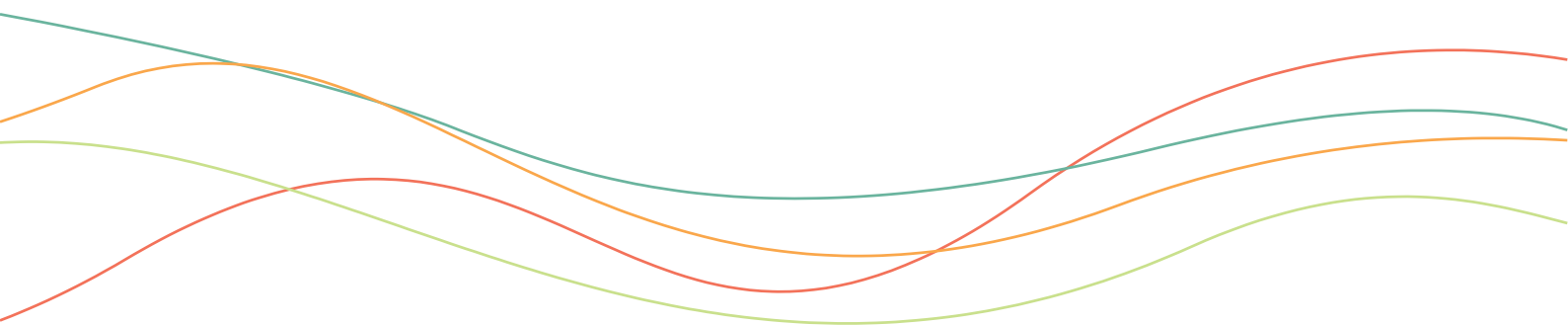




Embraco Position Paper: **Light Commercial Refrigeration**

Refrigerants Outlook – 2018



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Introduction

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The global community, with Kigali Amendment to Montreal Protocol, made another important step towards 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 imposes ban of high GWP refrigerants in next few years in several categories of commercial applications and is considerably limiting 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 is performing numerous 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.

EU F-Gas Regulation

European Union with F-Gas Regulation (517/2014) is limiting use of refrigerants with high GWP values (GWP – Global Warming Potential). The EU deadlines for use of refrigerant substances for different refrigeration segments are:

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 makers 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, unless when using reclaimed or recycled refrigerants, if available, it 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 is controlled with quota allocation system (see Fig.1) and led to its declining supply and significant increase of HFC prices (see Fig.2). Quantities of HFC gases available for all applications are be limited based on GWP value (in 2018 49% less if compared with 2015 usage - 87MTCO₂_{equiv}) and industry is 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_{equiv}

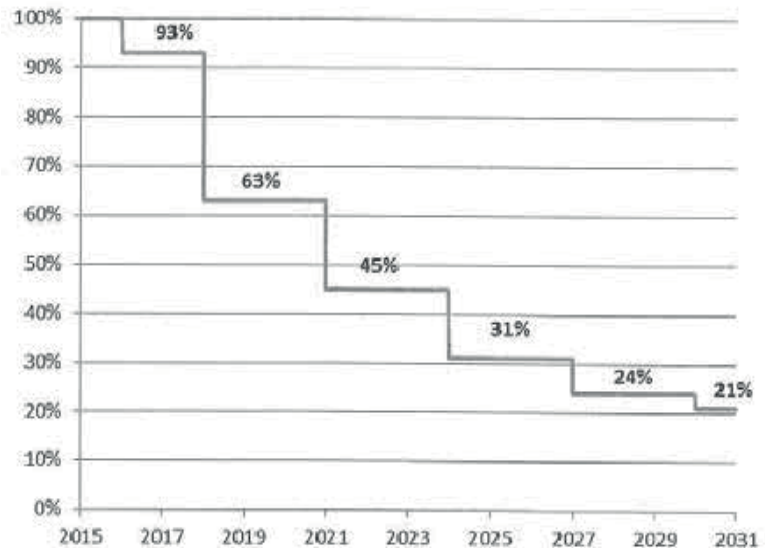


Fig.1 HFC Phase Down Schedule
(EU regulation 517/2014)

