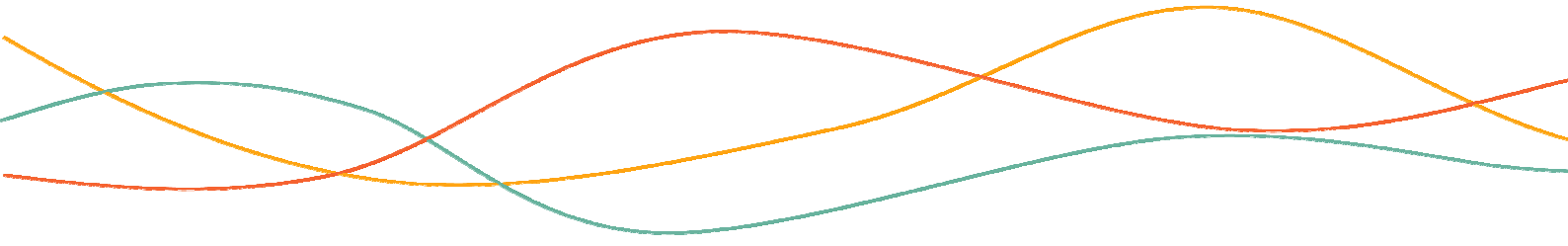
Embraco Position Paper:

Light Commercial Refrigeration

Refrigerants Outlook – 2016



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Introduction

The global community, as a conclusion of Paris COP21 meeting in December 2015,s decided very aggressive targets for reduction of CO2 emissions due to human activities, in order to preserve our planet for future generations. The global phase-down of HFCs in refrigeration sector is representing an important contribution to the international mitigation efforts.

Embraco for many years has been actively investing in this direction by developing and promoting hermetic compressors for use with low atmospheric impact refrigerants in all continents.

Apart from isobutane (R600a) in household appliances, significant progress is present also with propane (R290) implementation into light commercial plug-in systems as natural R404A alternative as well as use of carbon dioxide in supermarket sector.

Recent EU F-Gas regulation is considering ban of high GWP refrigerants in next few years in several categories of commercial applications and will considerably limit the available quantities of those refrigerants on the market. A number of alternative synthetic refrigerants were offered by chemical industry and more are coming. For this reason, Embraco performed a number of activities to assess their potential to replace high GWP refrigerants presently in use. Main difficulty found was trying to replace R404A. This paper will summarize the present testing state of alternatives for both R404A and R134a replacements. Focus will be given to reliability and performances aspects as well as to the related safety legislation evolution.

Embraco Policy Statement

- **Embraco will extend its work on development and encourage use of low GWP refrigerants to support global effort of climate change mitigation for the future of mankind.**
- **Embraco will continue to provide solutions for refrigeration equipment to improve energy efficiency with low GWP refrigerants.**
- **Embraco will support proactively use of natural refrigerants without any compromise for safety of appliances including technician training.**
- **Embraco will continue to develop products for both natural and synthetic low-GWP refrigerants to exceed present and future energy efficiency standards to assure competitiveness of our customer products and meet final user's expectations.**
- **Embraco will continue working with international legislation organizations to allow safe use of low GWP options.**

DISCLAIMER

This Position Paper is based upon testing activities performed by Embraco Labs and supported by Embraco's experts, with the final aim to assess the transitory solutions towards low GWP refrigerants and to provide an overview of the main outcomes to Customers and stakeholders.

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Readers are then responsible for assessing the relevance and accuracy of the content of this Position Paper and any actions taken as a result of its interpretation shall be only the responsibility of the parties directly involved in the decision.

EU F-Gas Regulation

Most recent move of European Union is the new regulation (517/2014), limiting use of refrigerants with high GWP values (GWP – Global Warming Potential). The EU deadlines for use of refrigerant substances for different refrigeration segments:

NEW EQUIPMENT

1.

From January 1st, 2020

Refrigerators and freezers for storage, display or distribution of products in retail and food service (commercial use) hermetically sealed systems that contains HFC with GWP of 2500 or more, will be banned
(e.g. R404A, R507A)

2.

From January 1st, 2022

Refrigerators and freezers for storage, display or distribution of products in retail and food service (commercial use) hermetically sealed systems that contains HFC with GWP of 150 or more, will be banned (e.g. R134a, R407F, R407C, R410A)

3.

