Phase down of HFC consumption in the EU

Projections for the RACHP sector

Discussion Paper based on EPEE modelling of EU HFC Demand

1. Summary

This paper summarises results of detailed modelling of the EU market for HFCs. The modelling has been carried out on behalf of EPEE to provide an independent analysis that can be compared to the AnaFgas modelling that has been used by the European Commission during the formulation of their April 2022 proposal for a revised F-Gas Regulation. EPEE's modelling has been carried out using the *HFC Outlook EU* model. Like AnaFgas, this is a detailed bottom-up stock model of EU markets for HFCs. The *HFC Outlook EU* model differs from the AnaFgas model in three important ways:

a) It provides a more detailed analysis of key refrigeration, air-conditioning and heat pump (RACHP) market sectors.

b) For some parts of the RACHP market it uses different input assumptions about the optimum refrigerant choices for new equipment.

c) It provides estimates of energy-related greenhouse gas emissions from RACHP in addition to estimates of HFC demand and HFC emissions.

The results of EPEE's modelling show that:

- By the mid-2030s there is significant potential to increase the ambition of the HFC phase-down from the current 79% cut in the 2014 F-Gas Regulation.
- The cuts proposed by the Commission in 2024, 2027, 2030 and 2033 are unrealistic and are based on overly optimistic assumptions about (a) the rate of technology transition to lower GWP gases and (b) the quantity of HFCs required for servicing existing equipment. With the cuts proposed by the Commission in this period there would be insufficient HFC quota to support the vital roll-out of heat pumps and to service the existing bank of RACHP equipment, especially in the food cold chain.
- The cuts proposed by ITRE in this time period are more realistic, allowing more time for the required technology transitions, although there is still insufficient quota to support the expected rate of heat pump growth. The feasibility of the ITRE proposal also depends on the transition of the MDI sector, which is only excluded from the ITRE steps until the end of 2028.
- The cuts from 2036 onwards remain very challenging, but there is less discrepancy between the EPEE and AnaFgas modelling.
- EPEE's modelling of energy-related emissions give extra insights that are not available from AnaFgas. In particular, the amount of CO_2 emissions avoided through the decarbonisation of heating with heat pumps massively outweighs the small amount of HFC emissions from these heat pumps. It is more important to maximise the speed of heat pump roll-out than to force an unrealistic rate of refrigerant change.
- Energy modelling also shows that forcing inappropriate transitions away from some low GWP HFC / HFO refrigerant options can lead to loss of energy efficiency in some parts of the RACHP market. In some cases, this loss of efficiency will create extra CO_2 emissions that will be greater than the reduction in HFC emissions created by a forced transition.

Figure S1 shows a comparison of EPEE's estimated requirements for HFC quota in the RACHP market with the 3-yearly phase-down steps proposed by the Commission, ITRE and the ENVI rapporteur. It should be noted that the EPEE RACHP estimate (shown in red) does not include MDIs, whilst the three proposals include MDIs (ITRE includes MDIs from 2029). HFC quota required for the EU MDI sector are expected to be around 8 million tonnes CO_2 in 2024. Figure S1 clearly illustrates the significant gap between EPEE's estimate of required quota and the Commission proposal.

Figure S1: EPEE estimated HFC phase down for the RACHP sector, compared to phase-down proposals

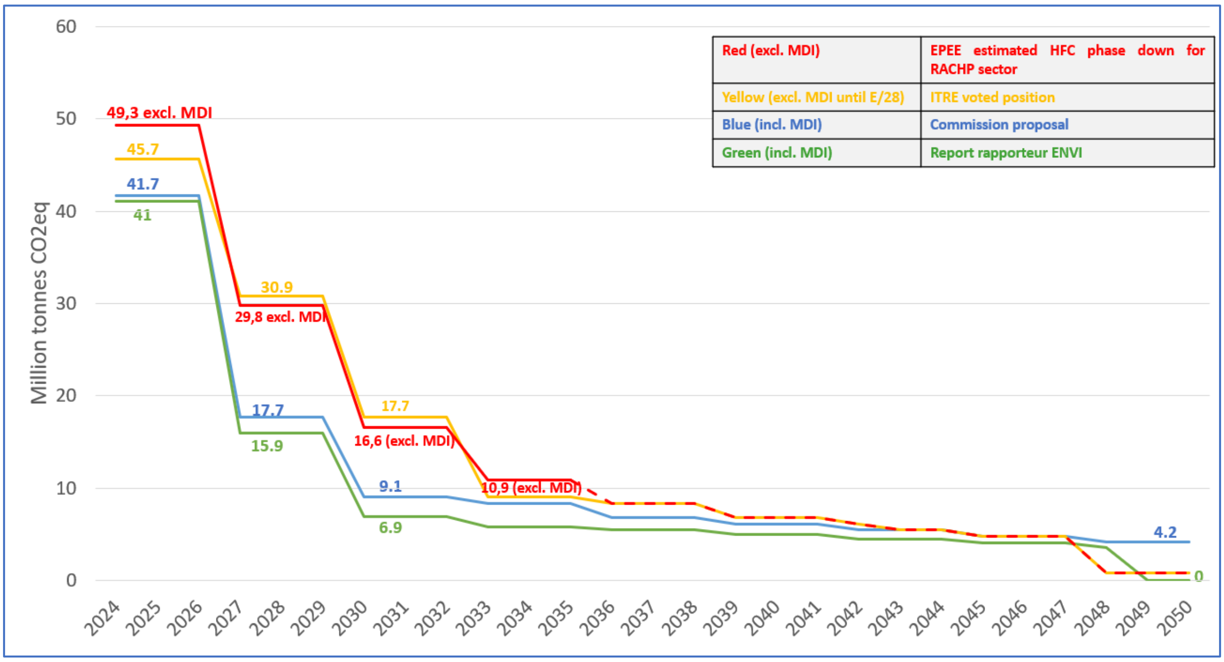
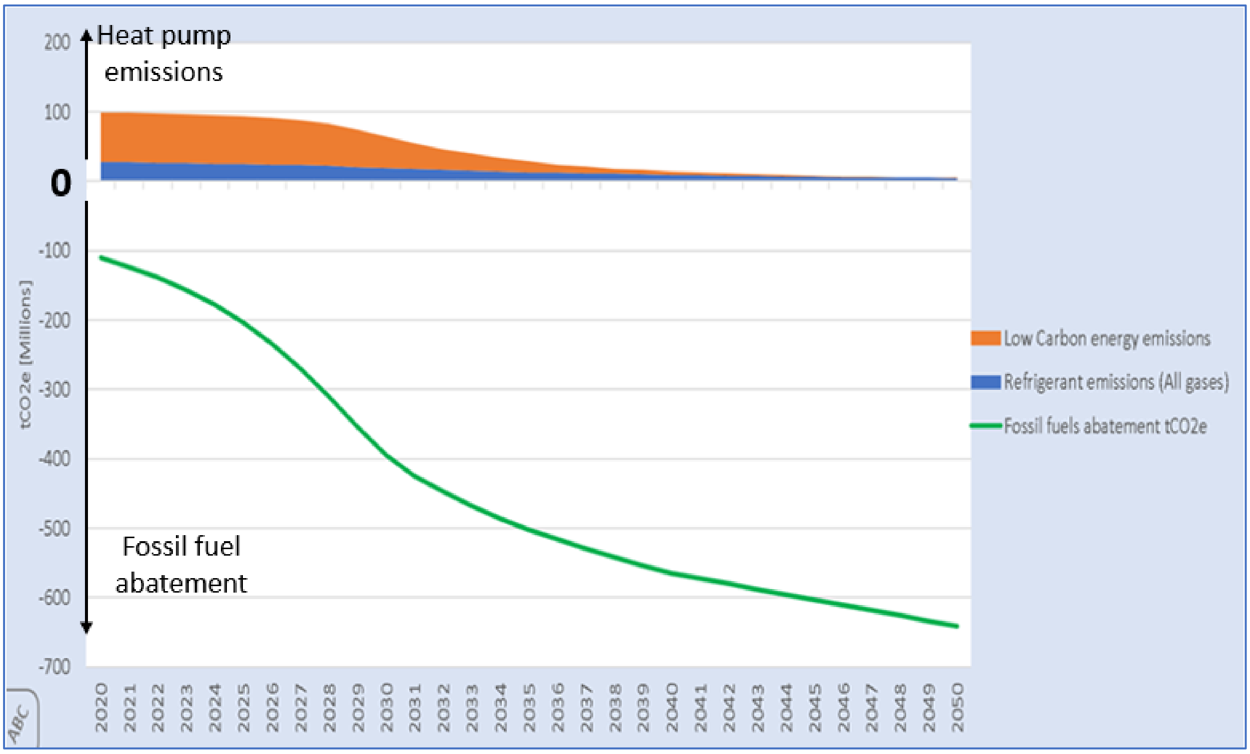


