that spans geographically across all of Europe with very good participation from Southern Europe (18 replies from Spain and Italy), and includes manufacturers (33% of respondents; multiple choices possible), installation, servicing and repair companies (24%), end-users/operators (20%) and refrigeration consultants (7%).

## Findings

### Current state of technology

The assessment highlights that the majority of newly installed commercial refrigeration systems today in Europe are still based on HFCs. R134a (GWP 1430), R404A (GWP 3922), the R407 series (GWP 1774-2107), R410A (GWP 2088) and R507A (GWP 3985) all featured prominently in respondents' replies (Figure 1). Commercially available HFC-HFO blends R449A (GWP 1397) and R448A (GWP 1273) are newly installed by around 30% of respondents. It should be noted that none of the above would be a viable option for direct expansion systems after 2022 due to the high GWP of these gases. More than half of the respondents mentioned the natural refrigerant R744, 36% mentioned R290 and 28% R717, all of which will not be subject to the requirement. Natural

refrigerants therefore are no longer a niche technology and appear to have gathered significant standing in the commercial refrigeration sector already.

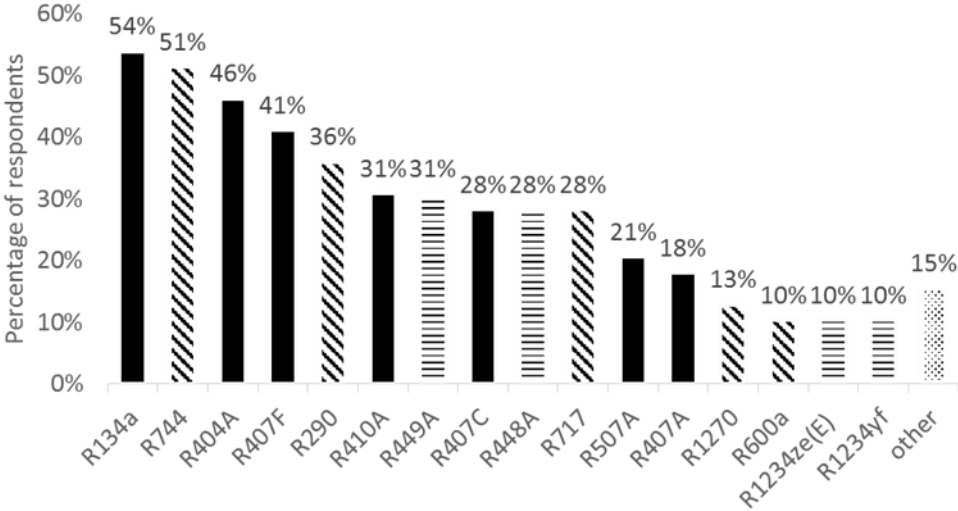


Figure 1 Percentage of questionnaire respondents indicating a particular refrigerant as currently installed or used for commercial refrigeration by them (multiple choices possible). HFC refrigerants are highlighted in bold, natural refrigerants shaded diagonally, HFOs and their blends shaded horizontally and others shaded with dots. Other includes R22, R401A, R401B, R413A, R417A, R422A, R422D, R434A, R442A, R450A, R452A, R453A and R513A (HCFCs mentioned by Swiss company; all mentioned by one respondent except R422D which was mentioned by two respondents).

The responses to the questionnaire further highlighted that the majority of commercial refrigeration systems currently installed are centralised systems in the meaning of the requirement quoted above (mentioned by 77% of respondents). 59% of respondents mentioned condensing units and 54% stand-alone systems as part of the installed base.<sup>i</sup>

As regards the technologies used in these systems, direct expansion (DX) of R404A in centralised systems and R404A in condensing units are mentioned by 49% and 44% of respondents, respectively.<sup>i</sup> The use of natural refrigerant technology is significant in stand-alone systems (R290 mentioned by 41% of respondents) and also plays an important role for centralised systems (44% mention CO<sub>2</sub> cascades and 38% transcritical systems). Indirect centralised systems with a secondary refrigeration circuit are mentioned by a sizeable fraction of respondents (31%), predominantly relying on a liquid heat transfer fluid like glycol.

**Existing technical options for meeting the 2022 low GWP requirement**

Multiple technological alternatives are already available on the market to meet the 2022 low GWP requirement for HFCs in large centralised multipack refrigeration systems for commercial use. Respondents thought that (i) stand-alone systems (69% of respondents), (ii) different types of indirect centralised systems (67%) and (iii) transcritical CO<sub>2</sub> centralised systems (64%) - among others - are generally available alternative technologies in this context.<sup>ii</sup> (Differences of opinion between manufacturers and end-users can be observed (see Figure 2). A larger fraction of manufacturers than end-users referred to transcritical CO<sub>2</sub> (94% vs. 36%) and indirect (75% vs. 55%) systems. More end-users than manufacturers on the other hand referred to stand-alone systems (82% vs. 75%).