From January 1st, 2020

Stationary refrigeration equipment, that contains, or that relies upon for its functioning HFCs with GWP of 2500 or more except equipment intended for application design to cool products to temperatures below -50°C will be banned

There are still some doubts in this new regulation interpretation, for example, it is not clear if commercial type of ice machines should fall under "refrigerators and freezers" category, or should be considered as a "stationary refrigeration equipment". Questions like this can be addressed to major industry associations (eg. ASERCOM, EPEE), or thru European Commission (DG Clima) website or/and contacting national authorities in charge of EU F-gas regulation.

EXISTING SYSTEMS MAINTENANCE

From January 1, 2020 the use of F-gases with GWP of 2500 or more to service or maintain refrigeration equipment with gas charge size exceeding 40TCO2equiv (ex. more than 10,2 kg of R404A) will be banned. Refrigeration equipment using reclaimed or recycled refrigerants, if available, is possible to service them until January 1, 2030. For systems impacted by the service & maintenance bans there are two options: retrofit with gases with GWP lower than 2500 or replace them with new equipment that uses lower GWP refrigerant.

QUOTA SYSTEM

EU F-gas regulation (517/2014) defines that sales and distribution of high GWP gases will be controlled with quota allocation system and will lead to its declining supply and increase of HFC prices (see Fig.1). Quantities of HFC gases available for all applications will be limited based on GWP value (in 2018 49% less if compared with 2015 usage - 87MTCO2$_{equiv}$) and industry will be forced to switch quickly to low GWP alternatives.

EU F-gas regulation considers the average consumption between 2009 and 2012 as a baseline to apply phase down steps expressed in MTCO2$_{eqiv}$

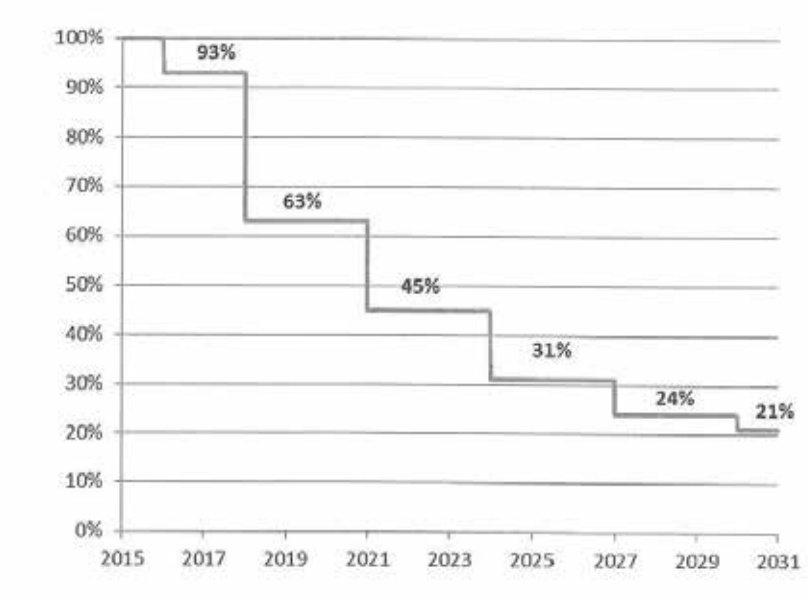


Fig.1 HFC Phase Down Schedule
(EU regulation 517/2014)

Alternative Refrigerants for Commercial Refrigeration

Embraco is working on products for light commercial refrigeration segment, to comply with both phases of EU F-gases regulation.

This means products for final solution (below 150 GWP) with natural and with synthetic refrigerants and as well as compressors for transition refrigerants, that should allow the industry to convert all their product portfolio into final low GWP refrigerants by 2022. We recommend, if possible, go directly to the final refrigerants. For the time being only hydrocarbons can be considered a final solution, while synthetic refrigerants options are still under development and the legislation to allow their use, is still under development. Every appliance producer has to make a choice: go natural or wait for new synthetic blends when ready. Here below are the main elements that should be taken in order to make this decision:

	High GWP HFC's	HC's	Low GWP HFC's
Safety Class	**A1 - Not Flammable**	**A3 - Highly Flammable**	**A2L - Slightly Flammable**
Environmental Impact	Bad	Excellent	Good
Refrigerant Cost	Ref	Normal	Very High*
Compressor Thermal Regime	Ref	Lower	Higher
Investments for Safety	Ref	Yes	Yes
System Efficiency	Ref	Much Higher	Higher
Charge Limit (IEC,EN)	No	150 g	150 g

(*) not yet in mass production

Final Solution - Hydrocarbons

PROPANE (R290)

Embraco offers full product line of HC compressors as a final solution to meet EU F-gases regulation.