Figure S2 illustrates an analysis of the impact of heat pumps, showing the direct HFC emissions and indirect energy-related emissions from the rapidly growing bank of heat pumps, together with the amount of CO_2 emissions avoided through the use of these heat pumps. The "prize" is the massive cut in fossil fuel emissions related to low temperature heating. In 2050 the "cost" in terms of heat pump emissions is more than **100 times smaller** than this prize, even though EPEE modelling includes some continuing use of HFCs in new heat pumps.

Figure S2: Avoided GHG Emissions through use of Heat Pumps



Examples of Unrealistic AnaFgas Assumptions

Some of the gas choice assumptions made in AnaFgas and used to create the Commission's phase-down proposals are considered by industry experts to be unrepresentative of the state of the market in the EU and are the key reason why the EPEE modelling shows a need for more HFC quota, especially in the period between 2024 and 2033.

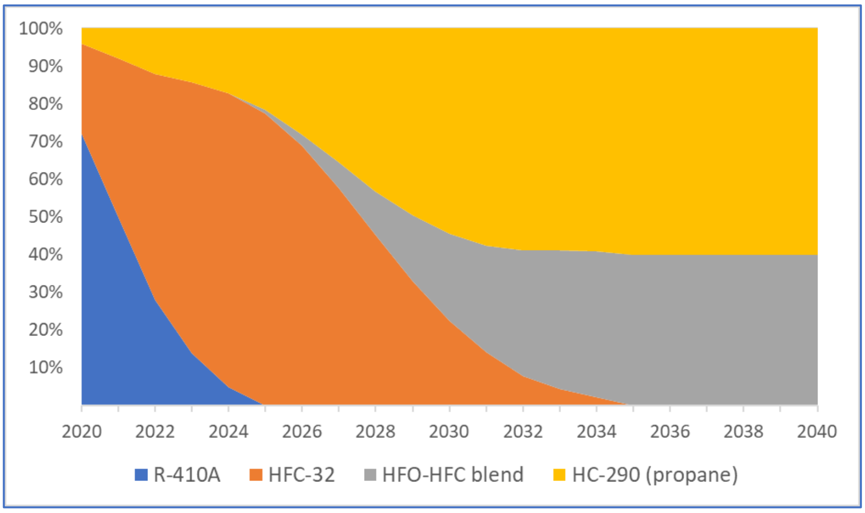
Residential Hydronic Heat Pumps: AnaFgas only models a single technology sector, based on an 11 kW air-to-water heat pump. They assume that in the period 2024 to 2036 that 97% of these heat pumps can use propane (100% by 2025). This is considered by EPEE to be incorrect because:

(a) Monobloc hydronic heat pumps located outdoors can safely use propane. For split hydronic heat pumps and for ground source heat pumps the use of propane will be very limited due to safety constraints[1]. EPEE modelling assumes that residential hydronic heat pumps will rapidly move away from R-410A and HFC-134a and make use of a mix of refrigerant solutions including propane but also a variety of other lower GWP refrigerant options including HFC-HFO blends.

(b) In 2021, only a small proportion of residential hydronic heat pumps (below 12 kW) sold in the EU used propane (under 10%). A report published by Umweltbundesamt (the German Environment Agency)[2] included a projection for the use of propane in heat pumps in Germany – in 2030 the estimate was between 30 and 50%%, which is significantly lower than the 100% figure used in AnaFgas. EPEE modelling assumes an increasing share of propane up to 55% by 2030, which is already significantly higher than current independent assumptions. The remainder cannot use propane for the reasons discussed in (a) above.

Figure S3 shows EPEE assumptions about gas choices for residential hydronic heat pumps, which can be compared to the unrealistic AnaFgas assumption of 100% propane by 2025. There is a rapid transition away from R-410A, mainly to HFC-32, followed by a steady build-up of propane in outdoor monoblocs and some ground source heat pumps and a transition to HFO-HFC blends in split hydronic systems and other ground source heat pumps

Figure S3: EPEE gas choices, new residential hydronic heat pumps (including monobloc and split-type)



[1] Safety standard IEC 60335-2-40 allows up to 5 kg of propane for units located outdoors – this is sufficient for residential monobloc heat pumps. In contrast, for systems where the refrigeration circuit is fully or partially indoors, the maximum charge is only 0.15 kg (without room size limitation) or up to 0.98 kg (dependant on a sufficient room size and additional safety measures).

[2] Hauswärmepumpen mit natürlichen Kältemitteln: Entwicklung von Anforderungen an klimafreundliche und energieeffiziente Geräte für den Blauen Engel, Umweltbundesamt, 2022

Air-to-air air-conditioning and heat pumps <12 kW: AnaFgas models a single technology sector, based on a 4.5 kW single split system. They assume that in the period 2024 to 2036 that 96.3% of all air-to-air units < 12kW can use propane (100% by 2027). This is considered by EPEE to be incorrect because:

(a) It is unrepresentative to model the whole of this important and large market sector with just one technology type. EPEE modelling uses 6 sectors (three sizes: 3.5, 7 and 12 kW; two configurations: single split and multi-split). The optimum gas choices depend on size and configuration.

(b) Currently this market has already moved from R-410A to HFC-32 and there is close to zero sales of propane air-to-air units in the EU. It is possible that in the small end of the size range for air-to-air single splits propane will build some market share, but the transition will need significant technology development followed by technician training. The needs for sufficient heating capacity (especially in cold climates), long piping lengths, installation complexity and needs,and higher energy efficiency requirements set by the Ecodesign lot 10 review pose barriers for propane in single splits. The EU Commission itself noted a number of limitations of the use of propane and other refrigerants in single-splits back in 2020[3].

