CAREL

Knowledge Center

White paper

Refrigerant scenario

Rules and trends in the near future

Concerns on environmental issues such as the greenhouse effect are driving governments to create new rules to control emissions.
In the coming years, significant actions are planned, and refrigerants will be particularly affected. Information is continuously being updated and the specificities of regulations create many questions among manufacturers and users:
How do the rules affect the most common refrigerants? What are the trends? Which is the best refrigerant for each application?
CAREL can help you answer these questions and find solutions that are compatible with the new regulations worldwide.

Connected Efficiency

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Definition of terms

CFC (Chlorofluorocarbon): substance which contains fluorine, carbon and chlorine. They are considered the "first generation" of refrigerants. CFC refrigerants have ODP and are greenhouse gases (high GWP). E.g. R-12.

Glide: temperature difference between the starting and ending temperature of a refrigerant phase change. It occurs when a refrigerant is a blend of components with different evaporation/condensation temperatures at the same pressure. This factor negatively affects the performance and related design of refrigeration circuits, especially evaporators.

GWP (Global Warming Potential): this is a characteristic factor estimating the greenhouse effect of a gas being released into the atmosphere compared to the effect of CO_2. For example, the GWP of CO_2 is 1 and the GWP of R-134a is 1430: this means that 1 kg of R-134a has the same greenhouse effect as 1430 kg of CO_2.

HC (Hydrocarbons): substance composed of hydrogen and carbon. They are natural, non toxic refrigerants that have no ozone depleting properties and minimal GWP.

HCFC (Hydrochlorofluorocarbon): substance which contains hydrogen, fluorine, carbon and chlorine. They are considered the "second generation" of refrigerants, substituting CFCs (chlorofluorocarbons) such as R-12. HCFC refrigerants have ODP and are greenhouse gases (high GWP). E.g. R-22.

HFC (Hydrofluorocarbon): substance containing hydrogen, fluorine and carbon. They are considered the "third generation" of refrigerants, with no ODP, but are greenhouse gases (high GWP). E.g. R-134a, R-32, R-404A.

HFO (Hydrofluoroolefin): substance composed of hydrogen, fluorine and carbon. They are considered the "fourth generation" of refrigerants, with a thousand times lower GWP than HFCs. E.g. R-1234yf, R-1234ze(E).

Natural refrigerants: chemicals which occur in nature's bio-chemical processes, i.e.: air, water, carbon dioxide, ammonia and hydrocarbons. They do not deplete the ozone layer and make a negligible or no contribution to global warming.

ODP (Ozone Depletion Potential): this is the potential for a single molecule of refrigerant to destroy the ozone layer, with R-11 being fixed as a reference at an ODP of 1.0.

Rules and regulations

Synthetic refrigerants HCFCs and HFCs, also known as **fluorinated greenhouse gases,** are significant contributors to the greenhouse effect and are an important aspect of efforts to control emissions.

In the framework of the **Kigali amendment to the Montreal Protocol**, several actions are planned to be carried out by different countries, with the aim of limiting the increase in average global temperature to no more than 2 (possibly 1.5) °C above pre-industrial levels. Examples of related regulations are: F-gas regulation (EU), EPA SNAP Rules (USA) and Act on Rational Use & Proper Management of Fluorocarbons (Japan).

Most regulations state similar action plans: limitation of the production and phase-out of HFCs with a high GWP (Global Warming Potential).

1. Refrigerant history overview

The history of refrigerants started more than 180 years ago. From the beginning, it has been marked by the discovery of the drawbacks of the different options, which has led to the research of alternative solutions. During the last 30 years, the changes have also been dictated by international agreements that aim to protect people and environment. A summary is shown in the following timeline:

1834 | The first working vapor-compression refrigeration system was built, using ethyleter as refrigerant

Refrigerants available in nature were used

Natural refrigerants presented some security problems due to flammability and toxicity

1930 | Natural refrigerants were replaced by synthetic refrigerants, in particular **CFCs**

1950 | The development of CFCs led to the discovery of **HCFCs**

1973 | *It was found that the emissions of Cl^- atoms present in CFCs and HCFCs deplete the ozone layer*

1985 | Vienna Convention for the Protection of the Ozone Layer

1987 | **Montreal Protocol** on Substances that Deplete the Ozone Layer

Diffusion of **HFCs**

It was discovered that fluorinated refrigerants negatively increases the greenhouse effect

1992 | United Nations Framework Convention on Climate Change, Rio de Janeiro

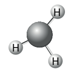
1997 | **Kyoto Protocol**: it required the developed countries to reduce greenhouse gas emissions by 5%

2015 | UN Climate Change Conference in Paris: agreement of limiting global warming to less than 2°C Celsius

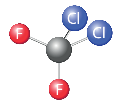
2016 | **Kigali Agreement** (Montreal Protocol Amended). Details are shown below.

Diffusion of **HFOs** and **natural refrigerants** (HCs, CO_2 and ammonia)

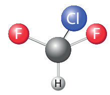
Ammonia (**Natural**)



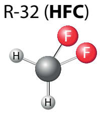
R-12 (**CFC**)



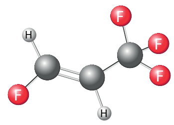
R-22 (**HCFC**)



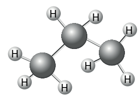
R-32 (**HFC**)



R-1234ze (**HFO**)



Propane (**HC, natural**)



Kigali Agreement

In the framework of the UN Climate Change Conference in Paris, an amendment to the Montreal Protocol was signed on October 2016 in Kigali. It involves the international phase-down of HFCs by 85 % by the late 2040s, which would help **prevent a 0.5 °C rise in global temperature by 2100, while continuing to protect the ozone layer.** Most developing countries will follow with a freeze on HFC consumption levels in 2024, and other developing countries will follow in 2028, as shown in the following graph (EU F-gas target limits have been included for comparison).

The Kigali Amendment was ratified by more than 20 parties to the Montreal Protocol, and entered into force on 1 January 2019. So far (December 2019), 91 countries have ratified/adopted/approved it.

As a consequence of these global treaties, each country establishes concrete measures to comply with the agreements. This is the basis for the rules and regulations presented in this document, for example F-gas in Europe or the EPA's SNAP rules in the USA.

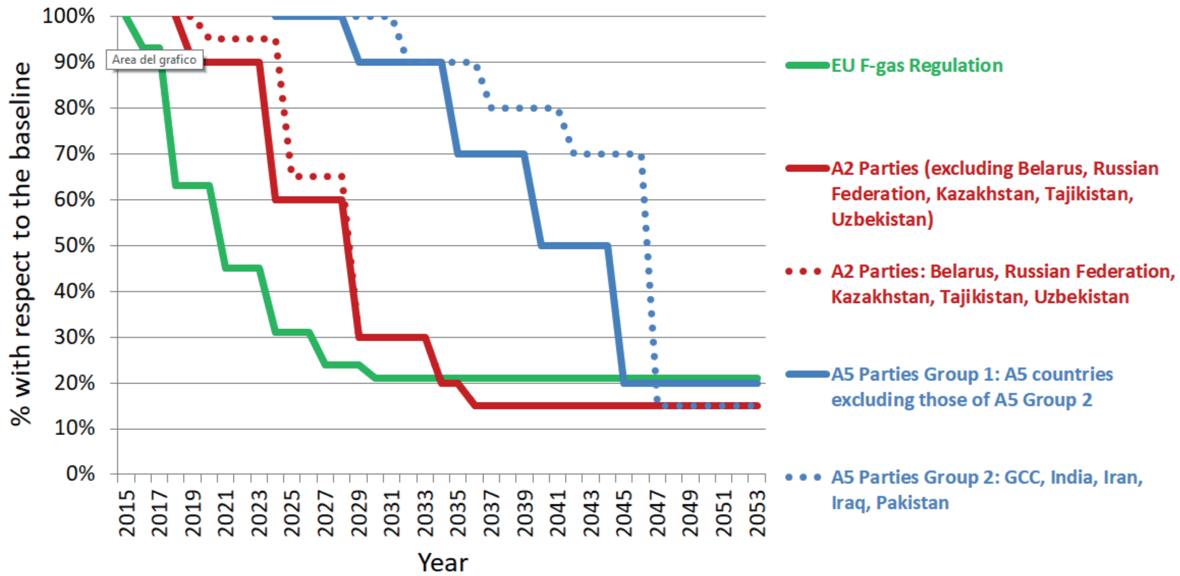


Fig. 1.a - Phase-down schedule for HFCs according to Kigali Agreement.