Propane (R290) is already widely used on several commercial and air conditioning applications and most of the existing light commercial application can be converted to use HC refrigerants. In case of larger applications due to general charge limit of 150 g, multi-circuit configuration is a feasible option and already applied in some systems. There are still existing barriers for use of hydrocarbons in some types of applications related to the safety issues of final product, its cost and appliance manufacturing line investments. Specific actions are necessary to overcome those issues. An important step to allow wider use of A3 class refrigerants is the safety standards modification.

Today, present IEC standard used for hermetically sealed applications, (EN60335-2-89), is limiting to 150 grams the charge of any flammable refrigerant. Under IEC SC61C/WG4 working group, the industry is trying to define specific additional measures needed to allow higher charge levels without increasing risks above the existing standard. This activity is in progress so no definitive conclusion can be predicted.

OTHER HYDROCARBONS – ISOBUTANE (R600a):

R600a, isobutane, represents a valid alternative solution for small appliances. It offers benefits in terms of efficiency, but has significant limitation in cooling capacity. Due to low specific cooling capacity it requires bigger compressor displacement if compared with other refrigerants and consequently bigger compressor frame having bigger size and weight. Isobutane proprieties also limit the evaporating temperature range.A full range of products, both for LBP and HBP application are present in Embraco's catalogue. The main applications are small chest freezers, bottle coolers and wine coolers etc.

OTHER HYDROCARBONS – PROPYLENE (R1270),

Propylene is very similar in terms of proprieties to propane, it can offer advantage of higher specific cooling capacity, but is slightly less efficient then propane. Use of propylene therefore has to be limited to very specific situations. Embraco has no any plans to develop compressors for propylene. Its use can be agreed for specific situations with ad-hoc solutions under supervision of Embraco technical support.

Next Generation HFCs

R404A ALTERNATIVES

For longer term scenario, the industry under AHRI AREP (Alternative Refrigerant Evaluation Program) is in the 2nd phase of testing a series of new mixtures that will meet requirement of GWP < 150. So far, all candidates are slightly flammable and have been classified as A2/A2L with a temperature glide up to 12 K. Some of long term alternatives to replace R404A in light commercial segment are under test in Embraco's labs and some considerations are presented in Table 5 and 6. Other refrigerants are being evaluated under AREP 2nd phase program. It is not yet clear which of them will be adopted in the future. What is very important for refrigeration industry is to avoid refrigerants proliferation. Hopefully the AREP program will define a preffered option which can be adopted globally. An important step to allow use of A2L class refrigerants is the safety standards modification (same applies to A3 safety class mentioned before). Today, with 150 grams of charge it's almost impossible to design any type of refrigeration system using A2L class refrigerants. Evaluation tests of A2L R404A alternatives are in progress. The best alternative is yet to be defined.

	R 404A	HDR110	DR-3	ARM-20a
Type	HFC blend	HFC blend	HFC blend	HFC blend
Safety class	A1	A2L	A2L	A2L
Boiling Temp @ 1atm	-47°C	-46°C	-45°C	-45°C
Critical Temp	72°C	83°C	82°C	84°C
Bubble-Dew @1 bar(abs)	0,8K	12,4K	8,2K	7,1K

Table 5. Alternative Blends Physical Data

	R 404A	HDR110	DR-3	ARM-20a
GWP	3920	146	146	139
Application Field	L/MBP	L/MBP	L/MBP	L/MBP
Capacity	Ref	Same	Lower	UD
Efficiency	Ref	Better	Better	UD
Reliability	Ref	NA	NA	NA
Lubricant	POE	POE	POE	POE
Drop – in	Ref	No*	No*	No*
Motor Temp	Ref	NA	NA	NA
Discharge Temp	Ref	Higher	Higher	NA

Table 6. (*) due to safety requirements for electrical components, UD – under development, NA – not available

Next Generation HFCs

R134a ALTERNATIVES

R1234yf is a valid alternative for R134a appliances. Embraco is offering some compressor models for this refrigerant in the catalogue. R1234ze, however, is not considered as a valid alternative to R134a for light commercial systems because of its low specific cooling capacity. It will require a completely new product line that, at this stage, seems to not be a solution for this market segment.