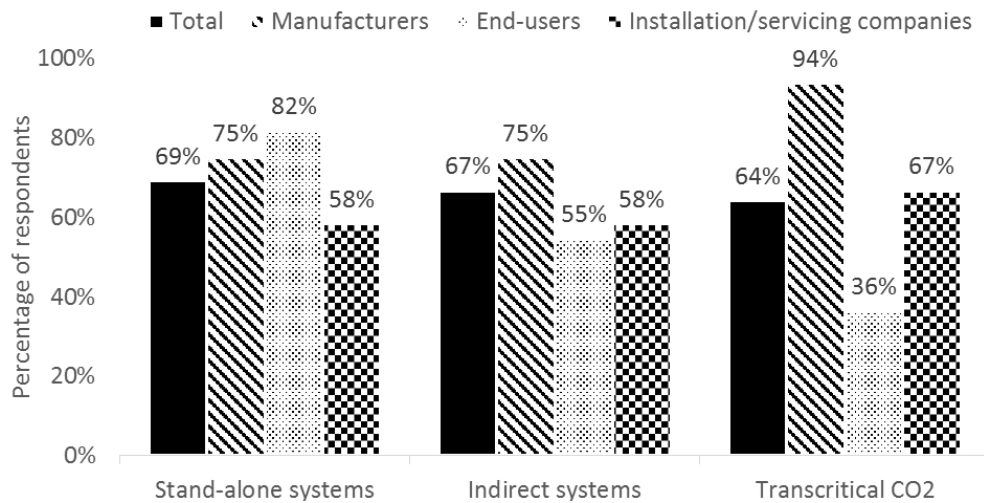


Figure 2 Percentage of questionnaire respondents indicating particular types of alternative technologies that fulfil the 2022 low GWP requirement as currently already available in the commercial sector (multiple choices possible).

### Feasibility and reliability of technical options

A qualitative assessment showed that all three alternative system types mentioned by stakeholders above are technically feasible:

(1) **Stand-alone systems** are very common around the World in light commercial applications. Such systems have proven to be technically feasible in larger stores as well.<sup>iii</sup> Variations on this type of system include so-called semi plug-ins that reject condenser heat into a glycol loop. Charge size limitations imposed by various safety standards for flammable refrigerants such as propane and isobutane are currently avoided by combining multiple smaller circuits.<sup>iv</sup> These standards are further currently under revision.<sup>v</sup> The use of CO<sub>2</sub> in stand-alone systems is gaining ground in terms of a technically feasible alternative to large centralised multipack refrigeration systems.<sup>vi</sup> Note that stand-alone systems are also subject to a separate requirement on HFCs above GWP 150 from 2022 onwards.<sup>vii</sup>

(2) **Indirect centralised systems** are not as numerous in commercial refrigeration yet, but the technology has proven feasible in industrial applications and also in supermarkets already in the 1990s in Sweden, Norway, Luxemburg and Switzerland. Currently a number of retailers across Europe are installing propane chillers with glycol loops in their stores for example in Germany, UK, Belgium and Switzerland.<sup>viii</sup> NH<sub>3</sub>/CO<sub>2</sub> cascades are also in operation, for example in Hungary.<sup>ix</sup> Combinations with stand-alone units can further help to adapt technologies for increased heat recovery (see for example semi plug-ins).<sup>x</sup>

(3) **Transcritical CO<sub>2</sub>** in centralised systems is already a standard technology in many parts of Europe.<sup>xi</sup> Recent developments to improve the efficiency of this technology (parallel compression, mechanical subcooler, ejector and adiabatic gas cooler cooling) are eliminating the former so-called CO<sub>2</sub>-equator and make this technology an option in warmer climates as well (see Figure 3).

Reliability was not raised in the survey by stakeholders as being an issue and none of the respondents hinted at reliability problems associated with any of the three alternative system types. Millions of **stand-alone units** with natural refrigerants are in use around the World and at least hundreds of thousands in European supermarkets.<sup>xii</sup> Likewise, **indirect centralised systems** have proven reliable in a multitude of industrial and some commercial applications for many decades. **Transcritical CO<sub>2</sub>** technology in centralised systems is now already more than a decade old and has performed without any recorded reliability issues for as long, especially in Germany, Norway, Denmark and the UK. More than 8,700 transcritical CO<sub>2</sub> stores operate across the EU as of 2016.<sup>xiii</sup>

**Cost effectiveness today and tomorrow**

A third of the respondents highlighted transcritical CO<sub>2</sub> centralised systems and HFC-free stand-alone systems as cost-competitive solutions in medium to large supermarkets (< 100 kW), while more than half thought that transcritical CO<sub>2</sub> centralised systems are already cost-competitive in hypermarkets (> 100 kW). Expert interviews and additional input suggested similarly that transcritical CO<sub>2</sub><sup>xiv</sup> and stand-alone systems (including semi plug-ins) are generally already cost-competitive in the EU.<sup>xv</sup> This is also the case for larger stores since large CO<sub>2</sub> compressors with high pressure rating became available after 2010.<sup>xvi</sup> Indirect centralised systems can also be cost-competitive solutions, especially in warmer climates. This holds true in particular for large stores and hypermarkets where CO<sub>2</sub> cascades with NH<sub>3</sub>, propylene, propane or HFOs and pumped CO<sub>2</sub> systems can generally be cost-competitive solutions.<sup>xvii</sup> Multiple small propane chillers have also been installed in smaller supermarkets, for example in Germany, the UK and Belgium.<sup>xviii</sup> In addition, a quarter of respondents expected that transcritical CO<sub>2</sub> technology will become increasingly cost-competitive until 2022. A significant downward trend in terms of the cost of CO<sub>2</sub> technology over the past decade and a half – while achieving significant energy efficiency gains at the same time support this hypothesis (see Figure 3).

