

Position Paper

Light Commercial Refrigeration

Refrigerants Outlook for Europe
2020

Introduction

With the Kigali Amendment to the Montreal Protocol, the global community made another important step towards preserving our planet for future generations by reducing CO₂ emissions due to human activities. The global phase-down of HFCs in the refrigeration sector represents an important contribution to international climate change mitigation efforts.

For many years, Embraco has been actively investing in this direction by developing and promoting hermetic compressors for use with low-atmospheric impact refrigerants on all continents. In addition to isobutane (R600a) in household appliances, significant progress has been made in integrating propane (R290) into light commercial plug-in systems as a natural alternative to R404A, as well as in the use of carbon dioxide in supermarket sector.

EU F-gas regulations impose a ban on high global warming potential (GWP) refrigerants in several categories of commercial applications over the next few years and has considerably limited the available quantities of these refrigerants on the market. Several alternative synthetic refrigerants have been developed by the chemical industry and more are coming.

Embraco has performed extensive tests to assess the capacity of these alternatives to replace high-GWP refrigerants presently in use. The biggest difficulty was found in trying to replace R404A.

This paper will summarize current testing for R404A and R134a replacements, with a focus on reliability and performances as well as the evolution of related safety legislation.

Embraco Policy Statement

- Embraco will encourage the use of low GWP refrigerants to support global effort to mitigate climate change.
- Embraco will continue to provide solutions to improve the energy efficiency of refrigeration equipment with low-GWP refrigerants.
- Embraco will support proactive use of natural refrigerants without compromising appliance safety or technician training
- Embraco will continue to develop products for both natural and synthetic low-GWP refrigerants that exceed present and future energy efficiency standards in order to assure the competitiveness of our products and expectations of our end users.
- Embraco will continue to work with international legislative bodies on the safe use of low-GWP refrigerant options.

EU F-Gas Regulation

The European Union's F-gas regulations (517/2014) limit the use of refrigerants with high GWP values.

The EU deadlines for use of refrigerant substances for different refrigeration segments are:

From January 1st, 2020

- Hermetically sealed systems that contains HFCs with GWP of 2500 or more (e.g. R404A, R507A) will be banned in refrigerators and freezers used for storage, display or distribution of products in retail and food service **(commercial use)**.

From January 1st, 2022

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

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 designed to cool products to temperatures below -50°C) will be banned.

Questions on the interpretation of this new regulation can be addressed directly thru the European Commission (DG Clima) website or to major industry associations (e.g. ASERCOM, EPEE, AREA), and/or by contacting the national authority in charge of EU F-gas regulations.

EXISTING SYSTEMS MAINTENANCE

From January 1, 2020 the use of F-gases with GWP of 2500 or more in refrigeration equipment with gas charge size exceeding 40TCO₂equiv (e.g., more than 10,2 kg of R404A) will be banned. This does not include reclaimed or recycled refrigerants, which will be allowed until January 1, 2030.

For systems impacted by these service and maintenance bans there are two options: retrofit with gases with GWP lower than 2500 or replace them with new equipment that uses a lower GWP refrigerant.

QUOTA SYSTEM

EU F-gas regulations (517/2014) limit the sale and distribution of high-GWP gases under a quota allocation system (see Figure 1), leading to a declining supply and a significant increase in HFC prices (see Figure 2). The amounts of HFC gases available for all applications are limited based on GWP value (as of 2018, a reduction of 49% from 2015 usage - 87MTCO₂^{equiv}) and industry has been forced to switch quickly to low-GWP alternatives.

