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REPORT FROM THE COMMISSION

The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact

THE AVAILABILITY OF REFRIGERANTS FOR NEW SPLIT AIR CONDITIONING SYSTEMS THAT CAN REPLACE FLUORINATED GREENHOUSE GASES OR RESULT IN A LOWER CLIMATE IMPACT

1. Introduction

Regulation (EU) No 517/2014 on fluorinated greenhouse gases[1] (the F-gas Regulation) requires the Commission to assess if "cost-effective, technically feasible, energy-efficient and reliable alternatives exist, which make the replacement of fluorinated greenhouse gases (F-gases) possible in new small single split air conditioning systems" (Article 21(4)). This report responds to this requirement under the Regulation and is based on the findings of an external study and extensive stakeholder consultations carried out from September 2019 to April 2020, including by the F-gas Consultation Forum members.[2]

In light of the EU's objective is to become climate neutral by 2050 and the importance of early and ambitious action to achieve this objective, a transitional move to more climate friendly F-gases in new air-conditioning systems in the short term could result in an important reduction in the climate impact from new air-conditioning systems. Therefore, this report fulfills and complements the scope of the report under Article 21(4) of the Regulation by also assessing the feasibility of using specific F-gases as an alternative to commonly used F-gases, where the use of natural refrigerants (i.e. non-fluorinated gases) is not yet feasible and where a shift towards another F-gas would nevertheless result in a considerable reduction of the direct climate effect[3] to the hitherto most commonly used refrigerants.[4]

The report is not limited to small single-split systems, but examines the whole sector of split air conditioning (air conditioning) equipment. This comprises[5]:

- Single-split systems[6] consisting of (only) one indoor unit and one outdoor unit connected by a refrigerant-carrying pipe that require installation:
    - Small single-splits: below 3kg charge size[7] for a one-room solution;
    - Larger single-splits: charge size of 3kg or more, for larger rooms.
- Multi-split systems consisting of one outdoor unit connected by refrigerant-carrying pipes to two or more indoor units of choice; suitable to create different room climate zones and/or for multiple rooms or large rooms.

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1 OJ L 150, 20.5.2014, p. 195

2 Meetings of the F-gas Consultation Forum established in accordance with Article 23 of the F-gas Regulation: https://ec.europa.eu/clima/events/articles/0106_en. The link includes a briefing paper that provides further references of sources used to establish the current findings.

3 The climate effect considered is indicated by the global warming potential (GWP) measured in CO_2 equivalent, as listed in Annex I of the F-gas Regulation.

4 Some stakeholders have expressed concerns about using F-gases as alternatives on a large scale, *inter alia*, arguing that the metric 'GWP'[2] does not adequately show the actual climate risk of substances with atmospheric lifetimes considerably below 100 years, the need to include environmental concerns due to the mining of the raw materials, energy use and emissions during the production process, storage and transport, lack of efficiency of end-of-life recovery and concerns about toxic breakdown products.

5 "Ducted units", consisting of a central unit usually located on the roof, connected by *air* ducts to air outlets and sensors in each room are not discussed in this paper as they are rarely found in Europe.

6 According to the definition in Article 2 (39) of the F-gas Regulation.

7 In analogy to the prohibition in Annex III point 15of the F-gas Regulation.

The report is limited to new equipment. This is because retrofitting existing equipment is usually not possible for safety and warranty reasons. Moreover, the retrofit of smaller split systems often does not make much economic sense for the end-user given the low price of buying a new piece of equipment.

In 2019, the F-gases contained in split systems represented 74% of all F-gases imported into the EU in precharged equipment (measured in CO_2 equivalent) and small single-splits themselves made up 38% of all F-gases imported in equipment.[8] Many of these systems are reversible air-to-air heat pumps. They are increasingly popular in warmer climates including southern Europe as they serve not only cooling needs, but also have a heating function. This sector is therefore quite relevant in decarbonising the cooling and heating sector and achieving the goal of climate neutrality by 2050.

The F-gas Regulation stimulates the use of more climate friendly refrigerants in split air-conditioning systems, in particular by limiting the supply of hydrofluorocarbons[9] (HFCs) in the EU via the HFC phase-down, a quota allocation system that stepwise reduces the amount of HFCs that can be placed on the EU market. Also, from 2025 the use of F-gases in small systems, with a charge below 3 kg, will not be permitted unless the global warming potential (GWP) of that F-gas is lower than 750 CO_2 equivalent.