2. What are the rules in different parts of the world?

European union

"F-gas Regulation No. 517/2014"

F-gas Regulation classifies HFC refrigerants according to their GWP and specifies the date these are banned, if applicable, for each application (see the following table). Some provisions linked to the 2006 F-gas regulation remain valid for now.

Application	Refrigerants	Unacceptable as of
Domestic refrigerators and freezers	HFCs with GWP≥150	1 January 2015
Refrigerators and freezers for commercial use *Refers to hermetically sealed equipment.*	HFCs with GWP≥2500 HFCs with GWP≥150	1 January 2020 1 January 2022
Stationary refrigeration and air-conditioning equipment *Multipack centralized refrigeration systems for commercial use with a rated capacity of less than 40 kW is included.* *Exception: equipment intended for application designed to cool products to temperatures below -50 °C.* *Blends with GWP <2500 that have components with a higher GWP (such as R-125) could still be used.*	HFCs with GWP≥2500	1 January 2020
Multipack centralized refrigeration systems for commercial use with a rated capacity of 40 kW or more *Exception: primary refrigerant circuit of cascade systems where HFC with a GWP of less than 1500 may be used.* *Existing installations prior to that date can use R-134a for service and maintenance until the end of life cycle of the installation. 40 kW applies to the refrigeration capacity of the system at rated conditions at ambient temperature of 32 °C.*	HFCs with GWP≥150	1 January 2022
Movable room air-conditioning equipment *Refers to hermetically sealed equipment which is movable between rooms by the end user, including window air-conditioners.*	HFCs with GWP≥150	1 January 2020
Single split air-conditioning systems containing less than 3 kg of fluorinated greenhouse gases *Refers to those systems for room air conditioning that consist of one outdoor unit and one indoor unit linked by refrigerant piping, needing installation at the site of use. The Regulation does not specify heating/cooling and type.*	HFCs with GWP≥750	1 January 2025

Table. 2.a - Classification of refrigerants that will be banned in the EU according to the F-gas Regulation

It should be noted that in existing equipment, reclaimed or recycled gas with a GWP higher than 2500 will be allowed until 2030.

Moreover, since 2006, the F-gas Regulation introduced **regular leak checking**, initially depending on the HFC mass in a circuit expressed in kg, and from 2014 depending on the number of tonnes of CO_2 equivalent in the circuit (see Table 2.b).

F-gas also introduced the concept of "quotas", which refer to the reduction in the admissible production/import of HFCs over time. **Quotas will be reduced to 93% (2016), 63% (2018), 45% (2021), down to 21% (2030) compared to the average 2009-2012 EU HFC consumption**.

A comprehensive report on the effects of the F-gas regulation shall be published **by the end of 2022**, including an assessment of the need for further action by the Union and its Member States regarding the reduction of HFC emissions and a review of the availability of technically-feasible and cost-effective alternatives, taking into account energy efficiency.

Tonnes of CO_2-eq. per circuit	Frequency of leak checking
Less than 5 (=5000 kg) *e.g. for R-404A (GWP 3922): less than 5000/3922=1.3 kg*	Exempted
Less than 10, if hermetically sealed and labelled as such *e.g. for R-404A: less than 10000/3922=2.6 kg*	Exempted
5-50 *e.g. for R-404A: 1.3-13 kg*	Every 12 months (or 24 months with a leakage detection and monitoring system)
50-500 *e.g. for R-404A: 13-130 kg*	Every 6 months (or 12 months with a leakage detection and monitoring system)
Over 500 *e.g. for R-404A: over 130 kg*	Every 3 months (or 6 months with a leakage detection and monitoring system) *For stationary refrigeration equipment, stationary air conditioning equipment and stationary heat pumps, operators shall ensure that this equipment is provided with a leak detection system.*

Table. 2.b - Frequency of leak checks according to the F-gas Regulation

Japan

"Act on Rational Use & Proper Management of Fluorocarbons"

This regulation addresses issues throughout the lifecycle of fluorocarbons. It classifies refrigerants according to their GWP and specifies the date these are banned for each application (see the following table).

Designated products[1]	Present refrigerant	Target value (GWP)	Target year
Room air-conditioning	R-410A, R-32	Less than 750	2018
Commercial air-conditioning	R-410A	Less than 750	2020
Condensing unit and refrigerating unit	R-404A, R-410A, R-407C, R-744 (CO_2)	Less than 1500	2025
Cold storage warehouse *(for more than 50,000 m^3)*	R-404A, R-717 (Ammonia)	Less than 100	2019

Table. 2.c - Target value and year for each designated product in Japan according to the Act on Rational Use & Proper Management of Fluorocarbons

[1] With some exceptions

Other requirements:

- **indications and label** to designated products (showing "non-F-gas using" or degree of achievements to the target GWP value, target year and target GWP value, GWP value of the refrigerant used in the products), with the purpose of promoting designated products using low-GWP or natural refrigerant;
- **regular leak checks**, call service to arrange repairs before refilling as soon as leakages are found, record maintenance, and disclose to maintenance operators, etc;
- calculation of the **annual F-gas leakage amounts**. If that amount exceeds 1,000 tonnes of CO_2 equivalent, users, as a company, need to report it to the relevant competent ministries, with information on the offices and factories from which the leakage was detected. The Ministry of the Environment (MOE) and the Ministry of Economy, Trade and Industry (METI) will notify the relevant municipal and prefectural governors on the results and the names of the companies, etc., and will publish them;
- 2018 Revision of Ozone Layer Protection Law, in force since 1 January 2019: Manufacturers and importers of HFCs are controlled in accordance with Kigali Amendment to fulfil the obligation to the phase down of HFCs. This means that who seeks to **manufacture or import HFCs must receive a permission and be assigned a quota** from the Ministry of Economy, Trade and Industry.

USA

The last few years have been uncertain for refrigerant regulations in USA. The publication of Rule 20 in 2015 and Rule 21 in 2016, specifying some refrigerants as unacceptable in HVAC/R applications, triggered a confrontation between different companies.

In February 2017, a lawsuit was filed with the DC Circuit of Appeals Court by two chemical companies against the EPA, arguing that **the Clean Air Act did not provide authority for the EPA to determine that HFCs were unacceptable**. This was then appealed by two other chemical companies and an environmental group. This appeal was rejected by the Supreme Court in October 2018, thus vacating Rule 20. Six months later, Rule 21 was also vacated. Additionally, in October 2018 the EPA published a proposed rule that would remove requirements for maintenance and leakage repair provisions for equipment using substitute refrigerants such as HFCs.

In this context, some states have decided to take their own measures to reduce the use of HFCs. As of the date of this document, the states of California, New York, Maryland, Connecticut, Washington, Vermont and Delaware have announced their intention to apply both Rule 20 and Rule 21 in their territories. Indeed, **regulations focused on end-use prohibitions from the US EPA's SNAP Program Rule 20 and 21 were approved in California by the CARB (California Air Resources Board) in March 2018 and some of the bans are already in force for a number of supermarket applications**. It should be noted that the CARB regulation does not cover HFC uses in, and emissions from, motor vehicle air conditioning (MVAC) systems.

"EPA SNAP Rules"

The main rules affecting refrigerants are:
- Rule 17: lists **R-290 (Propane)** as acceptable for retail food refrigeration and freezers (new stand-alone units);
- Rule 19: lists **R-600a (Iso-butane)** as acceptable for retail food refrigeration and freezers (new stand-alone units); lists **R-290** and **R-600a** as acceptable for new vending machines; lists **R-32** and **R-290** as acceptable for new residential and light commercial air-conditioning, and new heat pumps-self-contained air conditionings;
- Rule 20: lists each single refrigerant that will be unacceptable for commercial refrigeration applications (see Table 2.d);
- EPA's Determination 30: acceptable replacements for R-404A are **R-448A**, **R-449A** for some refrigeration applications; acceptable replacement for R-134a are **R-450A** and **R-513A** for chillers.