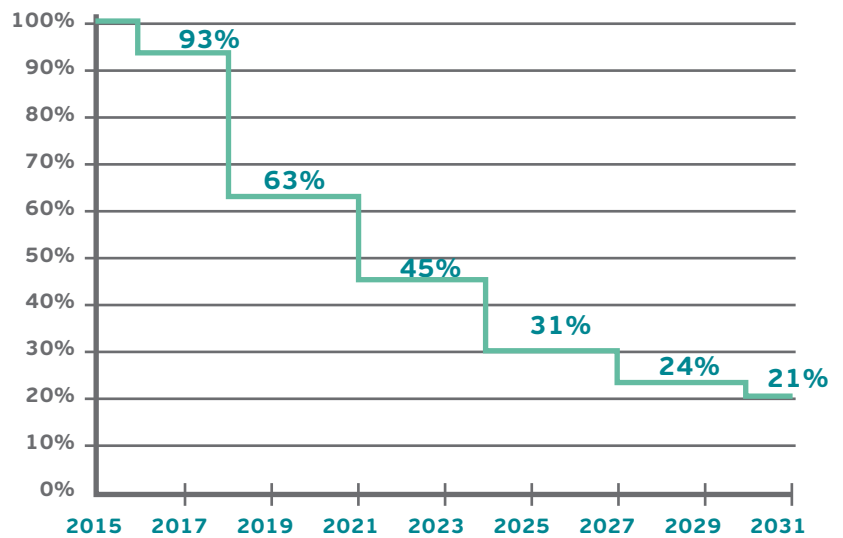


Fig.1 HFC Phase Down Schedule (EU regulation 517/2014)

EU F-gas regulation considers the average consumption between 2009 and 2012 expressed in MT CO₂^{equiv} as the phase down baseline

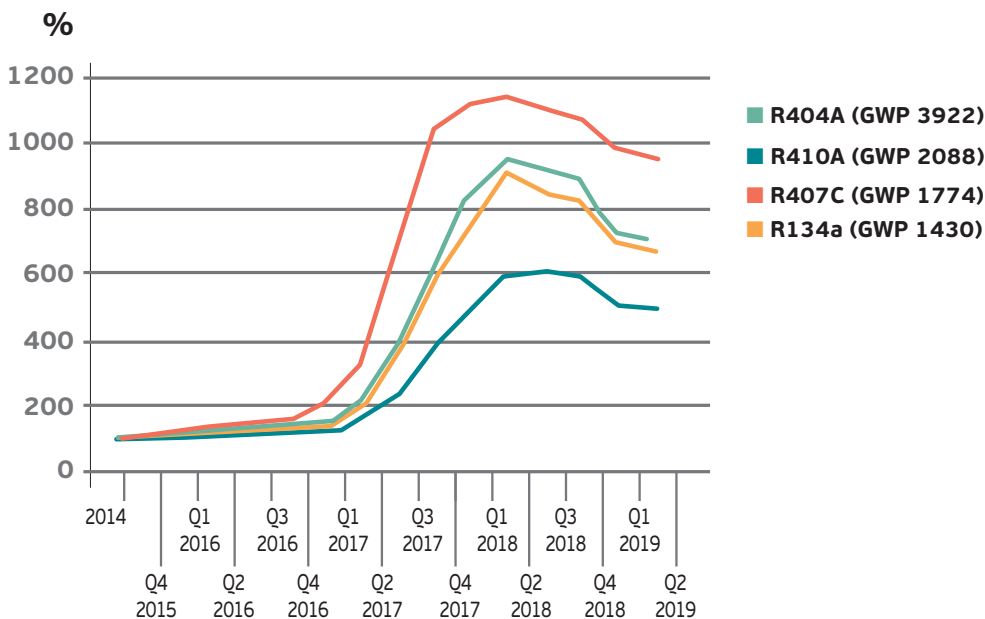


Fig.2 R404A and R134a Price Increases in the EU (2014 = 100%)

Alternative Refrigerants for Commercial Refrigeration

Embraco is working on products for the light commercial refrigeration segment that comply with both phases of EU F-gas regulations.

This means products that meet the final target limit (<150 GWP) with natural and with synthetic refrigerants, as well as compressors for transition refrigerants (150<GWP<2500), that should allow the industry to convert their product portfolio into final low-GWP refrigerants by 2022.