2. Existing alternatives with a lesser climate impact

This assessment only considers a refrigerant as a feasible, more-climate friendly alternative if it can also be sufficiently safe and energy-efficient, in addition to being reliable and feasible on technical grounds and having a lower GWP than in other solutions.

Regardless of whether a refrigerant contains F-gases or not, industry classifies the substance with an "R" and a number rather than using the chemical designation or name, i.e. the conventional refrigerant used in air conditioning systems in the EU is called R-410A (GWP 2088) which is a mixture of HFC32 and HFC125. These industrial classifications are used in this report.

2.1 Safety

Safety aspects are important regarding the manufacture, transport and storage, putting into service, installation, maintenance and the lifetime for the regular use of split air conditioning equipment. In addition, safety requirements exist for employers to ensure the occupational health of their employees including requirements for production, logistics and end of life treatment of such equipment. Different refrigerants have different properties that must be taken into account when designing the equipment to make it safe. The safety group classification according to standard EN 378-1 consists of two characteristics: a capital letter corresponding to toxicity (two groups: A and B) and a digit that refers to flammability (1, 2, 2L, 3). Table 1 below shows the classification into the different safety groups of the most relevant refrigerant alternatives for split systems, i.e. propane (R290) which is an A3 refrigerant.

Ammonia (R717), a refrigerant commonly used in many types of refrigeration system and which is not an F-gas, is not considered as an alternative in split air conditioning systems for toxicity reasons (classification of B2L). The necessary safety precautions would be too

[8] Larger single-splits represent 7% and multi-splits 29% of all F-gases imported in precharged equipment.

[9] HFCs are the most commonly used F-gases.

expensive and too complicated for private and small commercial settings where split systems are often used.

Table 1. *Safety group classification of the most relevant refrigerant alternatives currently available for split systems*

Toxicity levels **Flammability levels**	**A: lower toxicity**	**B: higher toxicity**[10]
1: **non flammable**	***A1:*** R466A[11] (HFCs and CF_3I mixture[12] GWP 733)	None
2L: lower flammability	***A2L:*** R32 (HFC32, GWP 675) R452B (HFC mixture, GWP 698)	None
2: flammable	***A2:*** R152a (HFC152a, GWP 140)	None
3: higher flammability	***A3:*** R290 (propane) not an F-gas, GWP 3 R1270 (propylene) not an F-gas GWP 2	None

In the table above only the highly flammable R290 (propane) and R1270 (propylene) are F-gas free. Almost all relevant solutions (with the possible exception of R466A, GWP 733) that are significantly more climate-friendly than R410A (GWP 2088) exhibit a degree of flammability. Due to the flammability there are a number of use limitations, e.g. imposed by local building codes, in some Member States, such as for high-rise and/or public buildings. Furthermore, relevant European standards often introduce restrictions. While following these standards is not mandatory for conformity with EU legislation, as other risk assessments methodologies can be equally used to prove the safety of the product, they are nonetheless commonly used as a reference to limit liability issues. Charge size, i.e. the amount of refrigerant in the equipment, is restricted in many standards for all flammable refrigerants (2, 2L, 3) linked to the location of use (e.g. public access or not, room size), room volume, how the equipment is mounted (e.g. roof, ceiling, floor, wall), the length of piping and/or the existence of risk minimization measures (e.g. fan).

A 2016 a Commission report[13] found "that standards (at international, European and national level) regarding the use of flammable refrigerants appear to be an important barrier to the uptake of climate-friendly alternatives to HFCs." The most relevant European standards for refrigeration, air conditioning and heat pumps are EN 378, as well as the product standard IEC EN 60335-2-40 (for air-conditioning systems). They impose restrictions that do not appear justified for safety reasons (anymore). Thus they need further updating in line with technological development and based on empirical appreciations of the actual risks showing that acceptable safety levels can be maintained while using flammable refrigerants. Until unjustified barriers are removed - there will remain some unnecessary obstacles for the introduction of climate-friendlier solutions.