Application	Refrigerants
Supermarket systems • multiplex or centralized; • operate with racks of compressors installed in a machinery room; • direct and indirect systems.	Retrofit [1]: **R-404A**, R-407B, R-421B, R-422A,R-422C, R-422D, R-428A, R-434A, R-507A
	New: HFC-227ea, **R-404A**, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A
Remote condensing units • typically 1-20 kW (6.5 TR), one or two compressors and the condenser and receiver integrated into a single unit; • commonly installed in convenience stores, specialty shops, supermarkets, and restaurants.	Retrofit [1]: **R-404A**, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A
	New: HFC-227ea, **R-404A**, R-407B, R-421B, R-422A, R-422C, R-422D, R-428A, R-434A, R-507A
Stand-alone equipment • refrigerators, freezers, and reach-in coolers, • refrigeration circuit is entirely brazed or welded, • fully charged with refrigerant at the factory and typically require only an electricity supply to begin operation.	Retrofit [1]: **R-404A**, R-507A
Stand-alone medium temperature units with a compressor capacity below 2,200 Btu/hour and not containing a flooded evaporator	New: FOR12A, FOR12B, **HFC-134a**, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**, R-407A, R-407B, R-407C, R-407F, **R-410A**, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R438-A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E, THR-03
Stand-alone medium temperature units with a compressor capacity equal to or greater than 2,200 Btu/hour and stand-alone medium temperature units containing a flooded evaporator	New: FOR12A, FOR12B, **HFC-134a**, HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/∑42.5/1.5), **R-404A**, R-407A, R-407B, R-407C, R-407F, **R-410A**, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), RS-44 (2003 formulation), SP34E,THR-03
Stand-alone low-temperature units	New: HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**, R-407A, R-407B, R-407C, R-407F, **R-410A**, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A, R-434A, R-437A, R-438A, R-507A, RS-44 (2003 formulation)
Vending machines	Retrofit [1]: **R-404A**, R-507A
	New: FOR12A, FOR12B, **HFC-134a**, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**, R-407C, **R-410A**, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D, R-426A, R-437A, R-438A, R-507A, RS-24 (2002 formulation), SP34E

Table. 2.d - List of refrigerants to be banned according to the EPA's SNAP Rule 20 (in bold the most commonly used)

[1] Retrofit= replacing an acceptable refrigerant in an existing system that previously used an HFC.

- **Rule 21:** lists several substances as unacceptable; and modifies the listing status for certain substances from acceptable to unacceptable (see Table 2.e). Additionally, EPA lists **propane** (**R-290**) as acceptable, subject to use conditions, as a refrigerant in new self-contained commercial ice machines, in new water coolers, and in new very low temperature refrigeration equipment.

Application	Refrigerants
Centrifugal chillers	New: FOR12A, FOR12B, **HFC-134a** [1], HFC-227ea, HFC-236fa, HFC-245fa, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**[1], R-407C, **R-410A**, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D,R-423A, R-424A, R-434A, R-438A,R-507A, RS-44 (2003 composition), and THR-03.
	New: **Propylene (R-1270)** and R-443A
Positive displacement chillers (Reciprocating, Screw, Scroll)	New: FOR12A, FOR12B, **HFC-134a** [1], HFC-227ea, KDD6, R-125/134a/600a (28.1/70/1.9), R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**[1], R-407C, **R-410A**, R-410B, R-417A, R-421A, R-422B, R-422C, R-422D,R-424A, R-434A, R-437A, R-438A, R-507A, RS-44(2003 composition), SP34E, and THR-03.
	New: **Propylene (R-1270)** and R-443A
Cold storage warehouses	New: HFC-227ea, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**[1], R-407A, R-407B, **R-410A**, R-410B, R-417A, R-421A, R-421B,R-422A, R-422B, R-422C, R-422D, R-423A, R-424A, R-428A, R-434A, R-438A,R-507A, and RS-44 (2003 composition).
	New: **Propylene (R-1270)** and R-443A
Household refrigerators and freezers	New: FOR12A, FOR12B, **HFC-134a**, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**,R-407C, R-407F, **R-410A**, R-410B, R-417A, R-421A, R-421B, R-422A, R-422B,R-422C, R-422D, R-424A, R-426A, R-428A, R-434A, R-437A, R-438A, R-507A,RS-24 (2002 formulation), RS-44 (2003 formulation),SP34E, and THR-03.
Residential and light commercial air conditioning and heat pumps	New: **Propylene (R-1270)** and R-443A Retrofit: All refrigerants identified as flammability Class 3 in ANSI/ASHRAE Standard 34-2013. All refrigerants meeting the criteria for flammability Class 3 in ANSI/ASHRAE Standard 34-2013.
Retail food refrigeration (refrigerated food processing and dispensing equipment)	New: HFC-227ea, KDD6, R-125/290/134a/600a (55.0/1.0/42.5/1.5), **R-404A**, R-407A, R-407B, R-407C, R-407F, **R-410A**, R-410B,R-417A, R-421A, R-421B, R-422A, R-422B, R-422C, R-422D, R-424A, R-428A,R-434A, R-437A, R-438A, R-507A, RS-44(2003 formulation).

Table. 2.e - List of refrigerants to be banned according to the EPA's SNAP Rule 21 (in bold the most commonly used)

[1] HFC-134a: Acceptable, subject to narrowed use limits, for military marine vessels, as of 1 January 2024; HFC-134a and R-404A: Acceptable, subject to narrowed use limits, for human rated spacecraft and related support equipment, as of 1 January 2024.

Canada

"Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations"

Canada indicates refrigerants that will be banned from 2020 onwards for each application according to the value of GWP:

Product	Use	Date	GWP
Stand-alone medium-temperature refrigeration system	Commercial or industrial	1 January 2020	1400
	Domestic appliances	1 January 2025	150
Stand-alone low-temperature refrigeration system	Commercial or industrial	1 January 2020	1500
	Domestic appliances	1 January 2025	150
Centralized refrigeration system	Commercial or industrial	1 January 2020	2200
Condensing unit	Commercial or industrial	1 January 2020	2200
Chiller	Commercial or industrial	1 January 2025	750
Mobile refrigeration system	Commercial or industrial	1 January 2025	2200

Table. 2.f - Regulations Amending the Ozone-depleting Substances and Halocarbon Alternatives Regulations in Canada

China

China has expressed the intention of ratifying the Kigali Amendment to the Montreal Protocol, however as of the date of this document, has not done so yet. The following table shows the recommended refrigerants that can substitute R-22 for each application, according to Government indications.

Refrigerant	Recommended Substitute	Application
R-22	R-290 (Propane)	Room air conditioner; Commercial independent refrigeration system
R-22	R-600a (Isobutane)	Commercial independent refrigeration system
R-22	R-744 (CO_2)	Household heat pump water heater; Industrial/commercial heat pump water heater; Vehicle air conditioner; Industrial/commercial freezing and refrigeration system (used as refrigerant and secondary refrigerant)
R-22	R-717 (Ammonia)	Refrigerated warehouse; Transport refrigeration; Condensing unit; Industrial refrigeration system
R-22	R-32	Unitary air conditioner; Water chilling (heat pump) unit; Heat pump water heater
R-22	HFOs	Water chiller (heat pump): Centrifugal unit and Screw chiller

Table. 2.g - First Catalogue of Recommended Substitutes for HCFCs (exposure draft), 2015, in China

Australia

"Ozone Protection and Synthetic Greenhouse Gas Management Amendment Bill 2017"

Australian bill came into force in January 2018. It consists in a gradual reduction of the **maximum amount of bulk HFCs permitted to be imported into Australia**, that will be managed through a quota system on imports. It is planned to reach 85 per cent by 2036, more ambitious than the limits of Kigali agreement proposal for a global phase-down. The baseline will be equal to: 15% of average HFC imports + 75% of average HCFC imports for the period 2011–2013.

- **1st January 2018:** starting of phase-down, by limiting the imports of synthetic greenhouse gases to 8 Mt CO_2-eq. (75% of the baseline).
- The intermediate reduction steps of the phase-down between 2018 and 2036 will all be equal to -7% and enforced every second year: -25% in 2018, -32% in 2020, and so on down to -15% in 2036.
- **31st December 2035:** reduction of the imports of HFC's to 15% of the baseline; the imports will remain at that level from then on.

The HFC's affected will be those covered by the United Nations Framework Convention on Climate Change and the Kyoto Protocol:

HFCs included in the Australian phase-down (also refrigerant blends containing these HFCs)[1]:
R-23, R-32, R-41, R-125, R-134, R-134a, R-143, R-143a, R-152, R-152a, R-161, R-227ea, R-236cb, R-236ea, R-236fa, R-245ca, R-245fa, R-365mfc, R-43-10mee

Table. 2.h - HFCs included in the Ozone Protection and Synthetic Greenhouse Gas Management Amendment Bill 201

According to Australia Bill (also called A-GAS), **HFOs and blends** will be the mid- and long- term alternatives to HFC's along with the already established **CO_2 and ammonia**.

3. Is GWP the best indicator of the environmental impact of a refrigerant?

First of all, it is important to better understand the concepts of GWP and TEWI:

GWP (Global Warming Potential): this is a characteristic factor estimating the greenhouse effect of a gas being released into the atmosphere compared to the effect of CO_2. It comprises the heat radiation absorption of a given gas and the resting time of molecules in the atmosphere. For example, the GWP of CO_2 is 1 and the GWP of R-134a is 1430: this means that 1 kg of R-134a has the same greenhouse effect as 1430 kg of CO_2. This is why it is important to move towards low GWP refrigerants.