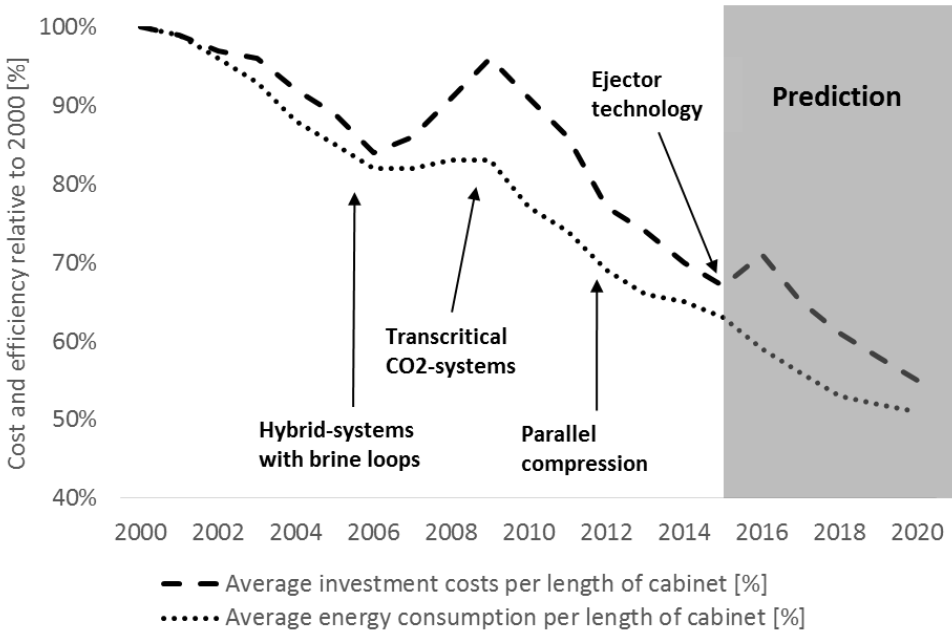


Figure 3 Price and efficiency development of refrigeration systems per meter of cabinets installed in Switzerland (Source: Frigo-Consulting AG).

## **Energy efficiency today and tomorrow**

The analysis of the questionnaire revealed that responses regarding energy efficiency were subject to a relatively clear bias. Manufacturers of CO<sub>2</sub> equipment and components indicated transcritical CO<sub>2</sub> systems as the most energy-efficient solution for medium-sized to large supermarkets. Overall 28% of all respondents indicated this technology. Manufacturers of stand-alone systems and associated compressors, refrigerant producers and distributors on the other hand instead indicated stand-alone systems as the most efficient, at least for medium-sized to large supermarkets (21% of all respondents). For large supermarkets and hypermarkets, respondents' replies were more uniform in indicating transcritical CO<sub>2</sub> technology as the most energy efficient solution (21% of respondents).

Feedback provided by respondents and experts suggests that all three alternative systems types can offer energy savings compared to HFC equipment. Currently installed transcritical CO<sub>2</sub> centralised systems for example were indicated to offer 7-30% energy savings.<sup>xxix</sup> Likewise, semi plug-ins appear to offer around 20% energy savings over traditional HFC systems.<sup>xxx</sup> Heat recovery can increase energy savings significantly by reducing energy required to heat the store, feed into the ventilation system and provide hot water.<sup>xxxi</sup> A number of respondents however indicated that state of the art HFC systems are still the most energy efficient today. For more information see also the case studies in Annex I.

## **Southern Europe**

The assessment also focused on special circumstances in Southern Europe. Climatic conditions – especially during summer months – have an impact on the energy efficiency performance of technologies in commercial refrigeration. Questionnaire respondents as well as additional sources of information highlight that centralised CO<sub>2</sub> cascade systems with R134a in the medium temperature loop are currently the most widely spread alternative system to HFC direct systems. Direct expansion of R134a will however not be an option from 2022 onwards.

The preliminary results suggest that all three alternative system types can operate efficiently also in Southern Europe. A number of transcritical CO<sub>2</sub> systems and stand-alone systems are already in operation in the region. Existing transcritical CO<sub>2</sub> installations in Spain, Portugal and Italy suggest energy efficiency improvements over R134a/CO<sub>2</sub> cascades and HFC systems.<sup>xxii</sup> Especially integrated systems with heat recovery can achieve parity with HFC technology in terms of cost for the entire store as well.<sup>xxiii</sup> Likewise, stand-alone solutions based on HCs and CO<sub>2</sub> for example in Spain have proven to save more than 20% energy compared to stand-alone systems with HFCs.<sup>xxiv</sup> Experience from Phoenix, AZ in the US<sup>xxv</sup> and two locations in South Africa<sup>xxvi</sup> further suggests that NH<sub>3</sub>/CO<sub>2</sub> cascades can offer significant energy savings in hot climates while being cost-effective at least in larger stores and hypermarkets. Likewise, indirect CO<sub>2</sub> cascades with a glycol loop for MT and R134a in the primary circuit have exhibited good energy performance close to the equator.<sup>xxvii</sup>