[10] There are currently no suitable refrigerants with higher toxicity (B) considered for use in split systems

[11] R466A is classified as A1 by ASHRAE 34 (American Society of Heating, Refrigerating and Air-Conditioning Engineers), but not yet classified by EN-378 or ISO 817

[12] Trifluoroiodomethane

[13] REPORT FROM THE COMMISSION on barriers posed by codes, standards and legislation to using climate-friendly technologies in the refrigeration, air conditioning, heat pumps and foam sectors, COM(2016) 749 final. https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-749-F1-EN-MAIN-PART-1.PDF

To expedite matters, the Commission issued, at the end of 2017, a mandate request (M/555)[14] to the standardization organizations in order to have a European standard on the use of flammable refrigerants, in particular those classified as A3, in refrigeration, air conditioning and heat pump equipment by February 2021. Work is currently being undertaken on the product standard IEC 60335-2-40 to expand the potential scope of applications within a boundary limit-value of 1kg for R290 (propane), and in working group 12 of standard EN 378. Different precautionary measures will be required depending on charge and room size. Alongside, the EU-funded project LIFE FRONT is providing, *inter alia*, relevant data such as a leak size/concentration database to support evidence-based risk assessment for the use of flammable refrigerants.[15] Most recently, the project has released a report with recommendations on how to safely raise the charge limits of A3 refrigerants.[16]

Besides limitations in standards and codes, the need for more training on flammable refrigerant use for installers and service companies has also been repeatedly emphasized by industry.[17,18]

2.2 Energy Efficiency

As regards energy efficiency, the principle used in this assessment is that a "suitable" alternative needs to ensure that the system using the alternative refrigerant can be at least as energy efficient as the conventional, F-gas based refrigerants on the market.[19] Equipment with alternatives must also comply with the efficiency standards of the Eco-design Directive, safeguarding that the positive climate impact of indirect emissions is also guaranteed.[20] By way of example, R134a (HFC) and R513A (HFC mixture) are not considered as suitable alternatives due to their low cooling capacity and a lack of efficiency for comfort cooling in appliances.

Ecodesign requirements continue to be refined as technologies develop. In this way, Ecodesign requirements have an impact on the charge amount needed, with higher efficiencies typically needing more refrigerant. Since A3 refrigerants (see risk classification above) are more limited in potential refrigerant charge size by existing standards, their scope regarding energy efficiency improvements continues to be more limited unless existing barriers are addressed (see above).

CO_2, a common, non-F-gas refrigerant, used in other refrigeration and air conditioning equipment is not used in split systems because of the requirements for high pressures and

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14 COMMISSION IMPLEMENTING DECISION C(2017) 7284 of 14.11.2017 on a standardisation request to the European Committee for Standardisation and to the European Committee for Electrotechnical Standardisation as regards use of flammable refrigerants in refrigeration, air conditioning and heat pump equipment. https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=578

15 www.lifefront.eu/

16 http://lifefront.eu/portfolio-posts/impact-standards-hydrocarbon-refrigerants-europe-report-2/

17 REPORT FROM THE COMMISSION on availability of training for service personnel regarding the safe handling of climate friendly technologies replacing or reducing the use of fluorinated greenhouse gases, COM(2016) 748 final. https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/COM-2016-748-F1-EN-MAIN.PDF

18 AREA: European association of refrigeration, air conditioning and heat pump (RACHP) contractors. http://www.area-eur.be/

19 As regards energy efficiency, the properties of the refrigerant are only one side of the coin; the other is system optimisation achieved by fine-tuning the relevant components to a certain refrigerant. Thus, further energy efficiency improvements can be expected through time and experience of the manufacturing process and use of a new refrigerant.

20 The Eco-design Directive sets efficiency standards for air-conditioners with a capacity of up to 12 kW.

related costs for obtaining a safe design but also due to lower efficiency in transcritical operation (in a market of small, mass-produced and price-sensitive products).

3. Market overview and trends

The technical annex to this report gives an overview of feasible, alternative refrigerants for use in split systems that have a lower GWP compared to the conventionally used refrigerant R410A (GWP of 2088) and that fulfill the criteria of being sufficiently energy efficient (at least the same level of efficiency as conventional refrigerants) and which can be used safely[21].

3.1 Natural (i.e. non-fluorinated gas) alternatives

There is currently one alternative that is not a fluorinated greenhouse gas and where equipment is ready for the EU market: propane (R290), which has a very low GWP (3).