(c) For multi-splits and larger sizes (above 6 kW) the optimum refrigerant choice is even more difficult to predict due to charge limitations, even longer pipping lengths, installation complexity (pipping in small occupied areas for instance) etc. EPEE's model assumes a transition to lower GWP HFO-HFC blends rather than propane – this is to ensure safe operation whilst achieving maximum energy efficiency.

(d) Some published reports and recent presentations oversimplify this market and make incorrect statements about the potential use of propane in the <12 kW air-to-air market. EPEE has published three position papers that show these assumptions are not realistic (e.g. analysis of the GIZ report)[4].

It is also not clear whether the AnaFgas modelling recognises that part of the heat pump growth required to achieve RePowerEU targets will be air-to-air units. There is already significant growth in many countries, including those with cold climates (Nordic countries). If AnaFgas growth assumptions for air-to-air units are too small, there will be insufficient HFC quota in the Commission proposal.

COULD WE SHOW HERE THE "SAME" GRAPH AS FOR HYDRONIC ?

Air-to-air air-conditioning and heat pumps >12 kW: AnaFgas models two technology sectors, based on a 30 kW roof top unit and a 27 kW VRF system. EPEE models four sectors, including two much larger options (150 kW RTU and 100 kW VRF) in addition to small sizes similar to AnaFgas. There is a significant market for commercial building heating and cooling that uses air-to-air units >12 kW. If the larger sizes of equipment have not been properly modelled the AnaFgas estimates of HFC quota will be too low. All these larger systems cannot use propane and will need other less flammable lower GWP alternatives.

The above examples clearly show why EPEE modelling shows the need for a larger HFC quota than proposed by the Commission. In addition, regardless the sector modelled and considered; the AnaFGas model disregards the time needed for any refrigerant transition. The Commission proposal refers to a four year timescale for the R-410A to HFC-32 transition and assumes this timescale can be applied to a further transition to any new refrigerant, for instance highly flammable ones. In reality the transition to HFC-32 required over 10 years of development and the fast EU transition relied on previous development work,

[3] The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact, European Commission, 2020

[4] EPEE comments on Proklima/GIZ study "Split air conditioners and air to air heat pumps", February 2023

mainly carried out in Japan. A further transition to propane and / or HFO-HFC blends is technically more complex than the transition to HFC-32 – a four year timescale is unrealistic.

Breakdown of the future requirements for HFCs

EPEE's modelling shows which parts of the market has on-going requirements for HFC quota. Figure S4 illustrates the split between (a) new refrigeration equipment, (b) new comfort cooling and heating equipment (CCH) and the servicing of all existing equipment. This clearly shows that new equipment in the commercial refrigeration sectors (e.g. food retail) has already transitioned away from HFCs. The bulk of HFC quota requirements are for new CCH equipment (driven by the rapid growth in heat pumps) and for the servicing of existing equipment. In the period 2024 to 2030 there is approximately a 50% / 50% split between new CCH and servicing requirements.

Figure S4: Forecast Use of HFCs in EU

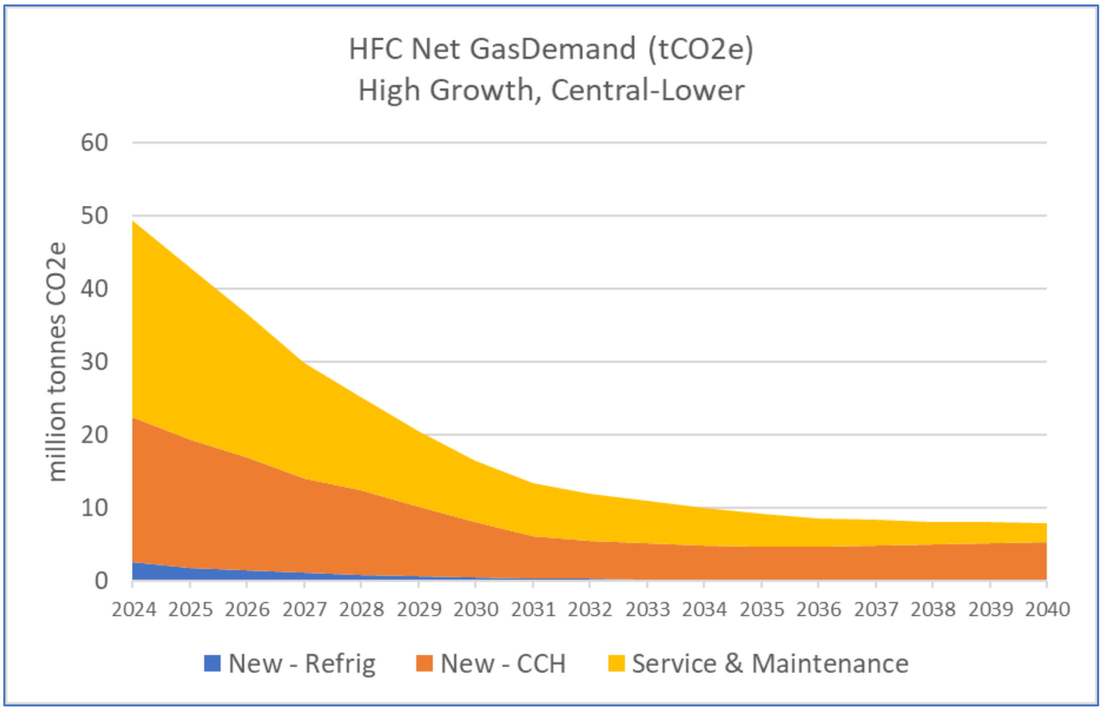


Figure S5 shows a more detailed breakdown of HFC requirements, averaged over the period 2024 to 2030.

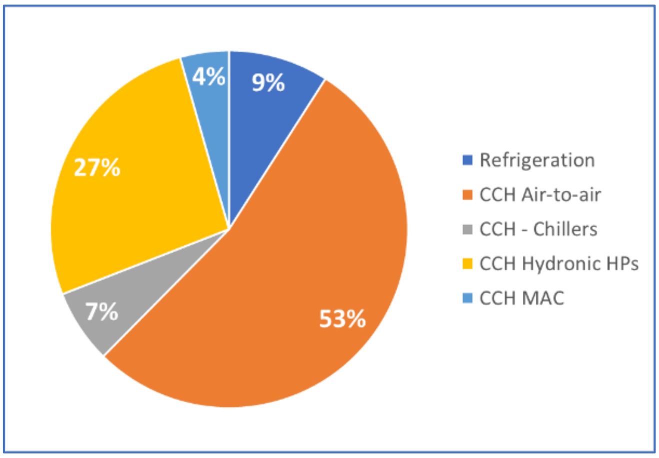
Figure S5a shows the split of the use of HFCs in new equipment. The two dominant sectors are CCH air-to-air (including both <12 kW and > 12 kW systems) and hydronic heat pumps (including residential and larger systems). These sectors represent 80% of the total, with the rest split between refrigeration applications, chillers for CCH and mobile air-conditioning.