We recommend, if possible, going directly to the final refrigerants. Every appliance producer has to make a choice: go natural or use one of the new synthetic blends presently available. Table 1 lists the main criteria that should be taken in consideration when making this decision:

Table 1 Alternative Refrigerant Options

	High GWP HFC's	HC's	Low GWP HFC's
SAFETY CLASS	A1 Not Flammable	A3 Highly Flammable	A2L Slightly Flammable
ENVIRONMENTAL IMPACT	Very High	Ultra Low	Low
REFRIGERANT COST	Ref	Lower	Very High
COMPRESSOR THERMAL REGIME	Ref	Lower	Higher
INVESTMENTS FOR SAFETY	Ref	Yes	Yes
SYSTEM EFFICIENCY	Ref	Much Higher	Higher
CHARGE LIMIT FOR SELF-CONTAINED HERMETICALLY SEALED SYSTEMS (IEC/EN)	No	IEC 13*LFL EN 150g	IEC 1,2kg EN 150 g

Final Target Limit 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. Most of the existing light commercial application can be adapted for use of HC refrigerants.

Recently the IEC standard used for hermetically sealed applications (IEC60335-2-89) was updated, raising the charge limit to approximately 500 g for propane or 1,2 kg for A2L safety class flammable refrigerants.

This makes the transition to low-GWP refrigerants much easier than under the previous 150 g limit. Under the IEC SC61C/WG4 working group, the industry has defined a series of specific additional measures needed to allow higher charge levels without increasing risk as set by the previous standard.

The IEC standard is directly applicable in most of the world, and with some regional deviations like es. in Europe, with EN version. These revisions are still in progress and will not be concluded before 2020.

Until when EU authorities will adopt recently approved new IEC global standard charge limit, it remains still at 150 g per circuit. In case of larger applications multi-circuit configuration is a feasible option.

OTHER HYDROCARBONS: ISOBUTANE (R600a)

R600a - isobutane - represents a valid alternative solution for small appliances. It offers benefits in terms of efficiency but has significant limitations in terms of cooling capacity. Due to its low specific cooling capacity, it requires bigger compressor displacement compared to other refrigerants and consequently,

a larger and heavier compressor frame. Isobutane's evaporating temperature range is also limited. The Embraco catalogue features a full range of products for both LBP and HBP applications, including small chest freezers, bottle coolers and wine coolers.

OTHER HYDROCARBONS: PROPYLENE (R1270)

Propylene has very similar properties to propane. Although slightly less efficient, it has the advantage of a higher specific cooling capacity.

Therefore, propylene use must be limited to very specific situations. Embraco has no plans to develop compressors for propylene.

Its use can be approved in ad-hoc solutions for specific situations under the supervision of Embraco technical support.

Next Generation HFCs

R404A ALTERNATIVES

In the long term, industry under the AHRI's AREP (Alternative Refrigerant Evaluation Program) has tested a series of new mixtures with GWP below than 150. All these candidates are slightly flammable and belong to the A2/A2L classification with temperature glide up to 12 K. Tables 5 and 6 list some long-term alternatives to R404A that Embraco is testing for the light commercial segment.

It is important for the refrigeration industry to avoid refrigerant proliferation. An important step toward allowing the wider use of A2L class refrigerants is the revision of safety standards. Adoption of new IEC charge limits in the EU is crucial because with only 150 grams of charge it's almost impossible today to design any type of refrigeration system falling under the scope of the -89 product standard using A2L

class refrigerants. However, Embraco is ready to address any specific customer requests for compressor for use with A2L refrigerants.

Hopefully market forces will help speed up the adoption of a global standard. (the same applies to A3 safety class mentioned before).