R290 has already been frequently used in *moveable* air conditioners[22] by Asian and European equipment producers for a number of years and is widely available on the European market. From 2020 onwards, R290 is expected to be the refrigerant of choice for this type of application due to the placing on the market prohibition set out by the EU F-gas Regulation (Annex III (point 14)). Major Asian equipment manufacturers perceived this policy measure as the main driver for the market uptake of hydrocarbon-based products.

Since 2012, R290 has also been used in commercially available split air conditioners (with cooling capacities up to 7 kW) by some major Chinese and Indian manufacturers. The conversion of production capacities for split air conditioning units in China from R22 (an HCFC now prohibited in the EU) to R290 of approximately 4 million units per year was completed in 2014. The current theoretical production capacity for R290 split air conditioning units is estimated at about 7 million units per year in 2019, so there is idle production capacity according to UNIDO. The actual globally installed base is over 1 million units today, mainly in India (800 000) and China (latest information is that 300 000 units have been surpassed). Eight Chinese manufacturers have published a schedule for increased production numbers from 2018, and a production target of 330 000 R290 split units has been set according to the Chinese Ministry of Ecology and Environment (MEE)/Foreign Environment Cooperation Center (FECO). In India, the manufacturers for these units have their own network of certified installers to assure qualified personnel for installation and servicing of these units.

Energy efficiency and cooling capacity of R290 split units compare favorably to conventional refrigerants, including the performance in warm climates, as demonstrated by e.g. the PRAHA project funded by the Montreal Protocol's Multilateral Fund (MLF).[23] Certain models of the range of split air conditioners offered by a Chinese manufacturer (2.6/3.5 kW cooling capacity) were granted the German ecolabel "Blue Angel" in 2018. Given the technical readiness and available production capacity, the EU market entry seems to have been delayed mostly as a result of standards and codes restricting the use of A3 refrigerants unnecessarily (see discussion under 2), which underlines the urgency of updating standards

[21] While it is not possible in the scope of this paper to exhaustively address all use limitations posed by codes and standards.

[22] Movable air conditioners are hermetically sealed and not considered part of the split air conditioner category.

[23] PRAHA: Promoting Low GWP Refrigerants for Air-Conditioning Sectors in High Ambient Temperature Countries. http://www.multilateralfund.org/Our%20Work/DemonProject/Document%20Library/7610p2%20-%20PRAHA.pdf

and codes so that the relevant equipment can be used where it is safe to do so. For 2020 a large Chinese manufacturer has declared its intention to start commercialization of a new single-split R290 split air conditioner system on the EU market.

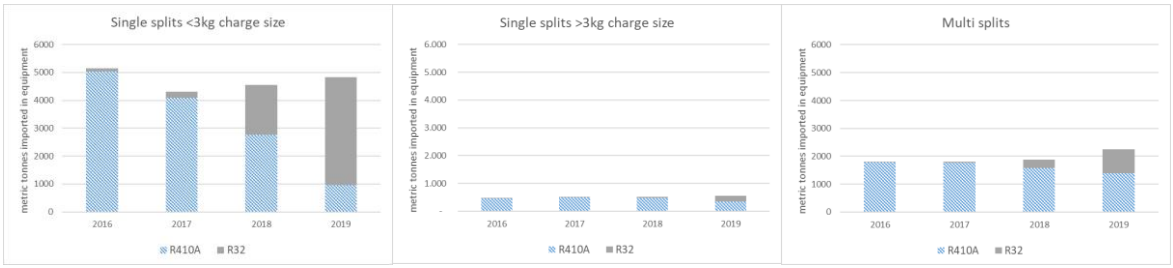
The use of R290 in single split systems allows for a reduction of the charges by about 50% compared to the conventionally used highly warming F-gas mixture R410A, which enables cost savings for units running on R410A. However, production costs are still somewhat higher than for HFC units (+6-10%) due to additional safety measures to address its flammability, and because economy of scale effects have not yet been exploited to the same degree as for R410A.

The other non-fluorinated gas alternative that appears feasible is propylene (R1270), but no market-ready units are available at this moment in time.