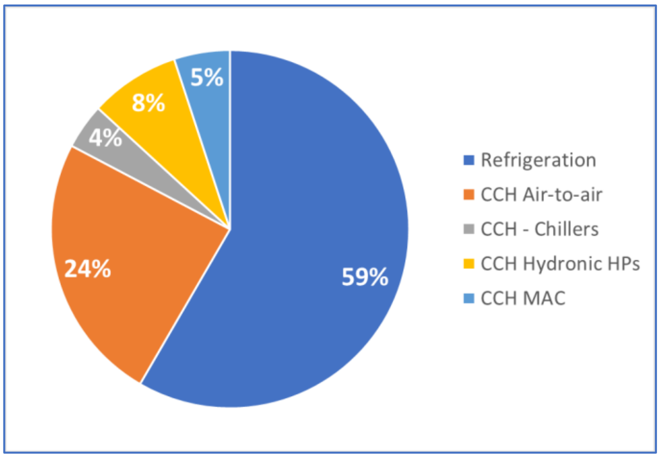
Figure S5b shows the split of the use of HFCs for servicing and maintenance. Here we see that the dominant requirement is for refrigeration applications, which represent nearly 60% of service usage of HFCs. Without sufficient HFC quota there is a risk that these existing refrigeration systems will be unable to get refrigerant for servicing.

Figure S5: Average HFC Requirements in the Period 2024 to 2030

Figure S5a: Split of HFC Use in New Equipment

Figure S5b: Split of HFC Use for Servicing


4%
9%
27%
7%
53%
Refrigeration
CCH Air-to-air
CCH - Chillers
CCH Hydronic HPs
CCH MAC


5%
8%
4%
24%
59%
Refrigeration
CCH Air-to-air
CCH - Chillers
CCH Hydronic HPs
CCH MAC

2. Introduction

General Background

The EU F-Gas Regulation is world leading legislation that is providing significant reductions in the EU consumption and emissions of fluorinated greenhouse gases. EPEE is a keen supporter of the EU F-Gas Regulation and has carried out many initiatives to help the refrigeration, air-conditioning and heat pump (RACHP) industry achieve the challenging HFC phase-down targets. The 2014 EU F-Gas Regulation is currently under review and a revision is expected in 2023.

The EU HFC Phase-down

The 2014 EU F-Gas Regulation requires a rapid HFC phase-down in the EU. By 2021 there has already been cut an HFC cut of 55% and in the final phase-down step in 2030 the cut specified in the Regulation will be 79%. The EU F-Gas Regulation phase-down is well ahead of HFC phase-downs in most other countries: under the Montreal Protocol Kigali Amendment, non-Article 5 (developed) countries will not reach the EU's 2021 reduction of 55% until 2029 and Article 5 (developing) countries will not reach the EU 2021 reduction until 2045 or 2047[5].

The EU phase-down of HFCs is regulated by a quota mechanism. Starting at an EU-27 baseline level of 176.7 million tonnes CO_2e in 2015, the original EU-27 target from 2030 onwards was a cut to 37.1 million tonnes CO_2e. The baseline was only for HFCs placed on the EU market in bulk. Since 2017, HFCs contained in imported pre-charged RACHP equipment are also included in the phase-down targets.

In the HFC phase-down baseline period (2009 to 2012) there were several important HFC markets including RACHP, technical aerosols, metered dose inhalers (MDIs), insulation foam and fire protection systems. Due to the impact of the current EU F-Gas Regulation and allowing for the current exemption of MDIs and feedstocks, by 2023 the only HFC market of significance is RACHP.

EPEE Assessment of HFC Phase-down Trajectories

EPEE has carried out detailed modelling of the future markets for HFCs in EU-27, with a main focus on the RACHP sector. This document provides a summary of some key outputs from this modelling to help policy makers understand the market dynamics and the drivers that affect greenhouse gas (GHG) emissions from the RACHP sector.

The modelling has been carried out using *HFC Outlook EU* which provides a detailed model of EU use and emissions of HFCs. The model also provides estimates of RACHP energy use and the energy related GHG emissions. A summary of the features of *HFC Outlook EU* is given in **Annex 2**.

An important aspect of the modelling is to make an estimate of market growth and to test the sensitivity of HFC demand forecasts to different rates of growth. Significant growth of RACHP markets is expected, especially in relation to the supply of decarbonised heat through the use of heat pumps. This growth will lead to the need for more refrigerants and more electricity to operate the equipment. **Section 3** provides EPEE's estimates of market growth.

EPEE's modelling is able to provide estimates of future use of HFCs, HFC blends, HFOs and non-fluorinated alternatives such as CO_2, ammonia and hydrocarbons. **Section 4** provides estimates of

[5] The Kigali Amendment splits Article 5 countries into 2 groups, with a slower phase-down timetable for 10 countries that have especially high ambient temperatures.

future refrigerant requirements and compares these to the current EU HFC phase-down schedule and proposed revisions to this schedule.

Key factors that influence HFC phase-down trajectories, such as the importance of decarbonisation of heating and cooling, and energy efficiency are discussed in **Section 5.** Further opportunities to reduce HFC emissions, such as improved end-of-life recovery and reduced leakage are discussed in **Section 6**.

Currently the EU is well ahead of the HFC phase-down scheduled required under the Kigali Amendment of the Montreal Protocol. On-going compliance with the Kigali Amendment is discussed in **Section 7.**

The RACHP Markets are not suited to "one-size-fits-all" policies

It is crucial to recognise the complexity of the RACHP market when making decisions on refrigerant choice for new equipment and the rate of HFC phase-down. These complexities include: (a) general factors such as location or equipment size and temperature level, (b) safety requirements, (c) energy efficiency implications, (d) application specific factors such as use of equipment in sensitive locations, (e) components availability and costs, (f) specific standards or regulations (for instance ATP rules for transport refrigeration[6]) and (g) availability of qualified personnel for installation, commissioning, maintenance, end-of-life treatment. There is no universal refrigerant to suit the diversity of RACHP technology sectors.

If these complexities are ignored, there is a risk that revisions to the EU F-Gas Regulation will lead to increased energy use, no available solution in some applications, or unsafe conditions for users and for people carrying out transport, installation, repairs and waste treatment of RACHP equipment.

Interaction of EU F-Gas Regulation with Other EU Policy Measures

It is important to maximise the reduction in HFC emissions. However, it is also very important to ensure that the F-Gas review is not treated in isolation from other related EU policies. In particular:

a) **EU policy to address Energy Efficiency First**. Energy efficiency is identified as key for achieving climate neutrality at the lowest possible cost. It is embedded in the EU Green Deal, the governance on EU Energy Union and Climate Action, the strategy for Energy System Integration, the Renovation Wave Strategy and the Circular Economy Action Plan. If an EU F-Gas Regulation revision prevented the uptake of higher energy efficiency RACHP solutions, it would contradict the goals of Energy Efficiency First, which would imply, among other things, an increase of CO_2e emissions. For information on the EU policy, see: [Energy efficiency first | Energy (europa.eu)]

b) **EU policy to decarbonise cooling and heating**. According to 2019 figures from Eurostat, approximately 75% of heating and cooling is still supplied using fossil fuels. To fulfil the EU's climate and energy goals, the heating and cooling sector must not only reduce its energy consumption but also cut its use of fossil fuels. In buildings and industry, heat pumps can make a massive contribution to the decarbonisation of heating in the EU. If an EU F-Gas Regulation revision creates barriers for the roll-out of heat pump technology, it would limit the potential to decarbonise heating. The recent REPowerEU policy, published in response to the energy crisis