## **Existing obstacles**

The questionnaire asked stakeholders explicitly to name existing obstacles to using alternative solutions not falling under the HFC GWP requirement. Overall investment cost was most frequently mentioned as a hurdle to alternative technologies. Next, the restrictive nature of safety standards and in some cases building codes were mentioned, alongside with energy efficiency of alternative technologies in warmer climates. The next most commonly indicated hurdle was the availability of training for flammable, toxic or high pressure refrigerants. This was the most common for systems in medium to large stores (28% of respondents mentioned it in that category). The remaining three

perceived hurdles featured overall less prominently. Among them were general safety concerns around particularly flammable refrigerants (hydrocarbons and unsaturated HFCs), the higher complexity associated with transcritical CO<sub>2</sub> centralised systems and other alternatives as well as the availability of parts. It should be noted that 2-3 respondents (depending on the capacity range) indicated no hurdles of a technological nature at all.

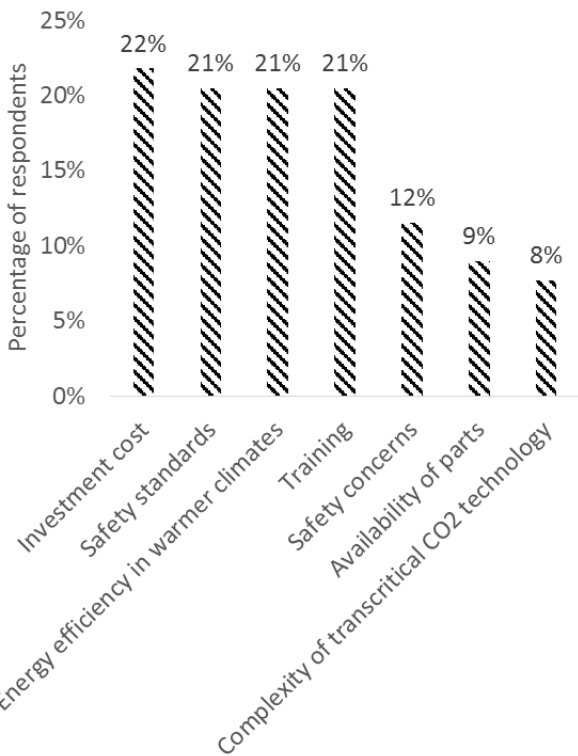


Figure 4 Percentage of questionnaire respondents indicating particular existing barriers to successful implementation of alternative technologies (multiple choices possible; answers for <100kW and >100kW weighted equally).

**Preliminary conclusions**

The outcome of this preliminary assessment is that there are a number of technically feasible, energy-efficient and reliable alternatives to HFC-based centralised multipack systems on the market today. Transcritical CO<sub>2</sub> centralised plays an important role today but stand-alone systems and indirect centralised systems also display significant potential. The results further suggest that many of these alternatives are already or will be cost-competitive by 2022, when the new requirement enters into force. It is also important to keep in mind that this rule will only apply to newly installed equipment after 1 January 2022, but not to equipment that was installed before that date.