	R 134a	R1234yf	R1234ze(E)
Type	HFC	HFC	HFC
Safety class	A1	A2L	A2L
Boiling Temp @ 1atm	-26°C	-30°C	-18°C
Critical Temp	101°C	95°C	110°C
Bubble-Dew @1 bar(abs)	0K	0K	0K

Table 5. Alternative Blends Physical Data

	R 134a	R1234yf	R1234ze(E)
GWP	1430	Below 1	Below 1
Capacity	Ref	Slightly lower	Much Lower
Efficiency	Ref	Lower	Lower
Reliability	Ref	Same	NA
Lubricant	POE	POE	NA
Drop – in	Ref	No*	No*
Motor Temp	Ref	Same	NA
Discharge Temp	Ref	Same	NA

Table 6. (*) due to safety aspects of electrical components, NA – not available

HFC Transitory Solutions

R404A REPLACEMENT

The chemical industry is offering a series of refrigerants to replace currently used high GWP HFC refrigerants. Except hydrocarbons, final replacement for R404A and R507A is not yet ready to meet European regulations in a long term. A series of intermediate GWP blends were proposed in order to bridge the transition to a later final situation. The most significant intermediate refrigerant candidates are HFC blends like **R407F, R407A, R448A, R449A** and **R452A.** They are all in safety class A1 (not toxic, not flammable) and they are characterized by considerably higher temperature glide comparing to R404A. The main physical proprieties and Embraco's evaluation summary are indicated respectively in table 1 and table 2

	R 404A	R407F	R407A	R448A	R449A	R452A
Type	HFC blend	HFC blend	HFC blend	HFC blend	HFC blend	HFC blend
Safety class	A1	A1	A1	A1	A1	A1
Boiling Temp @ 1atm	-47°C	-46°C	-45°C	-45°C	-46°C	-47°C
Critical Temp	72°C	83°C	82°C	84°C	82 °C	75°C
Bubble-Dew @1 bar(abs)	0,8K	6,4K	6,4K	6,3K	6,1K	3,8K

Table 1. Alternative Blends Physical Data

	R 404A	R407F	R407A	R448A	R449A	R452A
GWP	3920	1820	2100	1386	1397	2140
Application Field	LBP,MBP	MBP	MBP	MBP	MBP	LBP,MBP
Capacity	Ref	Same	Same	Better	Better	Same
Efficiency	Ref	Lower	Lower	Better	Better	Same
Reliability as drop - in	Ref	Much Lower	Much Lower	Lower	Lower	UD
Lubricant	POE	POE	POE	POE	POE	POE
Drop – in	Ref	No	No	No	No	Yes
Motor Temp	Ref	Much Higher	Much Higher	Higher	Higher	Same
Discharge Temp	Ref	Much Higher	Much Higher	Higher	Higher	Same

Table 2.Embraco Evaluation Summary

Compressor temperatures with the same system conditions tend to increase significantly with R407F and R407A. Relatively lower temperature increase was observed when testing R448A and R449A in particular. Increasing temperature can cause overheating of motor and/or tripping of the overload protector. Their use as a drop in can lead to reliability and life expectancy reduction (see conclusion notes for their eventual use). R452A presented a same or lower thermal profile when compared with R404A. R452A is also the only one that in this stage can be considered as a drop in for Embraco's R404A product line. In addition, customers have always possibility of converting the system for use of R134a in place of R404A for this transition period, just by changing compressor model and relative system design adjustment.

HFC Transitory Solutions

R134a REPLACEMENT

The only reason for use of above mentioned R134a alternative blends, during transition period, is the lower GWP that can allow higher quantities availability due to quota limitation.

	R134a	R450A	R513A
Type	HFC	HFC blend	HFC blend
Safety class	A1	A1	A1
Boiling Temp @ 1atm	-26°C	-24°C	-29°C
Critical Temperature	101°C	106°C	98°C
Bubble-Dew @1 bar(abs)	0K	0,8K	0,8K

Table 3 .Alternative Blends Physical Data

	R134a	R450A	R513A
GWP	1430	547	573
Application Field	L/M/HBP	L/M/HBP	L/M/HBP
Capacity	Ref	Lower	Same
Efficiency	Ref	Same	Same
Reliability as drop -in	Ref	UD	UD
Lubricant	POE	POE	POE
Drop – in	Ref	Yes	Yes
Motor Temp	Ref	Same	Same
Discharge Temp	Ref	Same	Same

Table 4.Embraco Evaluation Summary

Conclusions

Hydrocarbons (isobutane-R600a and propane-R290), represent the best, long term solution for light commercial applications both in low and medium pressure. The next future expected legislation changes will remove part of existing road blocks related to charge limits.