TEWI (Total Equivalent Warming Impact): this is the sum of the direct (leakage and venting) and indirect (due to input energy) emissions of greenhouse gases from a certain equipment during its useful life. TEWI is calculated in accordance with the following equation:

$$TEWI = GWP \cdot L \cdot n + GWP \cdot m \cdot (1-\alpha) + n \cdot E \cdot \beta$$

where:
GWP - Refrigerant Global Warming Potential (equivalent to CO_2) [kg CO_2/kg refrigerant]
L - Annual leakage rate [kg/year]
n - System operating life [years]
m - Refrigerant charge [kg]
α - Recycling factor [%]: proportion of refrigerant charge (from 0 to 1) that is recovered from the equipment when it is decomissioned at the end of its useful life
E - Annual energy consumption [kWh/year]
β - CO_2 emissions on energy generation [kg CO_2/kWh]: depending on the country and the energy sources used, β may vary from 0.35 to 0.9 with a worldwide average value of 0.53 kg CO_2/kWh[2]

TEWI, measured in kg of CO_2 equivalent, represents the global warming impact during the equipment life cycle, including:
- **direct effect**, caused by the release of refrigerant during working life and decommissining;
- **indirect effect** resulting from the emissions of fossil fuel used to generate the electricity needed for its operation.

Direct emissions are proportional to refrigerant warming potential and therefore the use of low GWP fluids is the most obvious and sound measure to contain equipment carbon footprint. However we should not neglect the simple equation: no leakage= no direct warming contribution.
Refrigeration equipment should be designed with the lowest possible refrigerant charge - for the same capacity - and with the minimum achievable leakage rates. Adopting the above measures, indirect emissions become the predominant factor in the warming impact (up to 95% of TEWI, even with mid-GWP refrigerants) **therefore shifting the focus to the thermodynamic efficiency of the equipment**.

According to recent information[1], indirect emissions (related to energy type and consumption) typically represent more than 80% of total emissions, whereas direct emissions (related to refrigerants) represent a far smaller share of total emissions. It is clear that **both are interrelated and need to be addressed to reduce total emissions**.

[1] Andrea Voigt (2019), Webinar "How refrigerants affect modern life"
[2] source: IEA - International Energy Agency

4. How do the rules affect the most common refrigerants?

The following table summarises the most common refrigerants used now and probably in the next few years. In green are refrigerants that can be used generally in the long term worldwide; in blue are those that will be progressively delisted or phased down; in red are those that will be generally delisted worldwide.
Information about the USA has been omitted since the EPA's SNAP rules are not in force as of the date of this document. Some states have decided to apply them, but Federal Government indications have not yet been defined.

Refrig.	GWP	S.g.[1]	EU	JAPAN	CANADA	CHINA	AUSTRALIA
Natural							
R-717 (Ammonia)	0	B2L	Accepted in all the applications.[2]	Accepted in all the applications.[2]	Accepted in all the applications.[2]	Recommended in ref. warehouse, transport ref., condensing unit, industrial ref. system.[2]	Accepted in all the applications.[2]
R-744 (CO_2)	1	A1				Recommended in heat pump water heater, Vehicle A/C, Industrial/commercial freezing and ref. system.[2]	
Natural (HCs)							
R-1270 (Propylene)	2	A3	Accepted in all the applications.[3]	Accepted in all the applications.[3]	Accepted in all the applications.[3]	-	Accepted in all the applications.[3]
R-600a (Isobutane)	3					Recommended in room A/C (only propane) and commercial independent ref. system.[3]	
R-290 (Propane)	3.3						
HFOs and relative blends							
R-1234yf	4	A2L	Accepted in all the applications.[4]	Accepted in all the applications.[4]	Accepted in all the applications.[4]	-	Accepted in all the applications.[4]
R-1234ze(E)	7					-	
R-455A Blend: R-1234yf/R-32/CO_2 (75.5/21.5/3)	145			Accepted in all the applications, except cold storage warehouse (more than 50,000 m³).[4]		-	Accepted, but the components R-32, R-134a and R-125 will be controlled by quota.[4]
R-454C Blend: R-1234yf/R-32 (78.5/21.5)	146					-	
R-515B Blend: R-1234ze(E)/R - 227ea (91.1/8.9)	299		Accepted in stationary ref. and A/C equipment and single split A/C systems containing less than 3 kg of fluorinated gases.[4]		Accepted, except domestic appliances.[4]	-	
R-454B Blend: R-32/R-1234yf (68.9/31.1)	465					-	
R-450A Blend: R-134a/R-1234ze (42/58)	547	A1				-	
R-513A Blend: R-134a/R-1234yf (44/56)	631					-	
R-452B Blend: R-32/R-1234yf/R-125 (67/26/7)	676	A2L				-	
R-466A Blend: R-32/R-125/ R-13I1/ (49/11.5/39.5)	733	A1				-	
R-448A Blend: R-32/R-125/ R-1234yf/ R-134a/R-1234ze(E) (26/26/20/21/7)	1273		Accepted in stationary ref. and A/C equipment.	Accepted in condensing unit and ref. unit.	Accepted in commercial or industrial stand-alone units, centralized ref. system, condensing unit and mobile ref. system.	-	
R-449A Blend: R-32/R-125/ R-1234yf/R-134a (24.3/24.7/25.3/25.7)	1397					-	
R-452A Blend: R-32/R-125/R-1234yf (11/59/30)	2141			Unaccepted in all the applications.	Accepted in condensing unit, centralized ref. systems unit and mobile refrigeration system.	-	

Refrig.	GWP	S.g.[1]	EU	JAPAN	CANADA	CHINA	AUSTRALIA
HCFO							
R-1233zd(E)	4.7	A1	Accepted in all the applications.	Accepted in all the applications.	Accepted.	-	-
HFCs							
R-32	675	A2L	Accepted in stationary ref. and A/C equipment and single split A/C systems containing less than 3 kg of fluorinated gases. [4]	Accepted in all the applications, except cold storage warehouse (more than 50,000 m³). [4]	Accepted, except domestic appliances. [4]	Recommended in unitary A/C, water chilling (heat pump) unit and heat pump water heater. [4]	Included in the phase-down. [4]
R-134a	1430	A1	Accepted in stationary ref. and A/C equipment.	Accepted in condensing unit and refrigerating unit.	Accepted in commercial or industrial low temperature stand-alone units, centralized refrigeration system, condensing unit and mobile refrigeration system.	-	
R-407C Blend: R-32/R-125/R-134a (23/25/52)	1774			Unaccepted in all the applications (ban dates will depend on final application and GWP value)	Accepted in condensing unit, mobile refrigeration system and centralized ref. system.	-	-
R-407F Blend: R-32/R-125/R-134a (30/30/40)	1825					-	-
R-410A Blend: R-32/R-125 (50/50)	2088					-	-
R-407A Blend: R-32/R-125/R-134a (20/40/40)	2107					-	-
R-507A Blend: R-143a/R-125 (50/50)	3900		Unaccepted in all the applications (ban dates will depend on final application and GWP value).		Unaccepted in all the applications (ban dates will depend on final application and GWP value).	-	-
R-404A Blend: R-143a/R-125 /R-134a (52/44/4)	3922					-	-
HCFC							
R-22	1822	A1	Delisted according to Commission Regulation 1005/2009.	Delisted	Delisted	Phase-out in progress.	Delisted

Table. 4.i - Most commonly used refrigerants in refrigeration (Ref.) and air-conditioning (A/C) application.

[1] S.g.: safety group according to ASHRAE Standard 34 (see Tab.4.j).
[2] National or local standards may apply.
[3] Being flammable refrigerants (classified as A3), international, national and local legislation and standards as well as explosion-proof requirements may apply (please refer to white paper "Flammable refrigerants: focus on hydrocarbons").
[4] Being flammable refrigerants (classified as A2L), international, national and local legislation and standards as well as explosion-proof requirements may apply providing limitations on maximum charge in indoor applications.

	Lower toxicity	Higher toxicity
Higher flammability	A3	B3
Lower flammability	A2	B2
	A2L	B2L
No flame propagation	A1	B1

Table. 4.j - Refrigerant safety classification according to ASHRAE Standard 34

5. Which is the best refrigerant?

Three and a half years after the publication of the first release of this document, the market has been considerably affected by refrigerant regulations, especially in Europe. As anticipated, GWP, flammability and other practical drawbacks, lobbying, application and country of end use mainly determine the choice of a refrigerant.