3.2 Fluorinated gas refrigerants

The most commonly used refrigerant in split air conditioners, before the current F-gas Regulation started to apply from 2015, was the HFC mixture R410A with a GWP of 2088. The annual company reporting on F-gases[24] provides import data on F-gases in products and equipment. Figure 1 below shows that R410A has recently started to be replaced by an HFC, R32, in split systems, in particular in the small single-splits. This is believed to be a direct result of the HFC phase-down (i.e. quota system) measure that strongly incentivizes replacing F-gas refrigerants with very high GWPs such as R410A (R32 has a medium-high GWP of 675 and therefore reduces the need for quota to a third). One EU-based producer of air conditioning equipment started to use reclaimed refrigerants (R410A and R134a) in the manufacture of new equipment in 2019 to limit the impact on F-gas quota.[25] However, R410A still remains the dominant refrigerant for larger air conditioning systems placed on the market in the EU today.

Figure 1. Refrigerants precharged in imported air conditioning equipment (metric tonnes)[26]



R32 is the main fluorinated gas alternative to R410A. Its energy efficiency was found to be comparable or better to R410A and allows the reduction of the refrigerant charge by about 20%-30%[27] compared to R410A to achieve the same cooling capacity. R32 units are also fully cost-effective compared to R410A. R32, as an A2L-flammable refrigerant, is subject to some use restrictions due to standards and codes today, even though some of these issues have been addressed recently. Besides R32, a number of other fluorinated gas alternatives are principally feasible but market-ready equipment is not yet available for these gases. While most of these

24 Pursuant to Article 19 of the F-gas Regulation.

25 Reclaimed gases do not fall under the quota system.

26 As reported for 2019 pursuant to Article 19 of the F-gas Regulation in categories 11A5 (single-splits <3kg), 11A4 (single-splits >3kg), and 11A6 (multi-splits).

27 Current models achieve 10-20%.

substances have medium-high GWPs ranging from ca. 300-750, two alternative substances (HFCs: R152a and R161) have low GWPs of 124 and 12, respectively, and would allow a further lowering of the climate effect in this sector. For R152a, there appear to be doubts on the cost-competitive design of such units.

R32 was introduced to the market in Japan around 2010. Starting in 2013, it was adopted by all major manufacturers of air conditioning equipment in their product portfolio for the EU market, and has become the dominant refrigerant for small single-split sales in the EU. The share of R32 units varies however between individual Member States and in most countries a market share of more than 80% was reached in 2019. In Italy and Spain building codes and installation requirements have been changed in the last two to three years to facilitate the use of some flammable refrigerants such as R32. In this way, R32 split air conditioning units have gained higher market shares, but are still somewhat lagging behind other EU countries. In France, national legislation about the use of flammable refrigerants in public access building has evolved in 2019, but still contains certain constraints depending on whether the refrigerant is A2/A2L or A3. In the case of high-rise buildings, the use of A2/A2L and A3 refrigerants is prohibited but some work on related legislation is still ongoing. About 60% of split systems put on the French market in 2019 were using R32. A roadmap has been established by the national association and all the manufacturers are committed to using a refrigerant with GWP < 750 in split systems with a refrigerant charge < 3kg before 2022.

AREA, the installers association, also expressed concerns on the continuing lack of trained personnel to properly maintain such equipment with a flammable refrigerant. The range of products containing R32 is not limited to single split air conditioning systems, but has been expanded to multi-split and even mini-VRF systems[28] recently.

3.3 Research and development activities

A number of research and development activities in and outside the EU aim at replacing R410A[29] in air conditioning applications including split systems with more climate-friendly fluorinated gas refrigerants, as follows.

- **R161** (GWP 12, an HFC) has been used in research on split AC to replace R22 and a demonstration project in China where a household air conditioner was developed but is not commercially available. The safety classification of R161 is incomplete due to the lack of toxicity testing, but it has been established as a flammable substance.
- **R452B** ("Opteon XL55"; GWP 698; safety class A2L, an HFC/HFO[30] mixture) has been approved by one component manufacturer for use in their scroll compressors. It is contained in industrial equipment such as reversible heat pumps and chillers supplied by several distributors in the EU, but not in split air conditioning at this stage.
- **R454B** ("Opteon XL41"; GWP 467; safety class A2L, an HFC/HFO mixture), has so far been approved by one component manufacturer for use in their scroll compressors. In Egypt, some split air conditioning manufacturers are considering to convert their production to this refrigerant within the HCFC phase-out under the Montreal Protocol and see it as an alternative to R32.
- **R454C** (GWP 148; safety class A2L, an HFC/HFO mixture) has been applied in Japan in air to air heat pumps for commercial use and in an air to water heat pumps by a

[28] VRF refers to Variable Refrigerant Flow which is used to describe ductless systems that provide heating and cooling. These systems are not included in the split system category of this paper.