For the transition period, before 2022, based on preliminary testing, Embraco cannot consider R407F, R407A, R448A, not R449A as a drop-in substitution for systems using Embraco R404A compressors. Usage of above referenced refrigerants may require system changes such as, system condensing temperature reduction (larger condenser, improved ventilation) or return gas temperature reduction in order to achieve a similar thermal profile as with refrigerant R404A. Final application needs to be validated by Embraco Technical Support Team case by case. Usage in systems operating under high compression ratio conditions in particular should be avoided. R452A can be in this stage considered as a drop-in refrigerant.

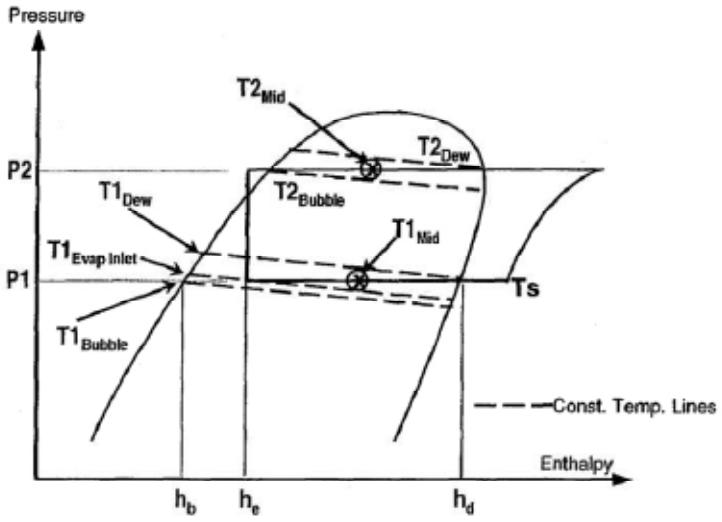
R1234yf is an acceptable alternative for R134a in the long term, but flammability aspects of all A2L refrigerants are not yet solved. Present legislation is not allowing more than 150g refrigerant charge. Consequently, the use of A2L's will be very limited in mid-term.

Current Refrigerant	Temporary Solution	Final Solution
R404A	R452A	R290*
R507A	R448A	unsaturated HFC's
	R449A	R1270
	R134a*	R744*
	R407F	
	R407A	
	R407F	
R134a	R134a	R1234yf
	R450A	R600a*
	R513A	R290*

* different displacement

Performance Evaluation

It is important to consider that refrigerants with significant glide have to be treated in different way than in the past. Dew point pressure approach cannot be used to define actual system operating conditions. Mid-point approach is the correct one in this case. Formulas how to define mid-point temperature is illustrated in the pictures below.



$$\frac{T1_{evap\ inlet} - T1_{bubble}}{T1_{dew} - T1_{bubble}} = \frac{h_e - h_b}{h_d - h_b}$$

$$T1_{mid\ point} = mean\,(T1_{evap\ inlet}\,;\, T1_{dew})$$

General Trends For Light Commercial Segment from Embraco Prospective

	Light Commercial Refrigeration		
Watt	150 - 5000		
Region / Year	2015	2020	2025
HC			
America	Regular use	Regular use	Main refrigerant
Europe	Regular use	Main refrigerant	Main refrigerant
China	Regular use	Main refrigerant	Main refrigerant
Rest of World	Regular use	Main refrigerant	Main refrigerant
HIGH GWP HFC's			
America	Main refrigerant	Regular use	Niche use
Europe	Main refrigerant	Niche use	Niche use
China	Main refrigerant	Regular use	Niche use
Rest of World	Main refrigerant	Regular use	Niche use
LOW GWP HFC's			
America	No clear	Regular use	Regular use
Europe	No clear	Niche use	Regular use
China	No clear	Niche use	Regular use
Rest of World	No clear	Niche use	Regular use
CO2			
America	Niche use	Regular use	Regular use
Europe	Niche use	Regular use	Regular use
China	Niche use	Regular use	Regular use
Rest of World	Niche use	Regular use	Regular use

- Main refrigerant
- Regular use
- Niche use
- No clear