Moreover, the price trend and the availability of each refrigerant depends on the "quota" according to EU F-gas and on the refrigerant's worldwide diffusion. Indeed, the price increase of HFC refrigerants was evident in 2016, 2017 and 2018, whereas low GWP refrigerants, especially natural refrigerants, gained a lot of attention.

Technologies have been developed very quickly and international standards are being revised to facilitate the use of low GWP refrigerants and face their drawbacks, such as flammability or high pressure. For instance, IEC 60335-2-40, the standard that defines specific requirements for electrical heat pumps, air-conditioners and dehumidifiers, was updated in 2018 to include special requirements and new charge limits for A2L systems. In 2019, the new standard for commercial refrigerating appliances, IEC 60335-2-89, was published, increasing the charge for flammable refrigerants, among other changes. In this scenario, natural refrigerants and some very low GWP HFOs are being increasingly widely used. The best refrigerant is the one that suits better the requirements of each application, but there is not a unique solution for all.

Trends in HVAC/R applications

Refrigerant trends in the **HVAC/R market** are definitively changing due to different factors, especially international rules and regulations. In this context, the choice of a refrigerant for a specific application becomes more complex.

Learning not only about the **standards**, but also other factors such as the **drawbacks** or the **market trends** of refrigerants, may represente the first step in being ready for the new scenario.

1. How will the new regulations affect the refrigerant applications market?

The global scenario can be summarised in general terms as follows:

- **EU:** The reduction in quota has had a great influence on the market in the last two years. High GWP refrigerant prices have increased significantly, pushing the market towards low GWP refrigerants. Added to this are concrete restrictions for each application: HFCs with **GWP≥150** are being progressively banned, with two exceptions (stationary equipment, **GWP≥2500**; and single-split air-conditioning systems, **GWP≥750**).
- **USA:** Pending clear indications from the Federal Government, each State is taking its own measures.
- **China: HCFCs** will be unacceptable with some exceptions and their substitution by natural refrigerants is recommended, however concrete regulation is not yet available.
- **Japan:** HFCs with **GWP≥750** (air-conditioning) and **GWP≥1500** (refrigeration) are progressively being banned, with some exceptions: cold storage warehouse (GWP≥100) and mobile air-conditioning (GWP≥150).
- **Canada:** refrigerants with **GWP≥150** will be banned in residential applications, whereas commercial and industrial ones will have GWP limits of **750, 1400, 1500 or 2200**.
- **Australia:** a gradual reduction of the maximum amount of bulk HFCs permitted to be imported is being carried out.

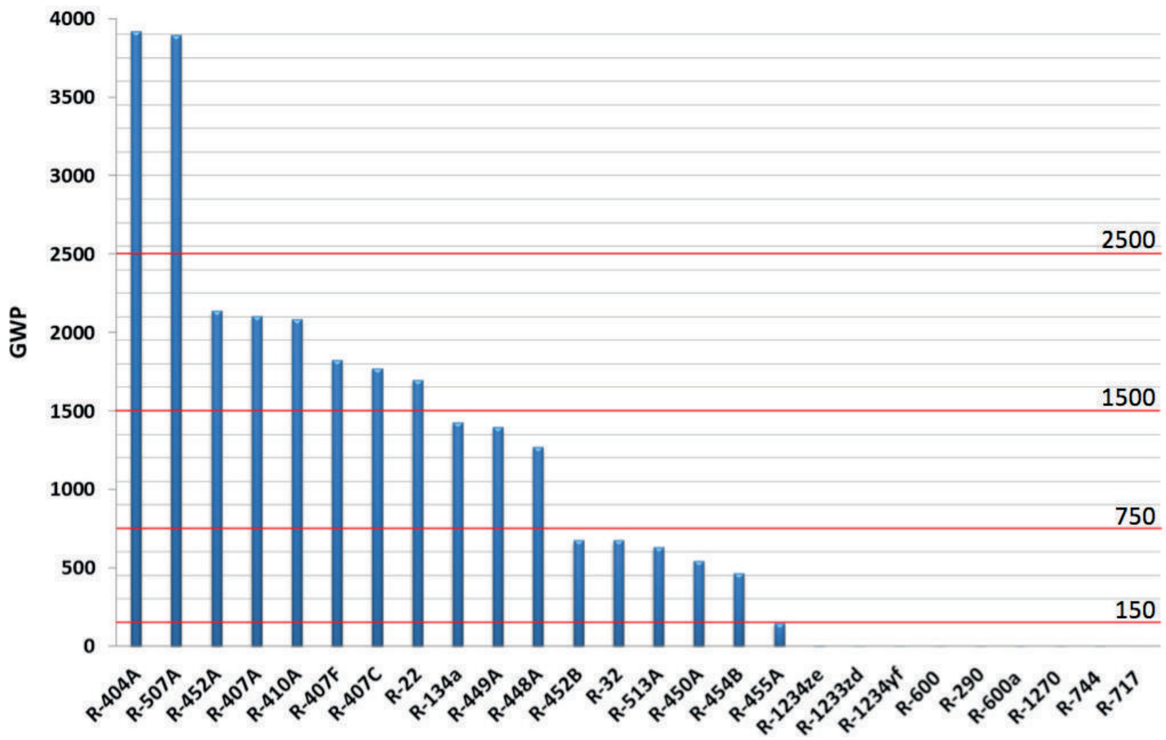


Fig. 1.a - GWP values of the most common refrigerants.

The trend is very clear: **a shift towards refrigerants with a low GWP**. Among these, **natural** refrigerants are gaining attention, in particular: R-744 (CO_2), R-717 (ammonia) and R-290 (propane). However, these feature certain limitations that make them suitable only with some restrictions, such as the high flammability of propane, the high pressure needed for CO_2, with related low efficiency in warm climates, and the high level of technical knowledge necessary, toxicity and corrosiveness of ammonia. See Table 2.a for more details.

Consequences are:

- HFC phase out or phase down is driving new design choices for all applications;
- refrigeration applications have been affected first, as these are currently designed with high GWP refrigerants, such as R-404A;
- design targets are: use of low GWP refrigerants, reduction in refrigerant charge, reduction in refrigerant leaks, increase in energy efficiency.

2. What are the trends?

- **Refrigeration:** in the countries where Kigali amendment has not been ratified and/or no concrete rules for the phase down of HFCs have been set, such as China and the United States, the use of R-404A may be extended for some years. In Europe, R-404A can be used as reclaimed/recycled for maintenance until 2030, but not for new equipment. Blends of HFCs and HFOs such as **R-448A** and **R-449A** have replaced as retrofits for some of the systems that previously used R-404A and R-507A. The use of low GWP HFC and HFO blends such as **R-455A** and **R-454C** is being experimented in some applications. In any case, the use of natural refrigerants has started to dominate new refrigeration equipment, especially in territories where HFC phase-down has started. **R-744 (CO_2)** was initially used in northern EU countries where climate conditions are more favourable, and now it is being increasingly used worldwide in new systems. **R-717 (ammonia)** is used at present in industrial refrigeration and will probably continue to be used in the future for the same application. The use of **R-290 (propane)** for stand-alone units is growing and is expected to increase more after the update of national standards to the new IEC 60335-2-89, allowing a charge of 500 grams instead of 150 in commercial refrigeration appliances.
- **Air-conditioning:** R-410A and R-134a are still the most commonly-used refrigerants, but due to their phase-down, they are progressively being replaced by lower GWP solutions, especially in Europe where an average of 230 GWP is expected to be reached by 2030 due to the quota allocation[1]. **R-32, R-452B** and **R-454B** are being increasingly used in new equipment. They are mildly flammable (A2L) and have a GWP of 675, 676 and 465, respectively. **R-290 (propane)** is also used when requirements due to flammability allows it. Currently, refrigerant manufacturers are working to find alternative non-flammable refrigerants. **R-466A**, a non-flammable mixture with a GWP of 733, was launched last year and some tests are being carried out, but the same refrigerant manufacturer has stated that is currently working on another replacement for R-410A. For larger sizes, R-134a is being substituted by **R-1234ze(E)**, **R-513A** and **R-450A**. The flammability of R-1234ze(E) is usually overcome by the fact that this type of application is usually located outside. As regards mobile air-conditioning, **R-1234yf** and **CO_2** are being used in new cars, instead of the commonly used R-134a.