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- <sup>i</sup> Note that responses were not restricted to capacities of over 40 kW in this section.
- <sup>ii</sup> Note that respondents were asked to only name alternatives that can provide total refrigeration capacities of above 40 kW.
- <sup>iii</sup> See for example The Natural Voice, Demystifying Natural Refrigerants, Shecco, Brussels, 2015, available at <http://thenaturalvoice.org/>.
- <sup>iv</sup> See for example AHT presentation at ATMOSphere Europe 2016 available at <http://www.atmo.org/media.presentation.php?id=799>
- <sup>v</sup> IEC Working Group 4 of Technical Subcommittee 61C for example is concerned with a review of IEC 60335-2-89:2010 that would allow for larger charge sizes.
- <sup>vi</sup> See for example Coca-Cola presentation at Atmosphere Europe 2015 available at <http://www.atmo.org/media.presentation.php?id=577>.
- <sup>vii</sup> Regulation (EU) No 517/2014 Annex III (11)
- <sup>viii</sup> See for example [http://www.hydrocarbons21.com/articles/6767/exclusive\\_the\\_colruyt\\_group\\_makes\\_r290\\_its\\_refrigeration\\_standard\\_across\\_all\\_belgian\\_stores](http://www.hydrocarbons21.com/articles/6767/exclusive_the_colruyt_group_makes_r290_its_refrigeration_standard_across_all_belgian_stores) or [http://www.hydrocarbons21.com/articles/3610/74\\_hfc-free\\_stores\\_across\\_john\\_lewis\\_partnership\\_s\\_estate\\_br](http://www.hydrocarbons21.com/articles/3610/74_hfc-free_stores_across_john_lewis_partnership_s_estate_br) or [http://www.energiekompetenzostal.de/sixcms/media.php/349/KlimavorOrt\\_Ausgabe%201.pdf](http://www.energiekompetenzostal.de/sixcms/media.php/349/KlimavorOrt_Ausgabe%201.pdf)
- <sup>ix</sup> QPlan presentation at Eurammon Symposium 2012 available at [http://www.qplan.hu/images/publikaciok/Success\\_with\\_NH3CO2\\_Cascade.pdf](http://www.qplan.hu/images/publikaciok/Success_with_NH3CO2_Cascade.pdf) and [http://www.r744.com/articles/1618/qplans\\_co\\_sub\\_2\\_sub\\_nh\\_sub\\_3\\_sub\\_cascade\\_systems\\_save\\_40\\_energy\\_in\\_tesco\\_and\\_auchan\\_hypermarkets](http://www.r744.com/articles/1618/qplans_co_sub_2_sub_nh_sub_3_sub_cascade_systems_save_40_energy_in_tesco_and_auchan_hypermarkets)
- <sup>x</sup> See for example Epta presentation at Atmosphere Europe 2016 available at <http://www.atmo.org/media.presentation.php?id=798>
- <sup>xi</sup> See for example Shecco, 2016, F-GAS REGULATION SHAKING UP THE HVAC&R INDUSTRY, available at <http://publication.shecco.com/publications/view/131>.
- <sup>xii</sup> See note iii.
- <sup>xiii</sup> See note xi.
- <sup>xiv</sup> Meeting with Jürgen Göller and Bernd Heinbokel at Carrier's CO<sub>2</sub>OLAcademy in Mainz on 12 July 2016.
- <sup>xv</sup> See for example Supermarkets Shift to HFC-Free Commercial Refrigeration Worldwide, Environmental Investigation Agency, London, UK available at <https://eia-international.org/report/supermarkets-shift-hfc-free-commercial-refrigeration-worldwide>
- <sup>xvi</sup> Personal communication with Akos Murin of QPlan on 31 October 2016.
- <sup>xvii</sup> See for example Danfoss presentation at Atmosphere America 2016 available at <http://www.atmo.org/media.presentation.php?id=870>
- <sup>xviii</sup> See note viii.
- <sup>xix</sup> See for example note xv.
- <sup>xx</sup> Indicated by Epta in their questionnaire and conform to what EIA stated in their response. See also note iv.
- <sup>xxi</sup> See Danfoss presentation at Atmosphere Europe 2016 available at <http://www.atmo.org/media.presentation.php?id=753> and Epta presentation at Atmosphere Europe 2015 available at <http://www.atmo.org/media.presentation.php?id=572>.
- <sup>xxii</sup> See case studies in Portugal and Spain.
- <sup>xxiii</sup> Heat recovery has been used in Scandinavian countries for more than 2 decades. See also Polzot A. et al 2016 PERFORMANCE EVALUTATION OF A R744 BOOSTER SYSTEM FOR SUPERMARKET REFRIGERATION, HEATING AND DHW presented at 12<sup>th</sup> IIR Gustav Lorentzen Natural Working Fluids Conference, Edinburgh, UK.
- <sup>xxiv</sup> See case study in Spain.
- <sup>xxv</sup> See for example note xvii.
- <sup>xxvi</sup> See <https://www.giz.de/expertise/downloads/Fachexpertise/giz2011-en-proklima-projectsheet-southafrica.pdf>

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<sup>xxvii</sup> See for example

[http://www.r744.com/articles/1574/second\\_brazilian\\_supermarket\\_invests\\_in\\_co\\_sub\\_2\\_sub\\_refrigeration-part\\_1](http://www.r744.com/articles/1574/second_brazilian_supermarket_invests_in_co_sub_2_sub_refrigeration-part_1)



## Annex I – Case studies

The assessment included the compilation of case studies that highlight current applications of alternative technical options in the EU. The focus was on applications in warmer climates which is why most of the case studies are located in Southern European countries (see Figure 5).