[6] ATP: UN Agreement on the International Carriage of Perishable Foodstuffs https://unece.org/atp-handbook

created by the war in Ukraine emphasises the importance of maximising the speed of heat pump roll-out[7]. For information on the EU policy, see: Heating and cooling | Energy (europa.eu) REPowerEU https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131

c) **The EU Green Deal industrial plan.** The Green Deal industrial plan aims to increase investments in the EU based manufacturing for net zero technologies, to protect the single market from unfair trade, as well as focus on developing the skills needed for a green transition. This is of particular relevance for the RACHP sector. The so called bank of quota authorizations (only accessible for equipment importers) is an argument used by DG Clima that there is sufficient "quota buffer" for the heat pump sector to grow. This would imply that quota shortages are to be solved by moving the heat pump production to outside the EU – which is fully contradictory to the EU Green Deal industrial plan. For information, see : The Green Deal Industrial Plan (europa.eu)

d) **EU farm to fork strategy**. The RACHP sector plays an important role throughout the food chain, by providing cooling and heating solutions for food production, food processing, transport, storage and for display to consumers. A revision of the EU F-Gas Regulation needs to take into account a growing demand for food chain solutions to avoid food loss and food waste. Shortage of HFC quota may pose a particular risk for the servicing of existing refrigeration solutions and thus pose a risk on the food cold chain. For information on the EU policy, see : Farm to Fork Strategy (europa.eu)

e) **EU Circular Economy Action Plan.** It is important to minimise emissions at RACHP equipment end-of-life. As well as supporting EU policies on the circular economy, the F-Gas review can prevent GHG emissions created by non-compliance with current rules for gas recovery. For information on the EU policy, see: Circular economy action plan (europa.eu)

f) **EU chemical strategy / REACH**. Some fluorinated gases are covered by the on-going REACH investigation of potential restrictions relating to PFAS (per- and polyfluoroalkyl substances). The Commission review of the F-Gas Regulation does not properly consider the impact of possible F-Gas bans under REACH. This creates a high risk to a successful HFC phase down and to the related decarbonization of heating and cooling.

g) **Health service decarbonisation strategy.** Some national health services are investigating how to reduce the climate impact of MDIs used for treatment of lung diseases such as asthma. MDIs are currently exempted from the HFC phase-down. Any change to the status of MDIs in the EU F-Gas Regulation should be made in coordination with relevant health service initiatives.

[7] The REPowerEU policy states: "The European Union should aim at doubling the current deployment rate of individual heat pumps, resulting in a cumulative 10 million units over the next 5 years.

3. RACHP Market Growth

The RACHP market is expected to grow rapidly, especially due to the need for low carbon heating. In terms of installed thermal capacity[8], EPEE's mid-growth forecast between 2020 and 2050 shows:

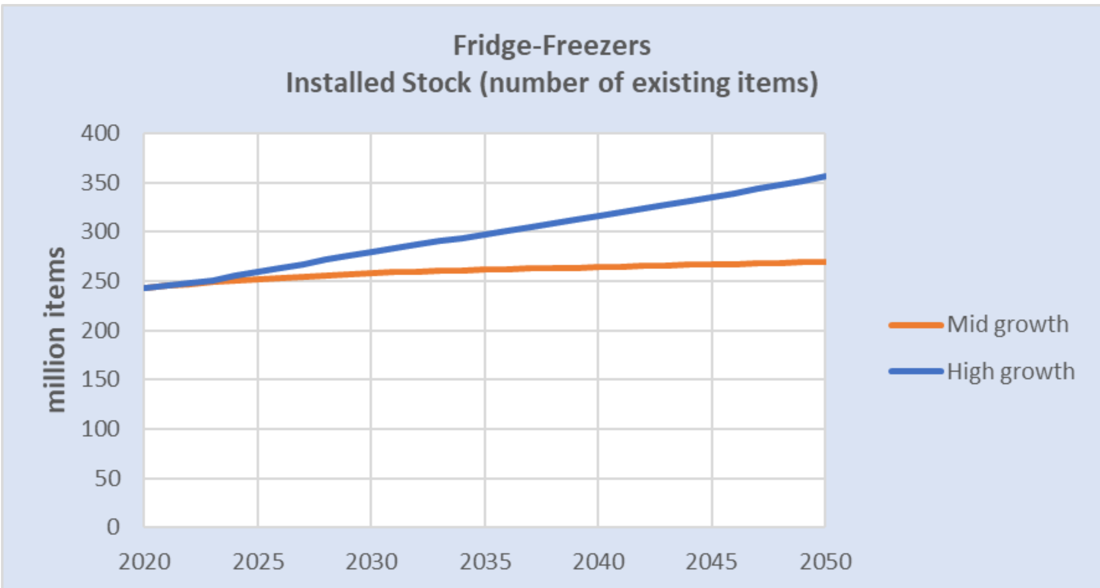
- a 42% increase in installed cooling capacity for refrigeration and air-conditioning applications
- a 750% increase in installed heat pump capacity for building space heating, domestic water heating and low temperature industrial heating (due to transition of fossil fuel boiler technology and direct electric heating to heat pump technology)

The EPEE model uses 50 technology sub-sectors (see Annex 2). A mid-growth scenario is defined individually for each sub-sector taking into account the characteristics of each part of the HFC market and making use of published forecasts such as those in independent EcoDesign studies and in the recent REPowerEU plan. A high-growth variant is modelled to provide a sensitivity analysis for several uncertainty factors in the model.

The rate of market growth is expected to vary considerably between different technology sub-sectors. Some examples are shown in Figures 1 to 3, for the mid-growth and high growth scenarios:

- Figure 1 shows forecast growth rates for the number of domestic refrigerators. This is a mature market and the mid-growth scenario only shows 11% growth between 2020 and 2050.
- Figure 2 shows forecast growth rates for small split air-to-air units, which are reversible units used for both room cooling and heating, with nearly 80% growth expected between 2020 and 2050. Air-to-air units will play an important role in the decarbonization of heating in the EU.
- Figure 3 shows the forecast growth rates for residential hydronic heat pumps. This market is expected to grow very rapidly, with 900% growth expected between 2020 and 2050. It is important to note that REPowerEU policies require a significant proportion of this heat pump growth by 2030 as illustrated in Figure 3.

Figure 1: Forecast Growth for Fridge-freezers



[8] Thermal capacity is the amount of cooling or heating that can be provided, in kW. For example a small air-to-air unit might provide 5 kW of comfort cooling and 4 kW of comfort heating and a large industrial refrigeration plant might provide 1,000 kW of cooling or heating.