Details on this plausible list of alternatives to the currently used refrigerants are shown in the following table:

Application	Refrigerants to be phase cut down	Alternative Refrigerants	GWP	Limitations
Refrigeration	R-404A, R-507A	**R-744 (CO_2)**	1	High pressure, high level of technical knowledge
		R-717 (Ammonia)	0	Lightly flammable and toxic (B2L), corrosive, high level of technical knowledge, license needed
		R-448A	1273	High GWP, glide= 6°C
		R-449A	1397	High GWP, glide= 6°C
		R-455A	145	Lightly flammable (A2L), glide= 12°C
		R-454C	146	Lightly flammable (A2L), glide= 6°C
Refrigeration and A/C	R-134a	**R-1234yf**	4	Lightly flammable (A2L)
		R-1234ze(E)	6	Lightly flammable (A2L)
		R-290 (Propane)	3.3	Flammable (A3)
		R-600a (Isobutane)	3	Flammable (A3)
		R-600 (Butane)	4	Flammable (A3)
		R-1233zd(E)	4.7	ODP= 0.0002
		R-450A	547	Medium GWP, glide= less than 1 °C
		R-513A	631	Medium GWP
A/C (in particular split units)	R-410A, R-407C, R-22	**R-32**	675	Medium GWP, lightly flammable (A2L), high discharge temperature
		R-452B	676	Medium GWP, lightly flammable (A2L), glide= 1.5 °C
		R-454B	465	Medium GWP, lightly flammable (A2L), glide= 1.5 °C
		R-466A	733	Medium GWP, glide= 1.5°C
		R-1270 (Propylene)	2	Flammable (A3)

Table. 2.a - Summary of refrigerants used in refrigeration and air-conditioning (in bold, the most common ones).

The above table also shows that the acceptable alternative refrigerants have drawbacks and limitations, such as flammability, glide (which means low efficiency and difficult design of the evaporators) or corrosiveness. Regulations can, at the same time, influence other variables worldwide, such as the **price of the refrigerant**, as have clearly been seen in Europe in the last three years (more details can be seen in Annex 1).

1 *Pachai, A. C., Kuijpers, L., Vonsild, A., 2018, Reviewing New Refrigerant Options for Industrial Refrigeration Systems, Proc. 13th IIR Gustav Lorentzen Conference on Natural Refrigerants, Valencia, Spain.*

In Europe and Japan, the rules on the frequency of **leak checking** will also affect the decision on the chosen refrigerant. Refrigerant choice will therefore represent a compromise between environmental aspects and cost of the different applications (design, development and maintenance).

Some examples are described below.

Condensing units

A condensing unit, according to European Ecodesign Regulation 2015/1095, is a product integrating at least one electrically driven compressor and one condenser, capable of cooling down and continuously maintaining low or medium temperature inside a refrigerated appliance or system, using a vapour compression cycle connected to an evaporator and an expansion device.
In the F-gas classification, a condensing unit falls within the category of "stationary refrigeration equipment". From 2020, HFCs with a GWP higher than 2500 will be unacceptable for this category. In Japan, the GWP limit for this application is 1500 from 2025, whereas in Canada the limit is 2200 from 2020. In California, the use of R-404A for condensing units has not been allowed since 1 January 2019. This means that the most commonly-used refrigerant in condensing units, **R-404A, is or will be banned in all of the above-mentioned territories**.

One current short-term alternative with a GWP of 2088 is very commonly used in A/C applications::

- R-410A

Other current short-term alternatives with a GWP lower than 1500 that are being used for this application, in most of cases for retrofits, are:

- R-448A, R-449A
  These are immediately available, as they have been designed to replace R-404A.

However, the GWP of these three refrigerants is still high. Taking as a reference what happened in Europe when the phase-down of HFCs started (increase in high-GWP refrigerant prices, lower availability), it is expected that they will have to be replaced in all countries sooner or later if the Kigali Amendment is ratified.

A long-term very low GWP option and unique natural refrigerant is:

- R-744 (CO_2)
  The drawbacks of high pressure and high level of technical knowledge have been overcome by the development of technology.

Other alternatives, suitable for medium and low temperature applications, are:

- R-455A, R-454C
  Their GWP is lower than 150, but they are mildly flammable (A2L) and have a glide of 12 °C (R-455A) and 6 °C (R-454).
  Ongoing tests will determine whether they can be a suitable option for this or other applications.

Plug-in cabinets

A plug-in cabinet usually falls within the category of "refrigerators and freezers for commercial use, hermetically sealed", according to the F-gas classification. From 2020, refrigerants with a GWP higher than 2500 will no longer be accepted, whereas from 2022, the limit will be 150. In Japan, a plug-in cabinet is categorised as "condensing and refrigeration units", thus the GWP limit will be 1500 from 2025. In Canada, the GWP for commercial stand-alone refrigeration systems from 2020 is 1400 for medium-temperature and 1500 for low-temperature. California has banned R-404A in all stand-alone equipment, R-410A in new ones, and R-134a for medium temperature. This means that the most commonly-used refrigerant, **R-404A, is or will be banned in all of the above-mentioned territories.**

One current short-term alternative with a GWP of 2088 (allowed in Europe until 2022 and in Japan until 2025, but already banned in Canada and California) is very commonly used in A/C applications:

- R-410A

Other current short-term alternatives with a GWP lower than 1500 that are being used for this application, in most of cases for retrofits, are:

- R-448A, R-449A

The options with a GWP lower than 150, and thus accepted worldwide, are:

- R-744 (CO_2)
  The drawbacks of high pressure and high level of technical knowledge have been overcome by the development of technology.
- R-290 (propane), R-600a (isobutane), R-600 (butane)
  These are flammable (category A3). In this application, the approval of the new version of the standard IEC 60335-2-89, which allows for an increase in the minimum charge limit for flammable refrigerants, can facilitate the diffusion of these refrigerants in coming years.

Other alternatives are:

- R-455A, R-454C
  Their GWP is lower than 150, but they are mildly flammable (A2L) and have a glide of 12 °C (R-455A) and 6 °C (R-454C). Ongoing tests will determine whether they can be a suitable option for this or other applications.

Chillers/Heat pumps

A chiller, according to European Ecodesign Regulation 2015/1095, is a product integrating at least one compressor and one evaporator, capable of cooling down and continuously maintaining the temperature of a liquid in order to provide cooling to a refrigerated appliance or system; it may or may not integrate the condenser, the coolant circuit hardware and other ancillary equipment.

'Heat pump' means an air heating product: (a) of which the outdoor side heat exchanger (evaporator) extracts heat from ambient air, ventilation exhaust air, water, or ground heat sources; (b) which has a heat generator that uses a vapour compression cycle or a sorption cycle; (c) of which the indoor side heat exchanger (condenser) releases this heat to an air-based heating system; (d) which may be equipped with a supplementary heater; (e) which may operate in reverse in which case it functions as an air conditioner (EU Commission Regulation 2016/2281).

Chillers and most of heat pumps fall within the category of "stationary refrigeration equipment", according to the F-gas classification. Therefore, refrigerants with a GWP higher than 2500 will be banned from 2020. The most commonly-used refrigerants nowadays (R-410A and R-407C for small chillers, and R-134a for large chillers) will still be accepted. However, **the increasing price and decreasing availability due to quota reductions has made manufacturers look for alternative solutions**.

In Japan, to the best of our knowledge, there are two categories for air conditioning applications: room and commercial. In the first case, the GWP limit will be 750 from 2018; in the second, 750 from 2020. Chillers and heat pumps may be commercial or non-commercial, but we assume that the limit for air conditioning is 750 for all applications, since no more information has been specified. Also in Canada, the GWP limit for chillers is 750 and applies from 2025. This means that **R-410A, R-407C and R-134a will not be accepted neither in Japan nor in Canada**.

For scroll chillers/heat pumps, short term solutions include:

- **R-32, R-452B, R-454B**;
  These are mildly flammable (A2L) and have a GWP of 675, 676 and 465, respectively.

A non-flammable alternative is:
- **R-466A**
  Its GWP is 733. Being a new refrigerant, initial tests are being carried out and will determine the advantages with respect to other refrigerants.

Alternatives with a lower GWP are:
- **Propane / propylene**
  These have a negligible GWP, but are flammable (A3).

For screw chillers/heat pumps, short term solutions include:
- **R-450A, R-513A**
  These have a GWP of 547 and 631, respectively.

Alternatives with a lower GWP are:
- **R-1234ze**
  Its GWP is 7, but it is mildly flammable (A2L). However, the fact that large chillers are generally installed outdoors means that according to standard IEC 60335-2-40, there are no charge limits due to flammability.
- **R-717 (ammonia)**
  It has a negligible GWP, but is mildly flammable and toxic (B2L).