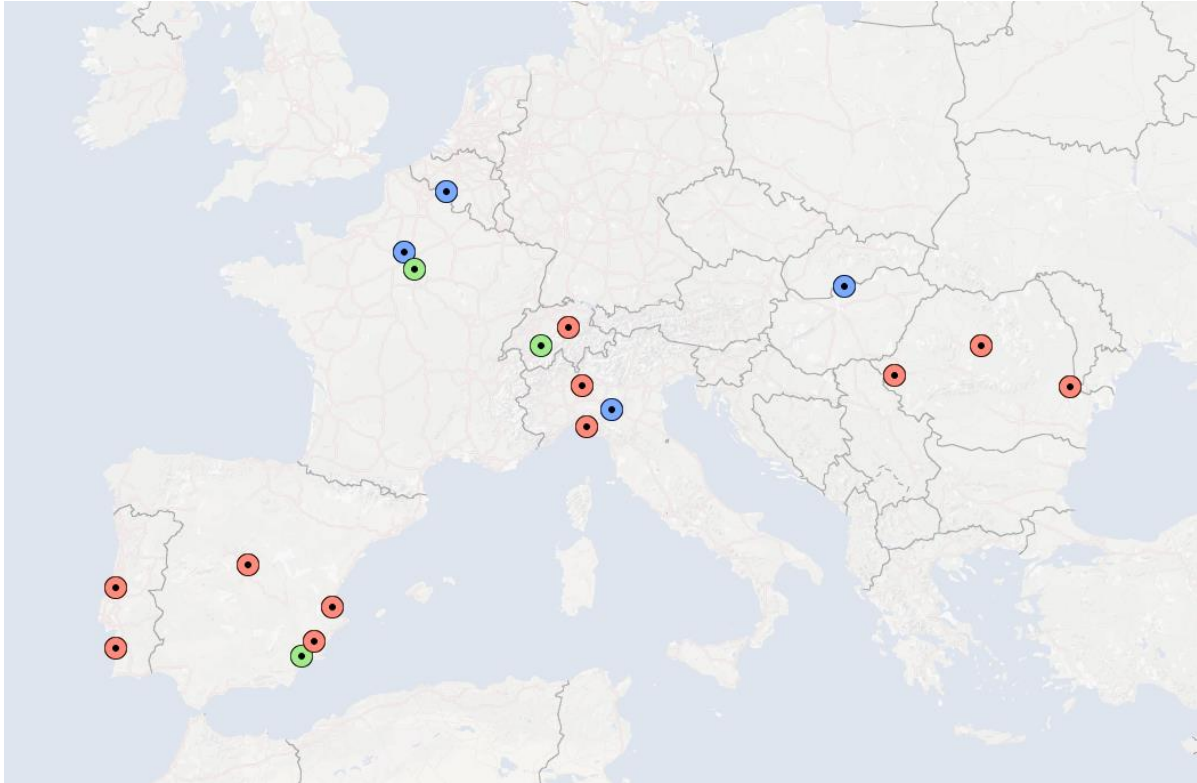


Figure 5 Map of case studies. Red markers indicate transcritical CO<sub>2</sub> systems, green ones stand-alone and blue ones indirect systems.

### Transcritical CO<sub>2</sub> centralised systems

From Norway to Portugal, transcritical CO<sub>2</sub> systems have been built in most European countries. This technology is already regarded as standard in Germany<sup>xxviii</sup>, Denmark, the rest of the Nordic countries and Switzerland. Thousands of systems are already installed in these countries in addition to France, Belgium, Austria and the Netherlands. First systems now also operate in more southern regions including in Italy, Spain, Portugal and Romania.<sup>xxix</sup>

Carrefour, for example, is a big driver for transcritical CO<sub>2</sub> systems, including in the South. The chain already operates 90 transcritical stores in Europe including 18 hypermarkets and one supermarket in Spain.<sup>xxx</sup> Carrefour's Alzira store just south of Valencia proves that this technology is cost-effective, feasible, energy-efficient and reliable in warmer climates as well. It utilizes parallel compression and features an additional external R1270-CO<sub>2</sub> subcooler to accommodate for high ambient temperatures. The system uses 35% less energy than the previous system and 10% less than a conventional HFC system would. The system also includes heat recovery, which is utilized to provide heated water for use in the store. Carrefour installed a very similar system in its Galati store in Romania. Instead of R1270 this system uses R290 for its CO<sub>2</sub> subcooler.

Frigo-Consulting, a refrigeration consultant based in Switzerland, is building transcritical CO<sub>2</sub> systems in the EU since 2006. The company has installed such systems for example in Switzerland, Spain and

Romania. Next to parallel compression their systems feature CO<sub>2</sub> subcoolers (essentially a separate small external refrigeration system), gas and/or liquid ejectors and more recently multi-ejectors. In 2014, the company installed a multi-ejector system in a Migros store in Ibach, Switzerland. The system features parallel compression, CO<sub>2</sub> subcooling via groundwater as well as 5 ejectors which makes it one of the most efficient transcritical systems in the World. The three measures are expected to make the system 25% more efficient than a standard CO<sub>2</sub> booster system. Overall the system has an energy consumption 45% lower than the system previously installed. Frigo-Consulting has installed similar systems in Switzerland and Romania for Carrefour and Selgross stores.

Together with Sintef and Arneg, Danfoss recently announced the installation of a transcritical CO<sub>2</sub> system in Italy's largest hypermarket store run by Iper in Milan. The system features a CO<sub>2</sub> subcooler and an ejector and integrates both air conditioning and heat recovery. Danfoss claims energy savings of up to 50% over conventional HFC systems. The ejector technology is currently trialed by Danfoss and its partners in 15 other EU stores.

Recently, Advansor announced the implementation of two transcritical CO<sub>2</sub> systems in Portugal, one in a distribution center and the other in a hypermarket. Both systems operate with parallel compression but no ejector technology. Investment costs for the entire store are comparable to those with HFC systems and early results suggest energy savings compared to R134a/CO<sub>2</sub> cascades.

#### **Stand-alone systems**

Millions of commercial and light commercial stand-alone systems operating with natural refrigerants are in use all over the World. Increasingly such systems are also implemented in supermarkets and discounters across Europe as an alternative to centralised multipack refrigeration systems. A separate rule on HFCs in hermetically sealed equipment means that stand-alone systems cannot be operated with HFCs with a GWP over 150 from 2022 on either.<sup>xxxi</sup>

Eurofred, for example, supplies CO<sub>2</sub> and propane stand-alone systems to Spanish retailers. A Cash Directo in Murcia installed 10 CO<sub>2</sub> cooler cabinets and 16 propane freezer islands in its store instead of a centralised system. The store claims 23% energy savings compared to an R404A system.

Epta recently installed a water-cooled stand-alone system in a REWE store in Hamburg. This system employs a CO<sub>2</sub> heat pump to recover 100% of the heat from the cabinets and cold rooms to provide heating of the store. No additional energy is required to heat the store and the whole system provides significant energy savings. Other EPTABlue systems rely on adiabatic cooling.