Figure 2: Forecast Growth for Small Split Air to Air Units

(Reversible systems for cooling and heating)

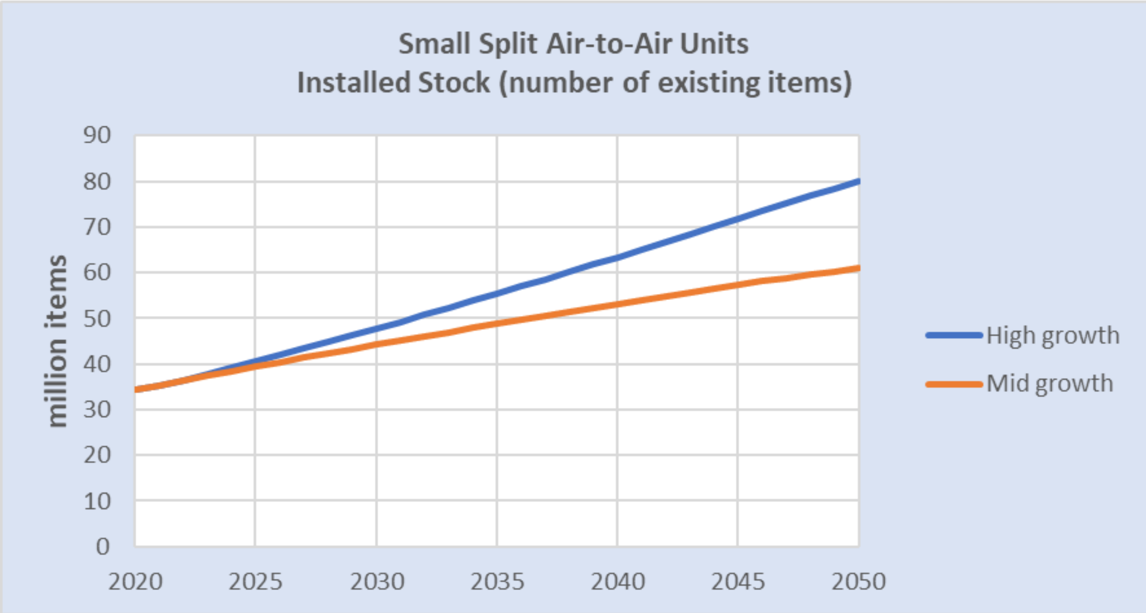
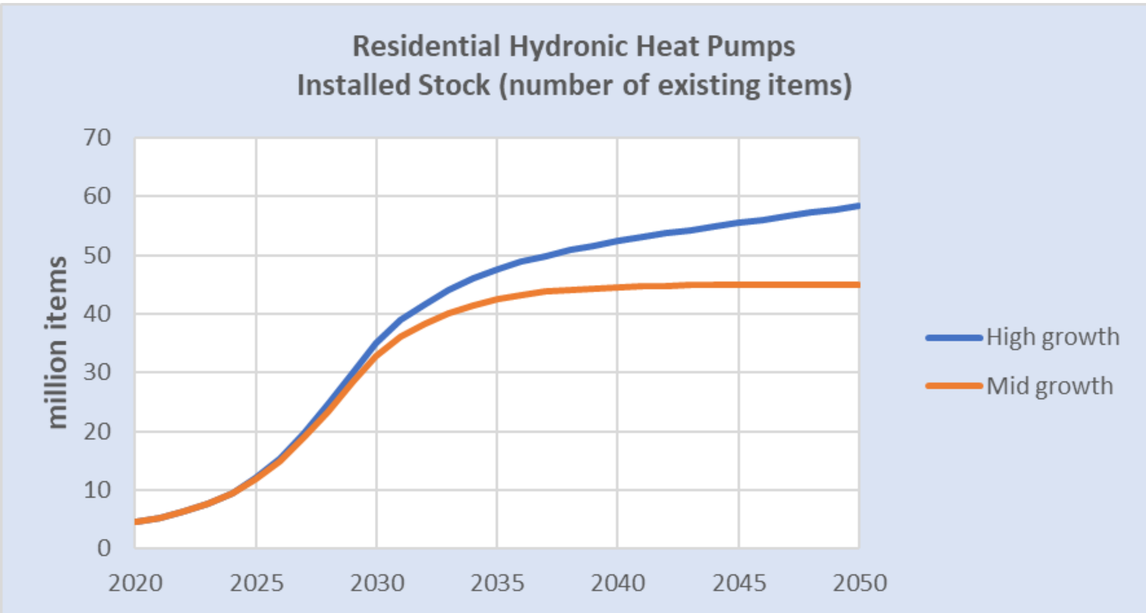
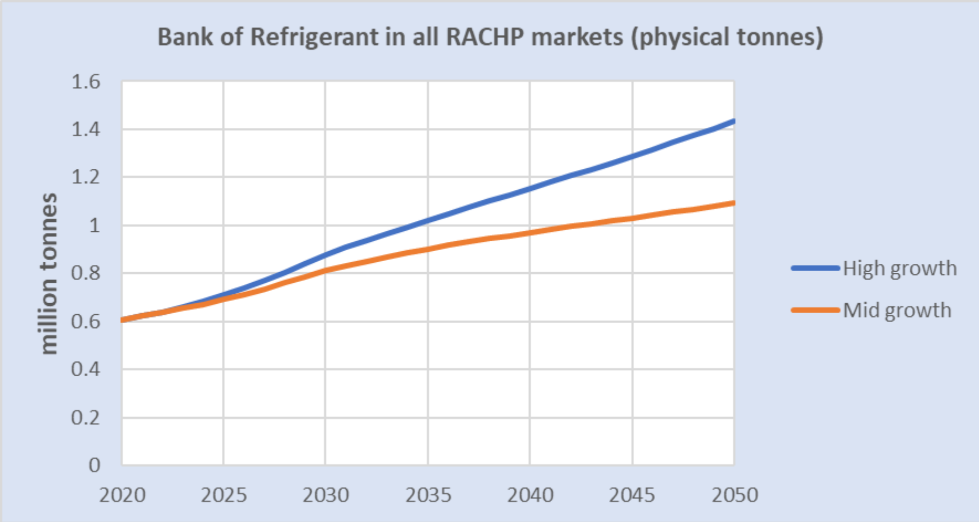


Figure 3: Forecast Growth for Residential Hydronic Heat Pumps



This forecast growth in the stock of RACHP equipment is accompanied by a growth in the refrigerant bank as illustrated in Figure 4, which shows the total RACHP bank in physical tonnes of refrigerant. In the mid-growth forecast the refrigerant bank is expected to grow by 80% between 2020 and 2050.

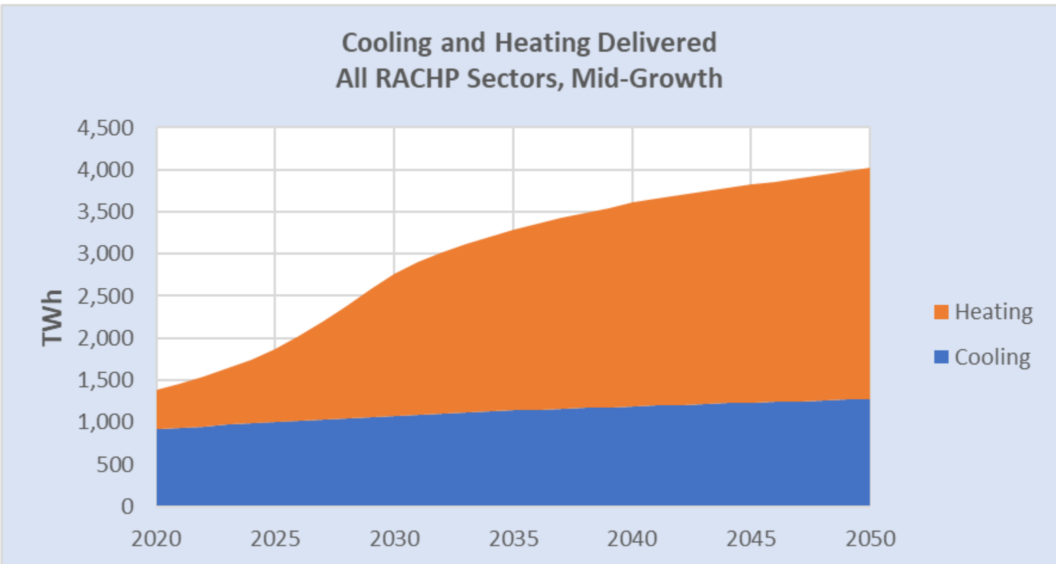
Figure 4: Forecast Growth of Refrigerant Bank



HFC Outlook EU is able to make estimates of the amount of energy used by RACHP equipment and hence to evaluate the GHG emissions created by the energy being used. The start point of these energy calculations is to estimate the usage of the cooling and heating equipment in each sub-sector of the RACHP market. Some types of equipment, such as a domestic refrigerator or an industrial cold storage warehouse, have a very high load factor – as they provide cooling constantly (8 760 hours per year). Other types of equipment can have relatively low load factors. For example, a typical car air-conditioning system is only used for a few hundred hours per year.