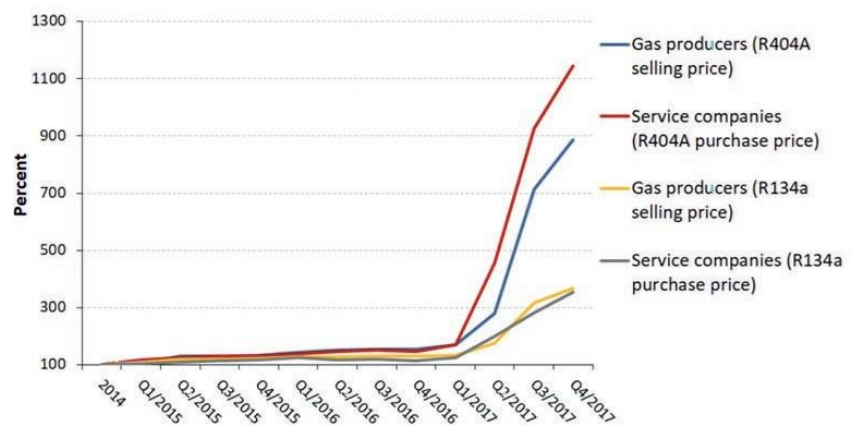


Fig.2 R404A and R134a Price
Development in EU (2014 = 100%)

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 (150<GW-P<2500), 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 | Very High | Ultra Low | Low |
| Refrigerant Cost | Ref | Less | 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

Table:1 Alternative Refrigerant Options

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 revision.

Today, present IEC standard used for hermetically sealed applications, (EN60335-2-89), is limiting to 150 grams the charge of any flammable refrigerant, which makes the transition to low GWP refrigerants difficult. 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 and will be concluded not before 2019.

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 properties also limit the evaporating temperature range. A full range of products, both for LBP and HB-P application are present in Embraco 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 properties to propane, it can offer advantage of higher specific cooling capacity, but is slightly less efficient than 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 alterna-

tives to replace R404A in light commercial segment are under test in Embraco 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 preferred

option which can be adopted globally. An important step to allow use of A2L class refrigerants is the safety standards revision (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 still in progress. The best alternative is yet to be defined.

| | R 404A | R455A | R454C | R457A |
|------------------------|-----------|-----------|-----------|-----------|
| 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 2. Alternative Blends Physical Data

| | R 404A | R455A | R454C | R457A |
|-------------------|--------|--------|--------|-------|
| 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 |
| Motor Temp | Ref | NA | NA | NA |
| Discharge Temp | Ref | Higher | Higher | NA |

(*) due to safety requirements for electrical components. NA - not available
 Table 3. Embraco Evaluation Summary

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, but presently with 150g flammable refrigerant charge limit its use to very

small applications. 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) | OK | OK | OK |

Table 4 . 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 |
| Motor Temp | Ref | Same | NA |
| Discharge Temp | Ref | Same | NA |

(*) due to safety aspects of electrical components. NA - not available

Table 5. Embraco Evaluation Summary

HFC Transitory Solutions

Compressor temperatures with the same system conditions tend to increase significantly with R407F, R407H 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. The consequence is reliability and life expectancy reduction (see conclusion notes for their eventual use). R452A presented the same or lower thermal profile when compared with R404A.

R452A can be considered as an alternative for Embraco's R404A product line (ECN R452A 2016) with same operating envelope of R404A both in LBP and MBP applications.

Recently, also R449A was approved as an alternative refrigerant to R404A for NEU/NT/NJ compressor series (ECN R449A 2018), but only for MBP application and with restricted envelope if compared to R404A, because of higher compressor internal thermal level. Restricted MBP envelope for R449A is presented in Fig.3.

Fig. 3 Restricted MBP R449A Envelope (max return 20 deg C)

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.