Table 2 Alternative Blends Physical Data

	R 404A	R455A	R454C
TYPE	HFC blend	HFC blend	HFC blend
SAFETY CLASS	A1	A2L	A2L
BOILING TEMP @ 1atm	-47°C	-46°C	-45°C
CRITICAL TEMP	72°C	83°C	82°C
BUBBLE-DEW @1 bar (ABS)	0,8K	12,4K	8,2K

Table 3 Embraco Evaluation Summary

	R 404A	R455A	R454C
GWP	3920	146	146
APPLICATION FIELD	L/MBP	L/MBP	L/MBP
CAPACITY	Ref	Same	Lower
EFFICIENCY	Ref	Better	Better
RELIABILITY	Ref	NA	NA
LUBRICANT	POE	POE	POE
MOTOR TEMP	Ref	Higher	Higher
DISCHARGE TEMP	Ref	Higher	Higher

NA – not available

Next Generation HFCs

R134a ALTERNATIVES

R1234yf is a valid alternative to replace R134a, Embraco offers some compressor models for this refrigerant in its catalogue, but nowadays its use is limited to very specific applications. R1234ze is not considered as a valid alternative to R134a for light commercial systems because of its low specific cooling capacity. Its use would require a completely new product line that, at this stage, does not seem to not be a solution for this market segment.

Table 4 Alternative Blends Physical Data

	R 134a	R1234yf	R1234ze (E)
TYPE	HFC	HFC	HFC
SAFETY CLASS	A1	A2L	A2L
BOILING TEMP @ 1atm	-26°C	-30°C	-19°C
CRITICAL TEMP	101°C	95°C	110°C
BUBBLE-DEW @1 bar (ABS)	OK	OK	OK

Table 5 Embraco Evaluation Summary

	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
MOTOR TEMP	Ref	Same	NA
DISCHARGE TEMP	Ref	Same	NA

NA – not available

HFC Transitional Solutions

R404A REPLACEMENT

To ease the transition to refrigerants that comply with target final GWP limits, the chemical industry offers several alternatives to existing high-GWP HFC refrigerants. The most notable intermediate refrigerant candidates are HFC blends like **R407F, R407A, R448A, R449A** and **R452A**.

They are all in safety class A1 (non-toxic, non-flammable) and are characterized by considerably higher temperature glide than R404A. Tables 6 and 7 outline Embraco's evaluation of the main physical proprieties of these blends.

Table 6 Alternative Blends Physical Data

	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 7 Embraco Evaluation Summary

	R 404A	R407F	R407A	R448A	R449A	R452A
GWP	3920	1820	2100	1386	1397	2140
CAPACITY	Ref	Same	Same	Better	Better	Same
EFFICIENCY	Ref	Lower	Lower	Better	Better	Same
RELIABILITY	Ref	Much Lower	Much Lower	Lower	Lower	Same
LUBRICANT	POE	POE	POE	POE	POE	POE
MOTOR TEMP	Ref	Much Higher	Much Higher	Higher	Higher	Same
DISCHARGE TEMP	Ref	Much Higher	Much Higher	Higher	Higher	Same

HFC Transitional Solutions

Compressor temperatures tend to increase significantly with R407F and R407A. A slightly lower temperature increase was observed when testing R448A and R449A. Increased temperature can lead to motors overheating and/or overload protectors being tripped. This leads to a reduction in reliability and life expectancy (see conclusion notes for their eventual use).

R452A presents the same or lower thermal profile than R404A. R452A can be considered as an alternative for Embraco's R404A product line (ECN R452A 2016) with the same operating envelope of R404A in LBP and MBP applications. Both R448A and R449A were approved as an alternative refrigerant to R404A for NE/NT/NJ compressor series (ECN R449A 2018 and ECN R448A 2019), but only with a more

restricted operating envelope than R404A due to the higher internal compressor thermal level. The restricted envelope for R448A/R449A is presented in Figure 3. If an application is using an Embraco R404A compressor outside of this restricted envelope, please contact Technical Support for further instructions on how to adjust the thermal level of the compressor eg. by reducing return gas temperature.