Sanden recently began offering R744 stand-alone units that either reject the condenser heat into the shop (what the company calls "air plug-ins") or into a water loop equivalent to the Epta system mentioned above (Sanden calls these "semi plug-ins"). About 200 of Sanden's air plug-in systems have been installed in Japan and to-date only a hand-full in Europe. These types of systems are however brand new and Sanden is expecting demand to increase significantly. The company expects investment cost of these units to be 15% higher than for equivalent R404A systems. Energy savings on the other hand are expected at 21%. These systems are available for MT applications at the moment. Sanden's semi plug-in systems on the other hand have been a priority for the company and about 800 units have been installed to-date in Switzerland, UK, France and Lithuania. According to Sanden, semi plug-in systems experience energy savings equivalent to R134a and hydrocarbon stand-alone units while being cheaper to implement than transcritical CO<sub>2</sub> systems.

### **Indirect centralised systems**

Indirect systems with natural refrigerants are widespread in industrial refrigeration and were used in various supermarkets as early as the 1990s. They constitute a very mature technology. Also, chillers frequently used for air conditioning of large buildings are indirect systems with water as heat transfer fluid. Similar systems have been implemented for commercial refrigeration in recent years. Luxemburg and Sweden have been the main countries so far due to specific legislation favouring indirect systems for supermarkets in these countries. The Belgian retail group Colruyt has piloted propane chillers in its Bio-Planet OKay and Colruyt stores and is planning to roll out at least 40 such units per year from 2016 onwards. A Bio-Planet system in Mons, Belgium for example uses 2 propane chillers with 31.5 kW capacity each. One of the units is installed for redundancy and peak refrigeration demand. Cooling is distributed to the cabinets via glycol loops and the condenser heat is rejected into a glycol loop with a drycooler.

Indirect systems also include different variations of CO<sub>2</sub> cascades. Johnson Controls, for example, has successfully installed an R1270/CO<sub>2</sub> cascade in a Tesco in Shrewsbury, UK already back in 2004. The propylene is used in two separate primary circuits to cool pumped CO<sub>2</sub> for medium temperature applications. Part of the CO<sub>2</sub> is further compressed and expands directly for low temperature demand. No energy consumption measurements were available from before the installation but Johnson Controls is certain that the system uses the same amount of energy than the system before while costing only slightly more. It should be noted that the system is already more than a decade old and improvements in terms of energy efficiency can be expected for any newly built unit.

More recent installations include for example an integrated cascade system installed by Honeywell and eCold in a U2 supermarket in Parma, Italy in December 2014. The system supplies refrigeration but also air conditioning and ventilation needs. The primary circuit utilizes the HFO R1234ze which is confined to a machine room. Similar to the system above, medium temperature is supplied via pumped liquid CO<sub>2</sub> and low temperature via a CO<sub>2</sub> cascade. The system achieves about a 30% reduction in energy usage (for the whole store, taking into account the integrated nature of the system) and cost approximately 5% more than a similar HFC-based system. About 90 similar systems are in operation with a variety of low-GWP refrigerants in the primary circuit.

Axima Refrigeration and Honeywell installed a similar system (albeit not an integrated one) in Auchan's Epinay-sur-Seine store in late 2013. The system uses R450A (a blend of R134a and R1234ze with a GWP of 547) in the primary circuit and the same combination of pumped CO<sub>2</sub> and a CO<sub>2</sub> cascade as above for providing medium and low temperature refrigeration. Honeywell reports energy usage comparable to that of an R134a/CO<sub>2</sub> cascade.

In 2008 and 2009 QPlan of Hungary installed 4 NH<sub>3</sub>/CO<sub>2</sub> cascades across Hungary in Tesco stores ranging from 3000 to 15,000m<sup>2</sup>. At the time, these systems achieved up to more than 35% savings in energy consumption but were more expensive than standard solutions. Since then QPlan has focuses almost exclusively on transcritical CO<sub>2</sub> systems due to the availability of large CO<sub>2</sub> compressors with high pressure ratings. QPlan still believes that cascades are a viable option however and would built such systems today in cases where they make sense.

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<sup>xxviii</sup> Phone conversation with Reiner Tillner-Roth of Epta Germany on 22 August 2016.