Using data about typical usage patterns and the stock of equipment in each market sub-sector, an estimate is made of the total amount of cooling and heating delivered each year. This is measured in TWh of cooling energy or heating energy. Figure 5 shows the likely growth in cooling and heating delivered by RACHP equipment for EU-27. For the mid-growth scenario, cooling delivered is forecast to grow by 40% between 2020 and 2050. The main growth in cooling relates to comfort applications. During the same time period, heating delivered by RACHP equipment is forecast to grow by nearly 600%, driven by the urgent need to decarbonise heating through the use of heat pumps.

Figure 5: Forecast Growth of Cooling and Heating Delivered, All RACHP Sectors, TWh



4. HFC Demand Forecasts for RACHP

Definitions of HFC consumption and demand

HFC Outlook EU uses a bottom-up stock model of all markets using HFCs and makes forecasts of annual HFC consumption and demand from 2000 to 2050. Details of the model are provided in Annex 2. It is important to recognise the distinction between the parameters gross and net consumption and demand used in EPEE modelling:

- **Gross Consumption** is the total quantity of bulk HFC gas required by the EU market, including both virgin and re-used HFCs.
- **Net Consumption** is the quantity of virgin bulk HFC gas required by the EU market. Net consumption is equal to Gross Consumption minus the amount of recovered HFCs that are re-used (through reclaim or recycling).
- **Gross Demand** includes HFCs in imported pre-charged RACHP equipment. Gross Demand is equal to Gross Consumption plus pre-charged equipment imports.
- **Net Demand** is equal to Net Consumption plus HFCs in imported pre-charged RACHP equipment. Net demand has been used by the European Commission since 2017 to assess compliance with the HFC phase down targets in the F-Gas Regulation.

Current EU F-Gas Regulation has an 81% cut in HFC net demand by 2030

The EU baseline (2009 to 2012) and the phase-down in 2015 and 2016 were measured in terms of **net consumption.** The baseline was 183.1 million tonnes CO_2e for EU-28. From 2017 onwards the phase-down is measured in terms of **net demand** as HFCs in imported pre-charged RACHP equipment are included in the phase-down calculations. This change hides the level of ambition in the F-Gas Regulation. EPEE modelling shows that the imports of pre-charged RACHP equipment in the baseline period were 20 million tonnes CO_2e per year, hence the "demand baseline" is 203 million tonnes CO_2e. With an EU-28 2030 target of 38.5 million tonnes CO_2e, this means that the 2030 cut in net demand is greater than the 79% cut specified in the Regulation – it is actually an 81% cut.

Exemptions increase the 2030 phase-down target for RACHP to 88%

The Commission has recalculated the HFC phase-down steps to take account of the exemptions listed in Article 15.2 using the methodology described in Annex V of the Regulation. This methodology places extra burdens on non-exempted sectors. In 2019 the adjustment made for exempted uses was 15.1 million tonnes CO_2e. The Commission used this adjustment to calculate an EU-28 2030 target of 23.3 million tonnes CO_2e for non-exempted uses[9].

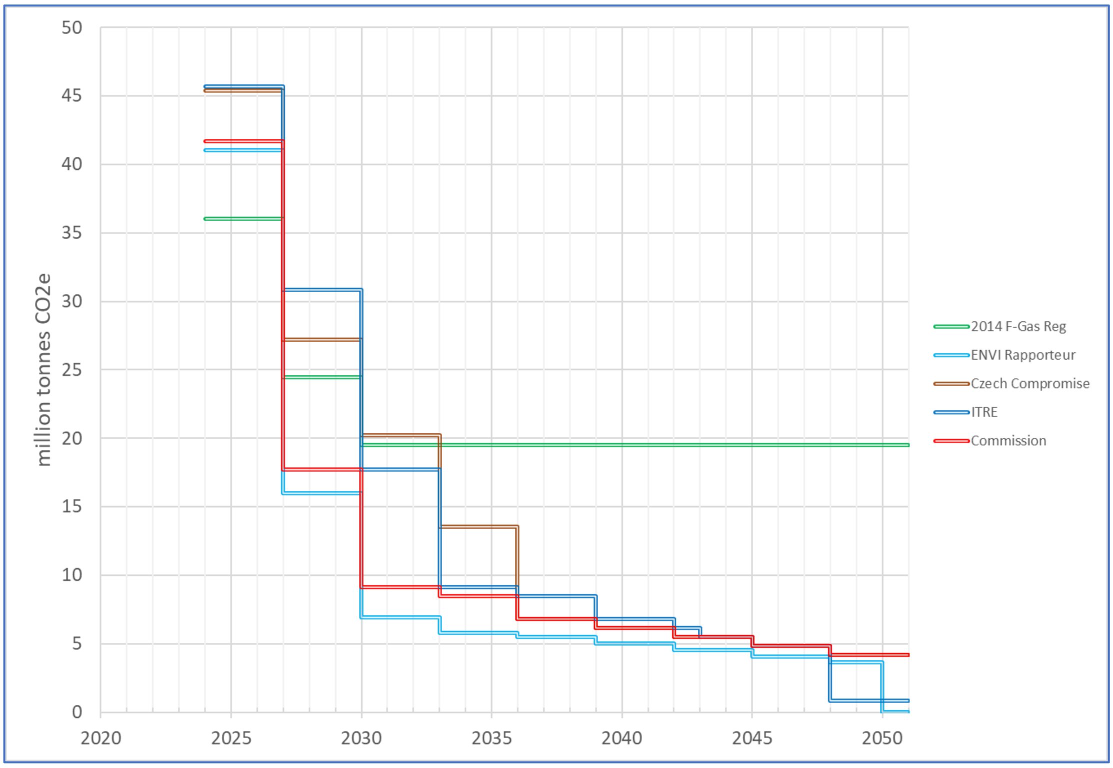
For EU-27 the Commission estimated a reduction of the new baseline value of 176.7 million tonnes CO_2e to 19.9 million tonnes CO_2e in 2030 without exempted uses instead of 37.1 million tonnes CO_2e including exempted uses. This means that the 2030 phase-down target for non-exempted uses is effectively an 88% cut from the demand baseline. In 2030 RACHP will represent almost all of the non-exempted uses and will need to shoulder this considerable burden.

[9] See 2020 EEA Report, Figure 5.1

Phase-down Proposals for F-Gas Regulation Revision

The phase-down schedule for the 2014 Regulation and four alternative proposals are given in Figure 6.