[29] Or, in case of non-EU countries, also the ozone-depleting substance R22.

[30] HFOs: hydorfluoroolefins or unsaturated HFCs, a synthetic fluorinated alternative (listed in Annex II, Section 1 of the F-gas Regulation).

German manufacturer. It is also considered as an option for room air conditioning applications but some stakeholders expressed doubts on the cost-efficiency of this solution due to the need for larger compressors and heat exchangers.

- Further options that include **R466A** (an HFC mixture) and other **mixtures with HCFOs[31] or CF3I** are at an early stage of refrigerant testing. Their suitability for split systems is not clear.

Further research by industry within and beyond the EU is directed towards lower GWP alternatives, aiming at a GWP below 10 (e.g. NEDO project[32], 2018-2023). It should be kept in mind that even when research and development on refrigerants is ongoing, it will still take a number of years for a refrigerant to be recognized under ASHRAE[33], ISO and EN standards, and for products to be developed using such refrigerants. There are also interesting attempts of developing cooling technologies for the split sector without the use of refrigerants.[34]

4. Conclusions

On the basis of the above, it appears technically possible to avoid F-gases today in new single split air conditioning with a cooling capacity below 7 kW by using the refrigerant R-290 (propane), unless national legislation or codes prohibit its use. The latter has apparently prevented a large-scale rollout of such equipment in the EU so far. R-290 units provide good energy efficiency and are available at a very modest price increase that would likely disappear if mass produced and marketed at large scale.

For single split systems > 7 kW it still appears necessary at this stage to use F-gases. In this case, the use of R32 is preferable to R410A, which has been the conventional refrigerant choice hitherto, because the climate impact of R32 is only a third of R410A with a comparable or even better energy- and cost-efficiency. Thus refrigerants with a GWP > 750 in new equipment are no longer needed in small single split systems, unless in applications where it is prohibited to use a flammable refrigerant by building codes and other legislative requirements.

An assessment of the current EU market shows that the majority of small single split systems sold in the EU no longer contain R410A. This shift has been driven by the HFC phase-down measure including the requirement for pre-charged equipment to be covered by the quota system. A large part of the market is thus already in compliance with the requirement to only use refrigerants in small single splits with a GWP of less than 750 from 2025.

It is expected that knowledge, practices and know-how related to flammable refrigerants in the manufacture, installation, use and end of life management of air conditioning equipment will be further refined in the coming years, as well as the availability of skilled personnel to handle them. Similarly, it is expected that further progress will be made on the revision of standards and codes to better account for the technological development, including for A3 refrigerants. Taking into account that a number of new mixtures with low GWPs are in the pipeline, it is likely that further alternatives with low GWPs will become market ready in the foreseeable future. A further significant reduction of the GWPs of alternatives to e.g. below

[31] HCFOs: unsaturated hydrochlorofluorocarbons, a synthetic fluorinated and chlorinated alternative (listed in Annex II, Section 1 of the F-gas Regulation); CF3I: Trifluoroiodomethane.

[32] https://www.jraia.or.jp/english/side/MOP31_05.pdf

[33] American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[34] E.g. Global Cooling Prize: https://globalcoolingprize.org/

150 may be possible in small single split systems in the medium term if the above constraints are addressed effectively.

The market assessment also shows that several manufacturers/importers are already selling larger single split air conditioning systems (with charges of 3 kg or more), multi-split systems and other types of air conditioning systems that are no longer using the traditional refrigerant R410A. Again, the dominant refrigerant is R32, but also some applications relying on R290 as well as HFO-based refrigerants are available. Given that many of these equipment types use higher charge sizes, which makes the use of flammable refrigerants more challenging, a complete phase-in of more climatefriendly refrigerants will take some time in these types of equipment, but good progress is expected in the medium term.

As part of the European Green Deal, the Commission has recently launched a review of the EU rules on fluorinated gases including the evaluation and proposal to revise the F-gas Regulation in Q4 2021.[35] The findings in this report will serve as a technical input to that review.