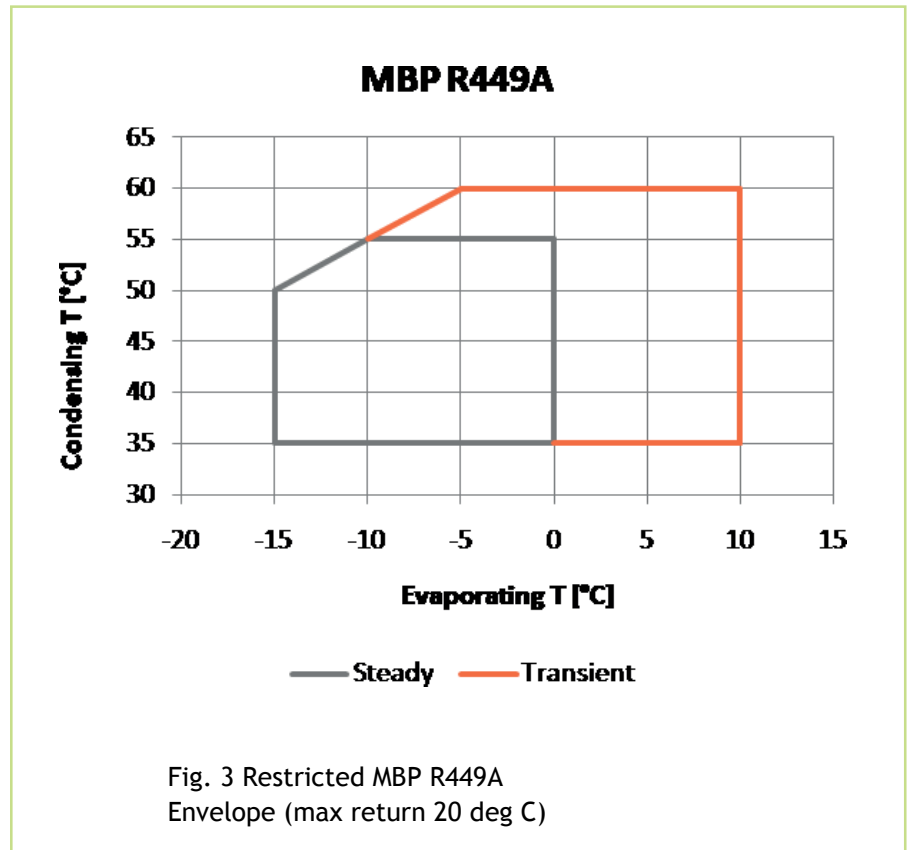


Fig. 3 Restricted MBP R449A Envelope (max return 20 deg C)

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**, **R407H**, **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 evaluation summary are indicated respectively in table 6 and table 7

| | R 404A | R407F | R407A | R447H | R448A | R449A | R452A |
|------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Type | HFC blend | HFC blend | HFC blend | HFC blend | HFC blend | HFC blend | HFC blend |
| Safety class | A1 | A1 | A1 | A1 | A1 | A1 | A1 |
| Boiling Temp @ 1atm | -47°C | -46°C | -45°C | -45°C | -45°C | -46°C | -47°C |
| Critical Temp | 72°C | 83°C | 82°C | 87°C | 87°C | 82°C | 75°C |
| Bubble-Dew @1 bar(abs) | 0,8K | 6,4K | 6,4K | 7K | 7K | 6,1K | 3,8K |

Table 6. Alternative Blends Physical Data

| | R 404A | R407F | R407A | R407H | R448A | R449A | R452A |
|-------------------|---------|-------------|-------------|-------------|--------|--------|---------|
| GWP | 3920 | 1820 | 2100 | 1495 | 1386 | 1397 | 2140 |
| Application Field | LBP,MBP | MBP | MBP | MBP | MBP | MBP | LBP,MBP |
| Capacity | Ref | Same | Same | Same | Lower | Lower | Same |
| Efficiency | Ref | Lower | Lower | Lower | Lower | Lower | Same |
| Reliability | Ref | Much Lower | Much Lower | Much Lower | Lower | Lower | Same |
| Lubricant | POE | POE | POE | POE | POE | POE | POE |
| Motor Temp | Ref | Much Higher | Much Higher | Much Higher | Higher | Higher | Same |
| Discharge Temp | Ref | Much Higher | Much Higher | Much Higher | Higher | Higher | Same |

Table 7. Embraco Evaluation Summary

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. Both R513A and R450A are approved for NB/NE/NT/NJ series (ECN R513A

R450A 2017) as alternative refrigerant for Embraco Slovakia R134a models.

| | 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) | OK | 0,8K | 0,8K |

Table 8. Alternative Blends Physical Data

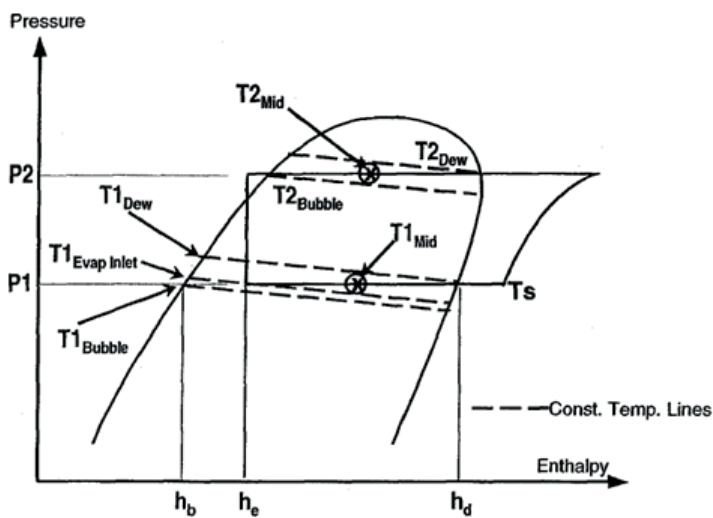
| | R134a | R450A | R513A |
|-------------------|---------|---------|---------|
| GWP | 1430 | 547 | 573 |
| Application Field | L/M/HBP | L/M/HBP | L/M/HBP |
| Capacity | Ref | Lower | Same |
| Efficiency | Ref | Same | Same |
| Reliability | Ref | Same | Same |
| Lubricant | POE | POE | POE |
| Motor Temp | Ref | Same | Same |
| Discharge Temp | Ref | Same | Same |

Table 9. Embraco Evaluation Summary

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.