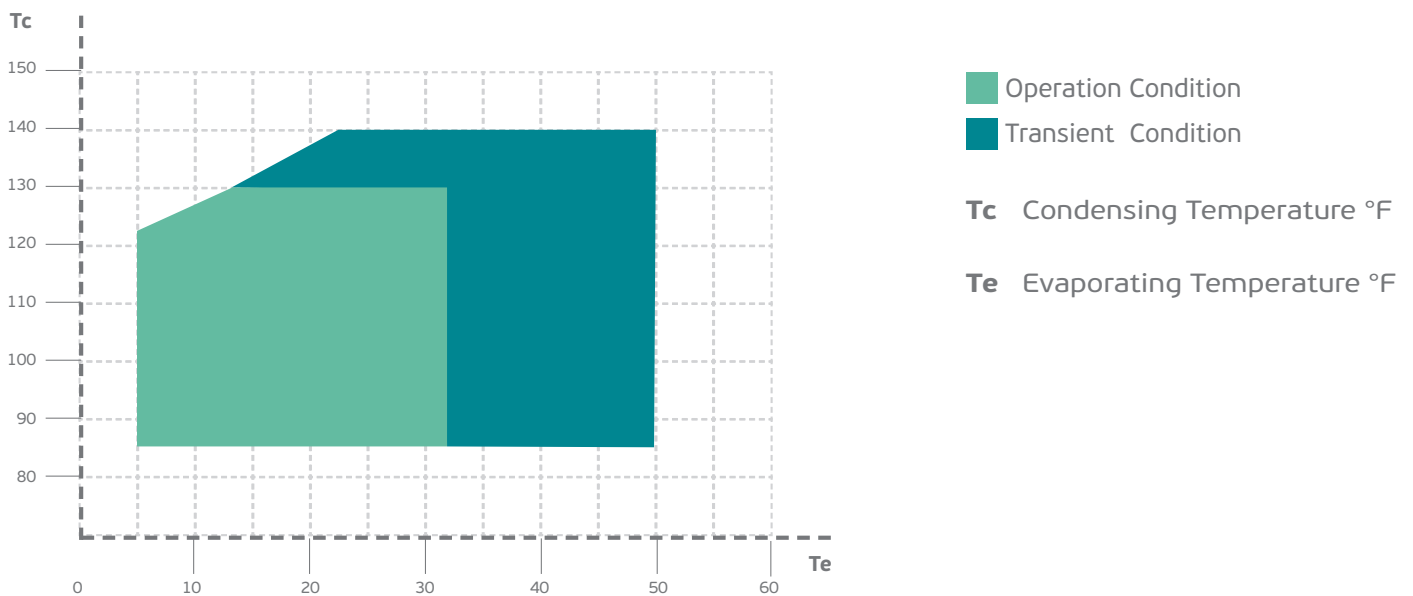


Fig.3 Restricted R448A/R449A Envelope (max. return 20°C)

In addition, customers always have the option of converting systems from R404A to R134a during the transition period just

by changing compressor models and **relative system design adjustment.**

HFC Transitional Solutions

R134a REPLACEMENT

The only reason to use the above mentioned R134a alternative blends during the transition period is because of their lower GWP allowing greater quantities under quota limitations.

Both R513A and R450A are approved for NB/NE/NT/NJ series (ECN R513A R450A 2017 and ECN CR/2966/en/18/10) as alternative refrigerant for Embraco R134a models.

Table 8 Alternative Blends Physical Data

	R134a	R450A	R513A
TYPE	HFC	HFC blend	HFC blend
SAFETY CLASS	A1	A1	A1
BOILING TEMP @ 1atm	-26°C	-24°C	-29°C
CRITICAL TEMP	101°C	106°C	98°C
BUBBLE-DEW @ 1 bar (ABS)	OK	0,8K	0,8K