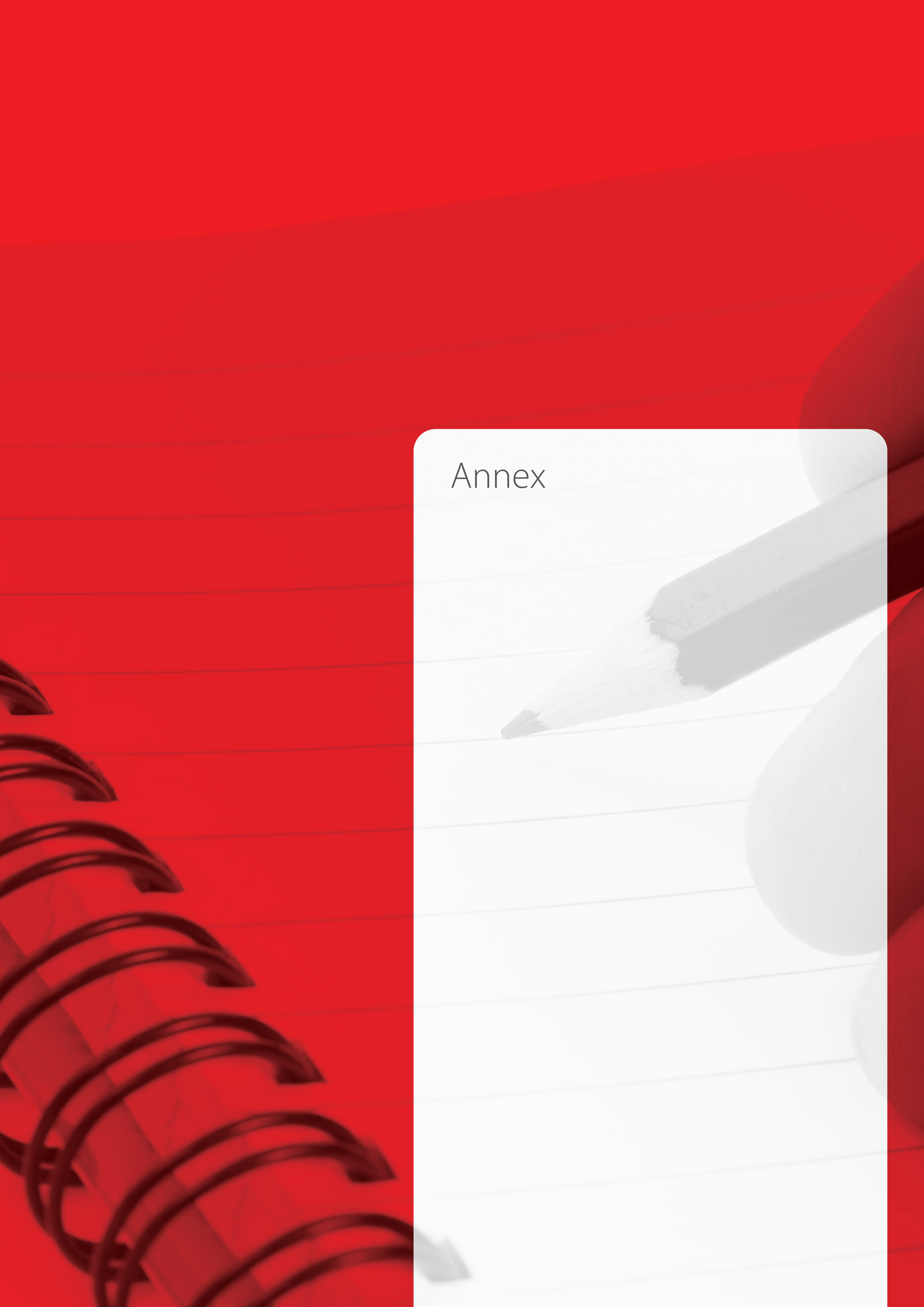
3. What will happen next?

The new refrigerant scenario has changed the market over the last four years. As specified throughout this document, research into new synthetic refrigerants and blends, the increasing in high-GWP refrigerant prices in Europe, illegal imports, the development of technology for the use of natural refrigerants and the updating of international standards for the use of flammable refrigerants have been the main consequences of the beginning of the HFC phase-down process. However, there are still some interesting points to see in the future:

- Will European market be the driver towards low GWP refrigerants worldwide, or will countries without rules cause the phase-down process to fail?
- Will developing countries wait until the first HFC reduction to start the transition towards low GWP refrigerants? Will high GWP refrigerant prices be affected as much as in Europe?
- Will new synthetic refrigerant alternatives be competitive and in time to market?

It will be interesting to follow the evolution of refrigerant trends and the consequences of regulations in the next few years…

Annex



1. Annex - Consequences of F-gas quota reduction

The changes on the European refrigerant market over the last three years are worth examining more in detail when talking about the current refrigerant scenario. The part of the F-gas regulation regarding quotas has had a major influence on refrigerant prices, and this has also increased the quantity of illegal refrigerants entering Europe.

The F-gas quota dictates the admissible production/import of HFCs to be reduced to 93% (2016), 63% (2018), 45% (2021) and 21% (2030) compared to the average 2009-2012 European Union HFC consumption, as shown in Fig. 1.a.
The first step (from 100% to 93%) was not high when compared with the second, and indeed passed practically unnoticed. However, the second (from 93% to 63%) really revolutionised the market.

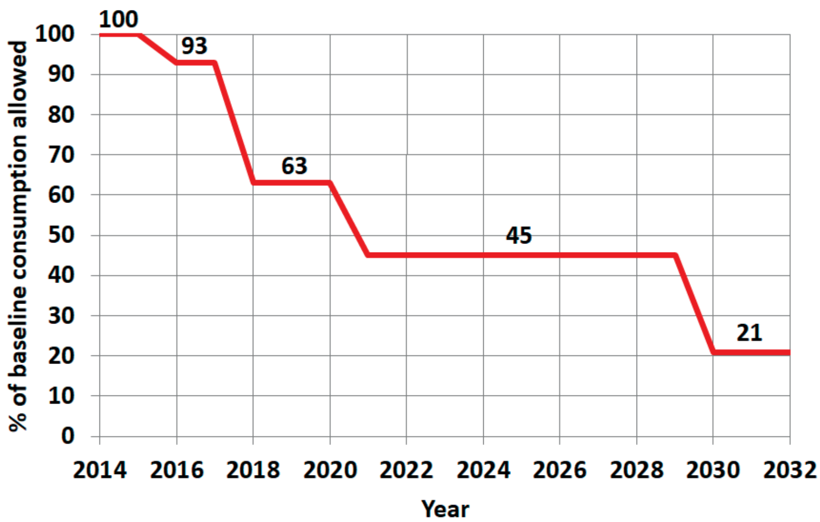


Fig. 1.a - F-gas quota reduction

As shown in Fig. 1.b, the prices of high GWP refrigerants started increasing in 2016, however that growth was almost insignificant in comparison with what happened some months later.

From January to December 2017, **the price of R-404A (GWP of 3922) rose by 900%. In the same period, R-410A and R-407C prices (GWP of 2088 and 1774, respectively) saw a 600% increase, whereas the price of R-134a (GWP=1430) increased about 300%**. Undoubtedly, these are unprecedented price rises in the history of refrigerants! Indeed, in 2017, a lot of news about refrigerant price increases and decreased availability frightened HVAC/R stakeholders.

During the first semester of 2018, the average prices of HFC refrigerants such as R-410A and R-134a continued to rise, whereas the price of R-404A decreased slightly. In that period, **for the first time since the beginning of HFC phase-down, the price of R-410A was higher than the price of R-404A**. The lack of a drop-in for R-410A and the fact that the alternatives to substitute it are flammable, are making it difficult to find a replacement.
In 2018, however, price increases were not the main news in the media. On the one hand, the increases were lower than the previous year. The demand for mixtures of HFC and HFO alternatives, such as R-448A, R-449A (as a replacement for R-404A) and R-513A (as a replacement for R-134a) increased, resulting in moderate price increases[1]. There were, however, many reports regarding the **illegal market of high GWP refrigerants** in many European countries. Specifically, EIA analysis suggests that as many as 16.3 million tonnes of CO_2 equivalents of bulk HFCs were illegally placed on the market in 2018, which represents more than 16% of the 2018 quota [2].

During 2019, with the quota remaining at 63%, **HFC prices are falling**. For R-404A, R-410A and R-134a, price declines have been reported by Öko-Recherche, with the price of R-410A again higher than the price of R-404A. On the other hand, prices for quota authorisations significantly fell to 10-20 €/t CO_2 equivalents due to lower demand[1].