[35] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12479-Review-of-EU-rules-on-fluorinated-greenhouse-gases

TECHNICAL ANNEX:

Feasibility, status and achievable energy efficiency of alternatives to high GWP refrigerants

	GWP	*Feasibility for split AC*	*Relevant use restrictions*	*Market readiness & production capacity*	*Cost efficiency compared to R410A (=conventional technology)*	*Energy efficiency compared to R410A (=conventional technology)*
Natural alternatives (i.e. NOT fluorinated greenhouse gases)						
Propane (R290)	3	Single splits currently up to 7 kW; Feasible also for larger single and multi-splits if charge limits in standards are increased	As A3 refrigerant, charge size and use limited by product standards/ building codes.	Market Ready – over 1 million units sold in India and China; capacity available to produce up to ca. 7millions of R290 split units per year in China; EU market entry foreseen for 2020.	Higher material costs to address flammability, but cost savings due to lower charge sizes/smaller diameter of heat exchanges; Currently costs up to 10% higher but will reduce with economies of scale	Better; also performs well in warm climates
Propylene (R1270)	2	Principally feasible[36], but mainly used in chillers today	As A3 refrigerant, charge size and use limited by product standards/ building codes.	No	*n.a.*	Better
***Synthetic alternatives (i.e. fluorinated greenhouse gases)* with medium-high GWP**						
R32 (HFC)	675	All	As A2L refrigerant, charge size and use limited by product standards/ building codes.	Product already widely sold on the EU market; all major manufacturers have launched products	Comparable to R410A	Better
R452B (mixture of HFCs (R32, R125) and HFO-1234yf)	698	All	As A2L refrigerant, charge size and use limited by product standards/ building codes.	No. Possibly conversion of R22 production lines in Egypt from 2020	*n.a.*	Similar; slightly better at elevated temperature (>35°)

[36] Some manufacturers expressed doubts on the stability of this refrigerant, but this does not seem to be supported by the scientific literature.

	GWP	*Feasibility for split AC*	*Relevant use restrictions*	*Market readiness & production capacity*	*Cost efficiency compared to R410A (=conventional technology)*	*Energy efficiency compared to R410A (=conventional technology)*
R454B ***(mixture of an HFC (R32) and HFO-1234yf)***	466	Principally feasible	As A2L refrigerant, charge size and use limited by product standards/ building codes.	No	*n.a.*	Similar; slightly better at elevated temperature (>35°)
R466A ***(mixture of HFCs (R32, R125) and trifluoroiodo-methane (CFI))***	733	Principally feasible	Safety classification not fully concluded[37]	No	*n.a.*	Similar
R448B ***(mixture of HFCs (R32, R152a) and HFO-1234ze)***	296	Promising results at research stage	As A2L refrigerant, charge size and use limited by product standards/ building codes.	No	*n.a.*	Apparently good efficiency in warm climates
R447A ***(mixture of HFCs (R32, R125) and HFO-1234ze)***	583	Promising results at research stage	As A2L refrigerant, charge size and use limited by product standards/ building codes.	No	*n.a.*	Similar
Other HFC mixtures ***containing R1123 (trifluoro-ethylene), R1132a (1,1-difluoro-ethene) and CF3I (tri-fluoroiodom ethane)***	Ca. 300	unknown	No safety classification yet for the mixtures but R-1132a is A2, CF_3I is A1 and R-1123 is A2L (expected), so charge size and use are limited.	No	*n.a.*	Ongoing research

[37] R-466A is not listed in EN378 and ISO817 yet. It is classified A1 in ASHRAE34.

***Synthetic alternatives (i.e. fluorinated greenhouse gases)* with low GWP (<150)**						
R161 ***(HFC)***	12	Principally feasible	As a flammable refrigerant[38], charge size and use limited by product standards/ building codes. Toxicity testing incomplete.	No Research on-going	*n.a.*	Better
R152a ***(HFC)***	124	Principally feasible but not considered for split systems as volumetric cooling capacity is low (units would have to be much larger)	As A2 refrigerant, charge size and use limited by product standards/ building codes.	No	*n.a.*	No information
R454C ***(mixture of an HFC (R32) and HFO-1234yf)***	148	Principally feasible	As A2L refrigerant, charge size and use limited by product standards/ building codes.	No	May be more costly due to need for larger compressors and heat exchangers	No information

Refrigerants are grouped by type (fluorinated greenhouse gas or not) and feasibility. More information on data sources in briefing paper to the Consultation Forum.[39]

[38] Safety classification is of yet incomplete due to the lack of full toxicity testing.

[39] https://ec.europa.eu/clima/events/articles/0106_en