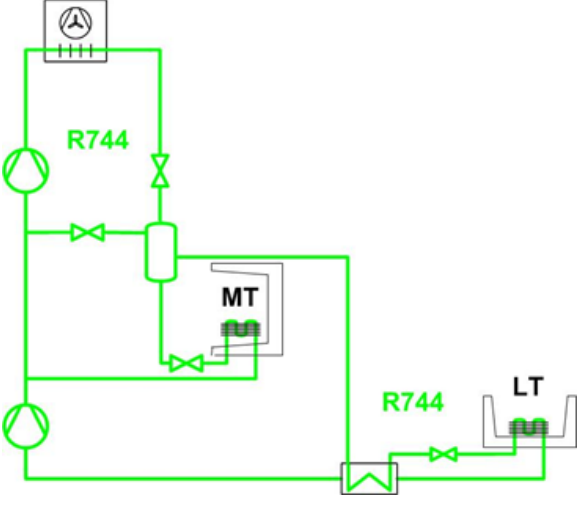
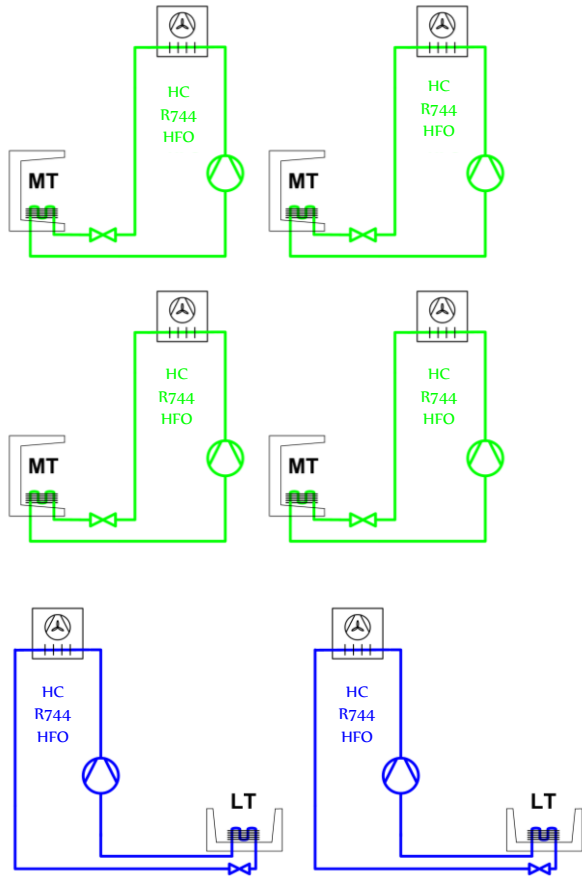
<sup>xxix</sup> See note xi.

<sup>xxx</sup> See

[http://www.r744.com/articles/7016/crossing the co sub 2 sub equator carrefour leads the march south.](http://www.r744.com/articles/7016/crossing_the_co_sub_2_sub_equator_carrefour_leads_the_march_south)

<sup>xxxi</sup> Regulation (EU) 517/2014 Annex III (11).

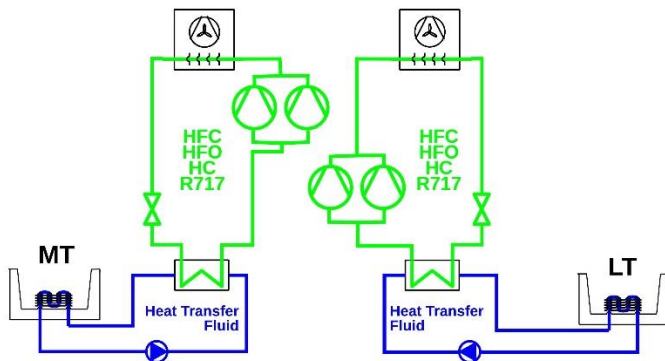
## Annex II – Sample schematics of the three principal technological solutions

Sample system schematic	System description	Requirement for system
	<p>Transcritical CO<sub>2</sub></p>	<p>-</p>
	<p><b>Stand-alone systems (hermetically sealed)</b></p>	<p>(According to Regulation (EU) No 517/2014 Annex III (11) HFCs above GWP 2500 are prohibited from 1 January 2020 and HFCs above GWP 150 from 1 January 2022 on.)</p>

**Sample system schematic**

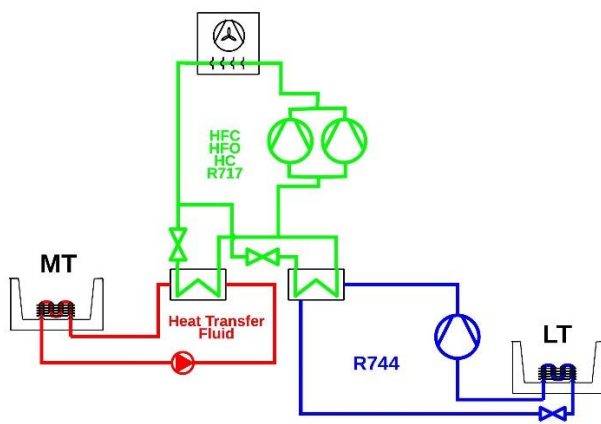
**System description**

**Requirement for system**



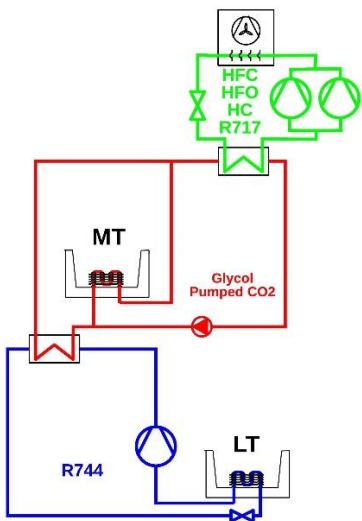
**Indirect centralised system**  
 (i) Separate secondary MT/LT refrigeration circuits

**< 150 GWP**



**Indirect centralised system**  
 (ii) Secondary MT refrigeration circuit and LT CO<sub>2</sub> cascade

**< 1,500 GWP in primary circuit**  
 and  
**< 150 GWP in other circuits**



**Indirect centralised system**  
 (iii) Secondary MT refrigeration circuit (e.g. pumped CO<sub>2</sub>) and LT CO<sub>2</sub> cascade

**< 1,500 GWP in primary circuit**  
 and  
**< 150 GWP in other circuits**