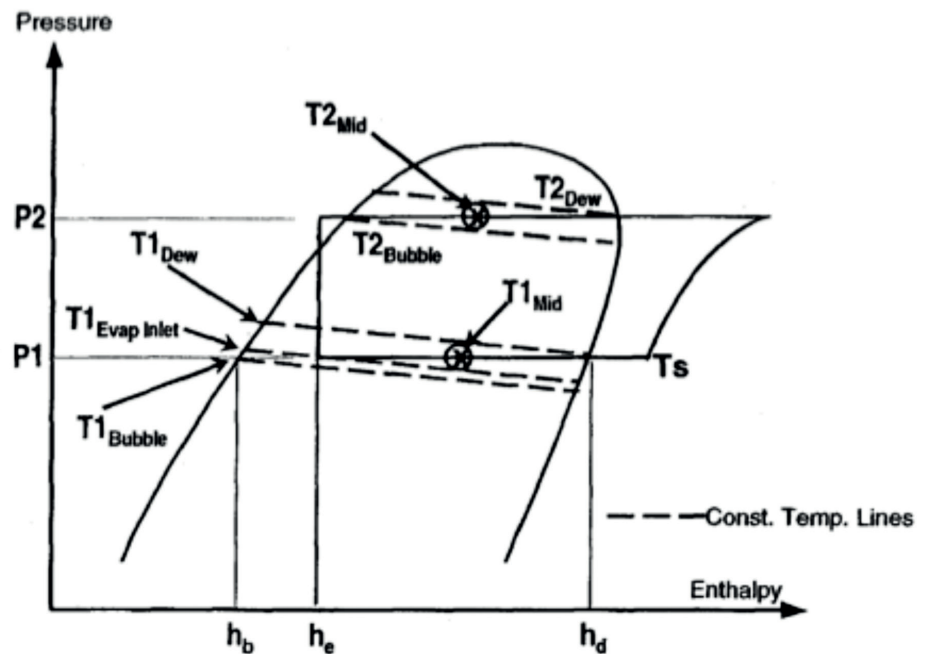
Table 9 Embraco Evaluation Summary

	R134a	R450A	R513A
GWP	1430	547	573
CAPACITY	Ref	Lower	Same
EFFICIENCY	Ref	Same	Same
RELIABILITY	Ref	Same	Same
LUBRICANT	POE	POE	POE
MOTOR TEMP	Ref	Same	Same
DISCHARGE TEMP	Ref	Same	Same

Performance Evaluation

It is important to consider that refrigerants with significant glide have to be differently than in the past. A dew point pressure approach cannot be used to define actual system operating conditions;

a mid-point approach should be used. How to define mid-point temperature is illustrated in Figure 4.



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

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

Fig.4 Mid-point Temperature Chart and Formulas

Warning

Warning Statement About Use of Flammable Refrigerants (A2L, A3) with Embraco Compressors, approved for A1 Safety Class Refrigerants (R134a, R404A, etc.)

Embraco is currently producing hermetic compressors for use with A3 and A2L refrigerants to replace high-GWP HFCs. However, it is important to note that:

1.

Embraco compressors designed and approved for non-flammable refrigerants (A1 class), **cannot be used** with any type of flammable refrigerants, including both A3 and A2L class refrigerants.

2.

All Embraco products mentioned in the Declaration of Conformity are compliant with all relevant EU directives.

3

For refrigeration systems falling under the scope of the harmonized standard EN 60335-2-89, EU regulations allow the use of flammable refrigerants up to 150 g refrigerant charge for each single refrigeration circuit until the new IEC limit is adopted.

4.

Given the above-mentioned charge limitations and considering that all flammable refrigerants require the same design, manufacturing and maintenance precautions, we strongly recommend the use of HC solutions wherever technically possible.

5.

Embraco offers a full portfolio of compressor models for R290, the refrigerant considered the best option for both systems with a 150 g charge limit as well as those with the new IEC charge limit once the harmonized EU standards are approved.

6.

Embraco declines any responsibility for compressors used without approved refrigerants (as listed above) and warns that potential reliability issues, such as motor overheating and electrical component malfunction, could occur following the use of unauthorized refrigerants.