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

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

Warning

Warning Statement About Use of Flammable Refrigerants (A2L,A3) with Embraco Compressors, approved for A1 Safety Class refrigerants (R134a,R404A,etc) Embraco is presently working on development of hermetic compressors for their use with A2L refrigerants to replace high GWP HFC's, however we would like meanwhile to remind:

1 Embraco compressors designed and approved for their use with not flammable refrigerants (A1 class), cannot be used with any type of flammable refrigerants, nor A3 neither A2L class

2 Embraco products mentioned in Declaration of Conformity are compliant with all the relevant EU Directives but presently none of them is approved in Cat.2 under PED

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 150g refrigerant charge for each single

refrigeration circuit.

4 Subject to the charge limitations above mentioned and considering that all flammable refrigerants require same precautions in design, manufacturing and maintenance, we strongly recommend the use of HC solution, wherever technically possible. Embraco is offering full range of R290 models which are the best option for systems with 150g charge limit of flammable refrigerants.

5 Specifically Embraco recommends the use of R452A, R449A (with restricted envelope) and R513A, R450A as "transitory" refrigerants, officially approved by Embraco for respectively R404A and R134a compressors.

6 Embraco declines any responsibility if its compressor will be used without approved refrigerant (as listed above) and warn about potential reliability issues, motor overheating and electrical components malfunctioning that could arise out of the use of unauthorized refrigerant.

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, R407H, R448A, as an alternative replacement refrigerant 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. To maintain Embraco warranty, final appli-

cation 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 an alternative refrigerant (see ECN R452A 2016) for both LBP and MBP and R449A can be used on specific Embraco MBP R404A series with restricted envelope as explained previously.

R513A and R450A are approved as acceptable alternative to R134a for transition period in specific Embraco R134a series (see ECN R513A R450A 2017). R1234yf is as well an acceptable alternative for R134a also for long term, but flammability aspects of all A2L refrigerants are not yet solved and with present legislation charge has to be limited to 150g.

| Current Refrigerant | Temporary Solution | | Final Solution | |
|---------------------|--------------------|-------------|----------------|-------------|
| | LOW TEMP | MEDIUM TEMP | LOW TEMP | MEDIUM TEMP |
| R404A | R452A | R452A | R290* | R290* |
| R507A | R134a* | R134a* | R455A | R455A |
| | R407C | R407C | R457A | R457A |
| | R448A | R448A** | R454C | R454C |
| | R449A | R449A** | R1270 | R1270 |
| | R407A | R407A | R744* | R744* |
| | R407H | R407H | | |
| | R407F | R407F | | |
| R134a | R134a | R134a | R1234yf | R1234yf |
| | R513A*** | R513A*** | R600a* | R600a* |
| | R450A*** | R450A*** | R290* | R290* |

| |
|-------------------------------|
| Embraco Approved Refrigerant |
| Pls contact Technical Support |
| Under evaluation |

*different displacement
 **only NE/NT/NJ restrict envelope
 ***only NE/NT/NJ products (for EM/FF range pls contact Technical Support)

General Trends For Light Commercial Segment from Embraco Prospective

| Light Commercial Refrigeration | | | | |
|--------------------------------|---------------|------------------|------------------|------------------|
| Watt | 150 - 5000 | | | |
| Region / Year | 2017 | 2020 | 2025 | |
| HC | America | Regular use | Main refrigerant | Main refrigerant |
| | Europe | Regular use | Main refrigerant | Main refrigerant |
| | Japão | Regular use | Regular use | Regular use |
| | 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 |
| | Japão | Main refrigerant | Regular use | Niche use |
| | China | Main refrigerant | Regular use | Niche use |
| | Rest of World | Main refrigerant | Regular use | Niche use |
| LOW GWP HFC's | America | Regular use | Regular use | Regular use |
| | Europe | Regular use | Niche use | Regular use |
| | Japão | Regular use | Regular use | Main refrigerant |
| | China | Regular use | Niche use | Regular use |
| | Rest of World | Regular use | Niche use | Regular use |
| CO2 | America | Niche use | Regular use | Regular use |
| | Europe | Niche use | Regular use | Regular use |
| | Japão | Regular use | Regular use | Regular use |
| | China | Niche use | Regular use | Regular use |
| | Rest of World | Niche use | Regular use | Regular use |

■ Main refrigerant ■ Niche use
■ Regular use No clear