There is still, however, a pending battle: **illegal HFC refrigerants** continue to enter across European borders. Indeed, imports of high GWP refrigerants such as R-134a, R-404A and R-32 have been seized in eastern European countries in recent months. Bulgaria, Romania, Lithuania, Poland and Greece are among the countries affected. The European Commission has said that it is concerned and is looking at ways to reduce/prevent this problem.

1. Öko Recherche, "Monitoring of refrigerant prices against the background of Regulation (EU) No 517/2014".
2. Fiannuala Walravens (2019), "HFCs Illegal Trade in Europe" Industria&Formazione.

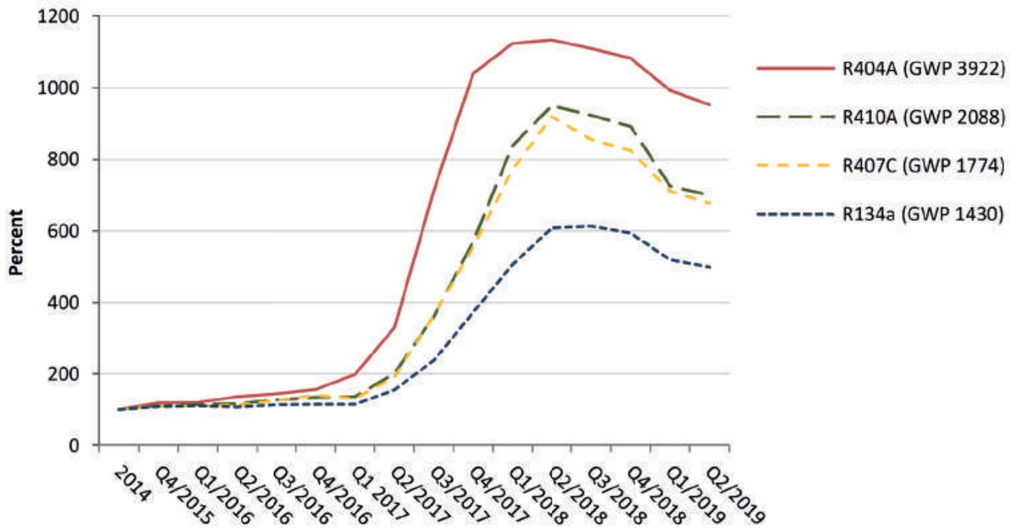


Fig. 1.b -Refrigerant price trends from 2014 to the second quarter of 2019

2. Annex - Alternative refrigerants

Other alternatives to the refrigerants presented in this document:
The list of available refrigerants is constantly increasing. The new options that have been launched aim to be a good alternative to high GWP refrigerants. Some of them are cited in the following table and intend to represent the other options in the market. As shown, refrigerants with the lowest values of GWP are in general slightly flammable (A2L). Moreover, **most of the options are zeotropic mixtures, therefore they have glide.**

Application	Current refrigerant	Refrigerant	GWP	Limitations
Refrigeration	R-404A	R-454A	238	Lightly flammable (A2L), glide= 5°C
		R-444B	295	Lightly flammable (A2L), glide= 8°C
		R-460B	1352	High GWP, glide= 7°C
		R-449B	1412	High GWP, glide= 5°C
		R-458A	1650	High GWP, glide= 6.5°C
Refrigeration and A/C	R-134a	R-441A	5	Flammable (A3), glide= 21.5°C
		R-513B	596	Medium GWP
		R-456A	630	Medium GWP, glide= 4°C
A/C	R-410A	R-459B	144	Lightly flammable (A2L), glide=8°C
		R-446A	461	Lightly flammable (A2L), glide=5°C
		R-459A	461	Lightly flammable (A2L), glide= 1.5 °C
		R-447A	582	Lightly flammable (A2L), glide= 4 °C
		R-447B	714	Lightly flammable (A2L), glide= 3.5 °C
		R-460A	2103	Glide= 6°C
	R-123	R-514A	2	Toxic (B1)
		R-1336mzz(Z)	9	

Table. 2.a - Summary of alternatives to the refrigerants presented in this document

In the following graph, all the refrigerants named in this document (including this annex) are shown, together with the GWP value and ASHRAE classification. **With the exception of CO_2, R-1233zd and R-1336mzz(Z), refrigerants with GWP lower than 547 are flammable, slightly flammable or toxic. In the range of GWP 547-1200, the five non flammable refrigerants are R-450A, R-513B, R-456A, R-513A and R-466A, typically used for medium temperatures.**
To sum up, the options at the time of choosing a refrigerant are increasing, but apparently no additional benefits are achieved. A deep study of refrigerant performance, acceptance, price and drawbacks should be carried out at the time of choosing the best refrigerant for a concrete application.

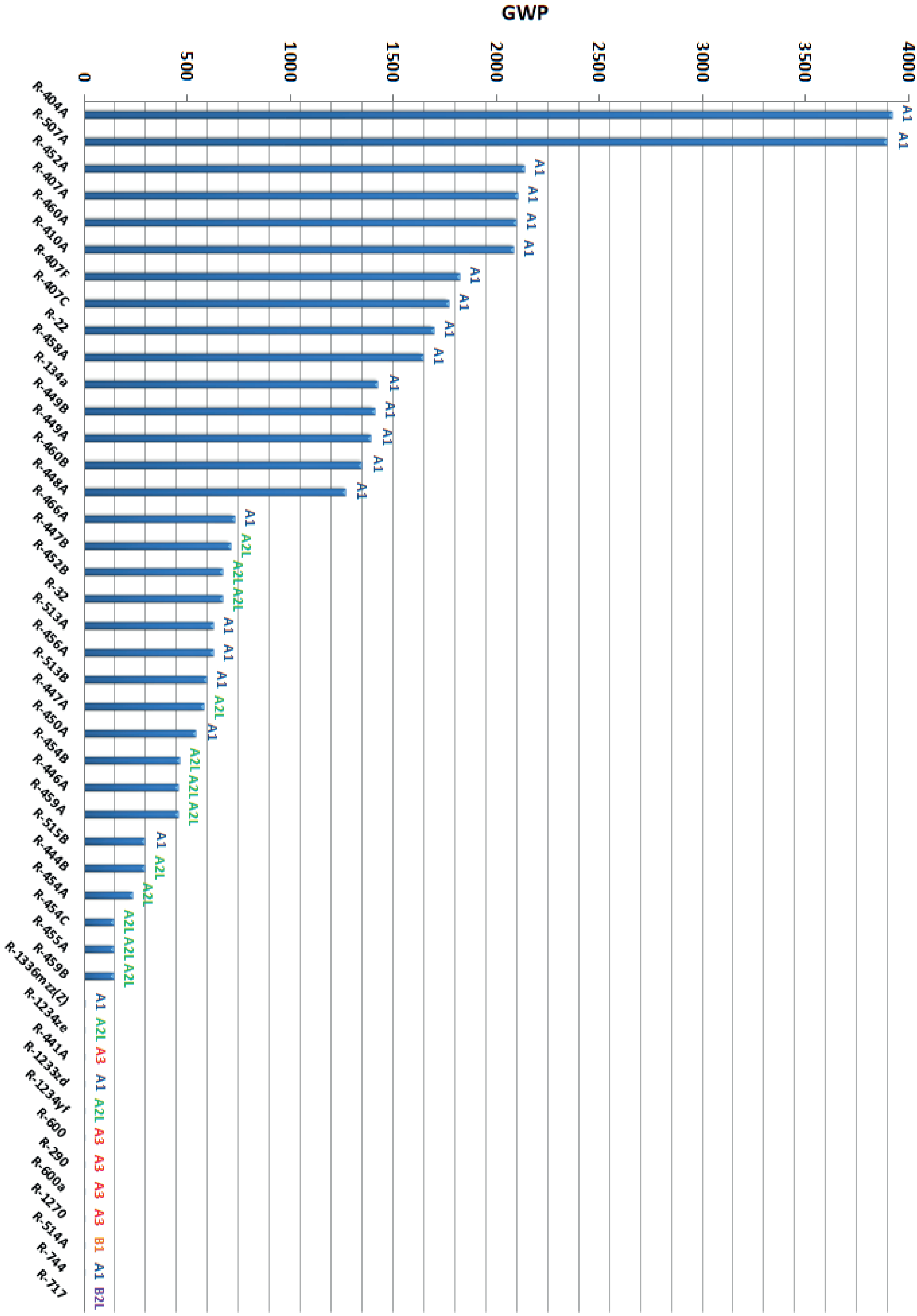


Fig. 2.a - GWP and safety group of all the refrigerants named in this document

Notes

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