Conclusions

Hydrocarbons (isobutane-R600a and propane-R290) represent the best long term solution for both low and medium pressure light commercial self-contained applications. Future EU legislation changes are expected to remove some of the existing roadblocks related to charge limits. As for the transition period between now and 2022, R452A can also be considered as an alternative refrigerant (see ECN R452A 2016) for both LBP and MBP but also R448A, and R449A mixtures can be used with specific Embraco R404A series within a restricted operating envelope (see ECN R448A 2019 and ECN R449A 2018). Using the blends mentioned above outside of Embraco approved system conditions, or using other transition blends like R407F or R407A as an alternative refrigerant for systems using

Embraco R404A compressors may require system changes such as a reduction in condensing temperature (larger condenser, improved ventilation) or return gas temperature in order to achieve a similar thermal profile to R404A. To maintain an Embraco warranty, the final application needs to be validated by the Embraco Technical Support Team on a case-by-case basis. In particular, using these blends in systems operating under high compression ratio conditions should be avoided. R513A and R450A are approved as alternative to R134a for use during the transition period in specific Embraco R134a series (see ECN R513A R450A 2017 and ECN CR/2966/en/18/10). Though its flammability must be taken into consideration, R1234yf is also an acceptable alternative for R134a for the long term.

- Embraco Approved Refrigerant
- Please contact Technical Support
- Not Approved

* different displacement

**NE/NT/NJ restrict envelope

***only NE/NT/NJ products

CURRENT REFRIGERANT	TEMPORARY SOLUTION		FINAL SOLUTION	
	LBP	MBP	LBP	MBP
R404A	R452A	R452A	R290*	R290*
R507	R134a*	R134a*	R455A	R455A
	R407C	R407C	R454C	R454C
	R448A	R448A**	R1270	R1270
	R449A	R449A**	R744	R744
	R407A	R407A		
	R407F	R407F		
R134a	R134a	R134a	R1234yf	R1234yf
	R513A***	R513A***	R600a*	R600a*
	R450A***	R450A***	R290*	R290*

General Trends

Light Commercial Segment from Embraco's Prospective

		LIGHT COMMERCIAL REFRIGERATION			
		WATT	150 - 5000		
		REGION/YEAR	TODAY	2022	2025
HC	AMERICA		REGULAR USE	MAIN REFRIGERANT	MAIN REFRIGERANT
	EUROPE		REGULAR USE	MAIN REFRIGERANT	MAIN REFRIGERANT
	JAPAN		REGULAR USE	REGULAR USE	REGULAR USE
	CHINA		REGULAR USE	MAIN REFRIGERANT	MAIN REFRIGERANT
	REST OF THE WORLD		REGULAR USE	MAIN REFRIGERANT	MAIN REFRIGERANT
HIGH GWP HFC's	AMERICA		MAIN REFRIGERANT	REGULAR USE	NICHE USE
	EUROPE		REGULAR USE	NICHE USE	NICHE USE
	JAPAN		MAIN REFRIGERANT	REGULAR USE	NICHE USE
	CHINA		MAIN REFRIGERANT	REGULAR USE	NICHE USE
	REST OF THE 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
	JAPAN		REGULAR USE	REGULAR USE	MAIN REFRIGERANT
	CHINA		NO CLEAR	NICHE USE	REGULAR USE
	REST OF THE WORLD		NO CLEAR	NICHE USE	REGULAR USE
CO ₂	AMERICA		NICHE USE	REGULAR USE	REGULAR USE
	EUROPE		NICHE USE	REGULAR USE	REGULAR USE
	JAPAN		REGULAR USE	REGULAR USE	REGULAR USE
	CHINA		NICHE USE	REGULAR USE	REGULAR USE
	REST OF THE WORLD		NICHE USE	REGULAR USE	REGULAR USE

- MAIN REFRIGERANT
- REGULAR USE
- NICHE USE
- NO CLEAR