Figure 6: Phase-down Proposals 2024 – 2050, EU-27



All proposals are significantly more ambitious than the current phase-down schedule in the 2014 Regulation. Important aspects to note are:

- The Commission and ENVI Rapporteur proposals require a rapid phase-down in the period 2024 to 2033 and further cuts in the 2030s and 2040s.
- The Czech Compromise and ITRE proposals reach the same level of ambition as the Commission proposal but give industry more time to invest in the required changes in the period 2024 to 2035.
- The 2014 F-Gas Regulation phase-down steps shown in Figure 6 do not include metered dose inhalers (MDIs) which are currently exempted from the phase-down. The four alternative proposals now include MDIs, as the proposals remove the exemption. Current EU use of HFCs for MDIs is around 8 million tonnes CO_2e per year.

EPEE's EU-27 Forecast scenarios

Forecast of future use must account for many important factors

HFC Outlook EU provides forecasts of demand for refrigerants in EU-27, taking account of:

a) The significant growth expected in the bank of RACHP equipment (see Section 3)

b) The important contribution to decarbonisation of heating created by heat pumps (see Section 5).

c) The trajectories for use of lower GWP refrigerants in new equipment that ensure the Energy Efficiency First principle is maintained and that safety is not compromised (see Section 5)

d) The potential to reduce leakage rates and maximise gas recovery and re-use (see Section 6).

EPEE modelling includes a review of a number of possible pathways for the future use of HFCs. In Figures 7 and 8 we present forecasts of HFC Net Demand for two HFC mitigation scenarios:

- **Current technology scenario**: This forecast is based on the technology trajectory that has been influenced by the current 2014 F-Gas Regulation.
- **Future technology scenario**: This forecast is based on an ambitious set of refrigerant choices for new equipment, maximising the amount of non-HFC and low GWP (<150) refrigerants that could be used. Many of the gas choices used in this scenario are not currently available in the EU market and there will be a considerable amount of investment required over the next 8 to 10 years to make these options commercially available.

Current Technology Scenario

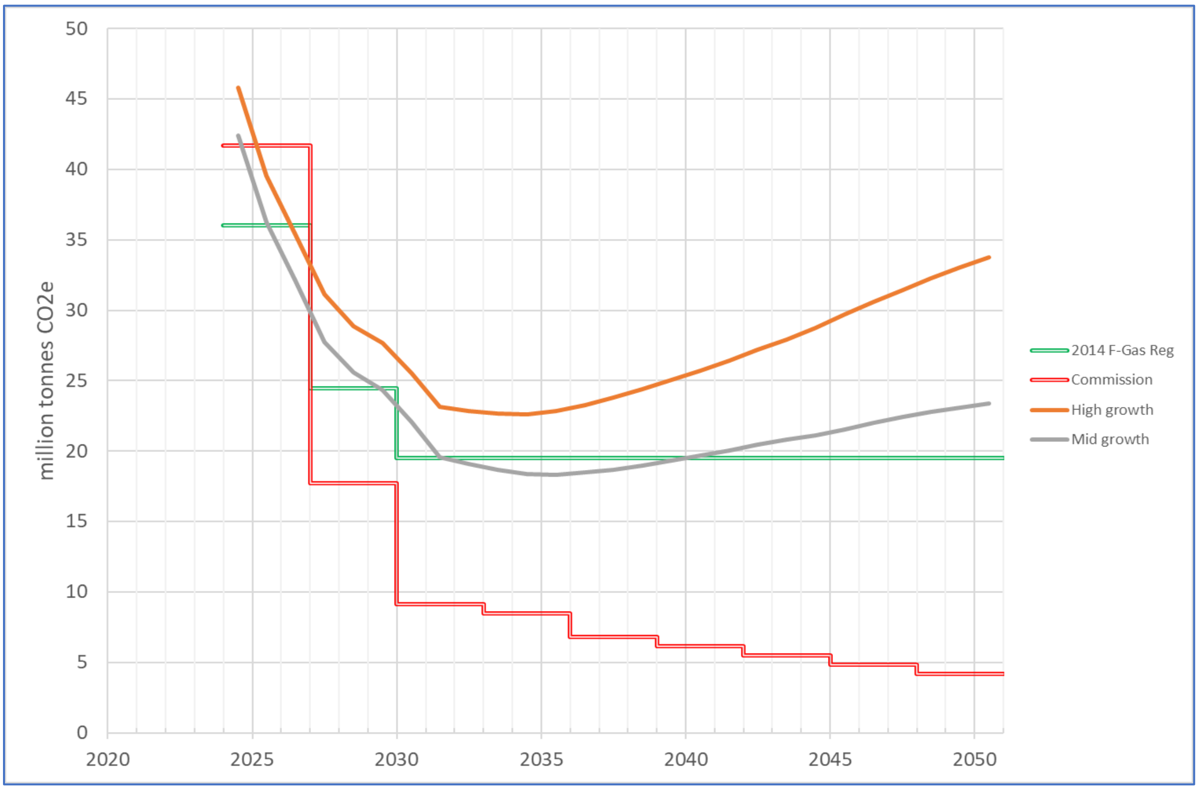
Figure 7 shows net RACHP HFC demand for the **Current Technology Scenario**. The forecasts exclude MDIs which are exempted from the phase-down under the 2014 Regulation. Figure 7 shows that:

a) Allowing for some use of previously banked HFC authorisations, under the mid-growth scenario the forecast predicts compliance with the targets in the current Regulation between 2024 and 2039. However, the growing refrigerant needs for heat pumps mean that there could be non-compliance from 2040 onwards.

b) If market growth is higher than expected (e.g. due to faster roll-out of heat pumps) that the current phase-down is hard to achieve under this scenario.

c) The Current Technology Scenario will not get close to the Commission's revision proposal between 2024 and 2050.

Figure 7: HFC Net Demand Forecast Based on Current Technology Scenario (excluding MDIs)



Future Technology Scenario

Following publication of the Commission proposal in April 2022, EPEE has re-evaluated the possible technology trajectories in each of the 50 technology sub-sectors being modelled. This re-evaluation has taken into account the various influencing factors discussed in Section 5 below.

The Energy Efficiency First principle is of particular relevance, as efficiency has a significant impact on the optimum choice of refrigerant for new equipment. The Future Technology Scenario is intended to minimise energy-related GHG emissions as well as direct refrigerant emissions. To ensure that maximum energy efficiency is achieved, the EPEE Future Technology Scenario includes significant use of HFOs and HFC-HFO blends in some technology sub-sectors.

In some technology sectors (e.g. commercial refrigeration) there is reasonable alignment between assumptions made in both EPEE and AnaFgas modelling. However, in a number of important sectors EPEE analysis shows that the AnaFgas assumptions are unrealistic and different assumptions are used. For example, the AnaFgas modelling assumes a rapid technology transition to 100% propane for residential hydronic heat pumps and the air-to-air split-types below 12kW, at equal cost and equal energy efficiency to fluorocarbon refrigerants. The EPEE model uses different assumptions because it considers the use of propane more limited in application due to safety, energy efficiency and applicability requirements.

Figure 8 shows net HFC demand for the **Future Technology Scenario**. The forecasts include MDIs which are expected to be reintroduced in the HFC phase-down from 2024, based on the new proposals.

Figure 8: HFC Net Demand Forecast Based on Future Technology Scenario (including MDIs)

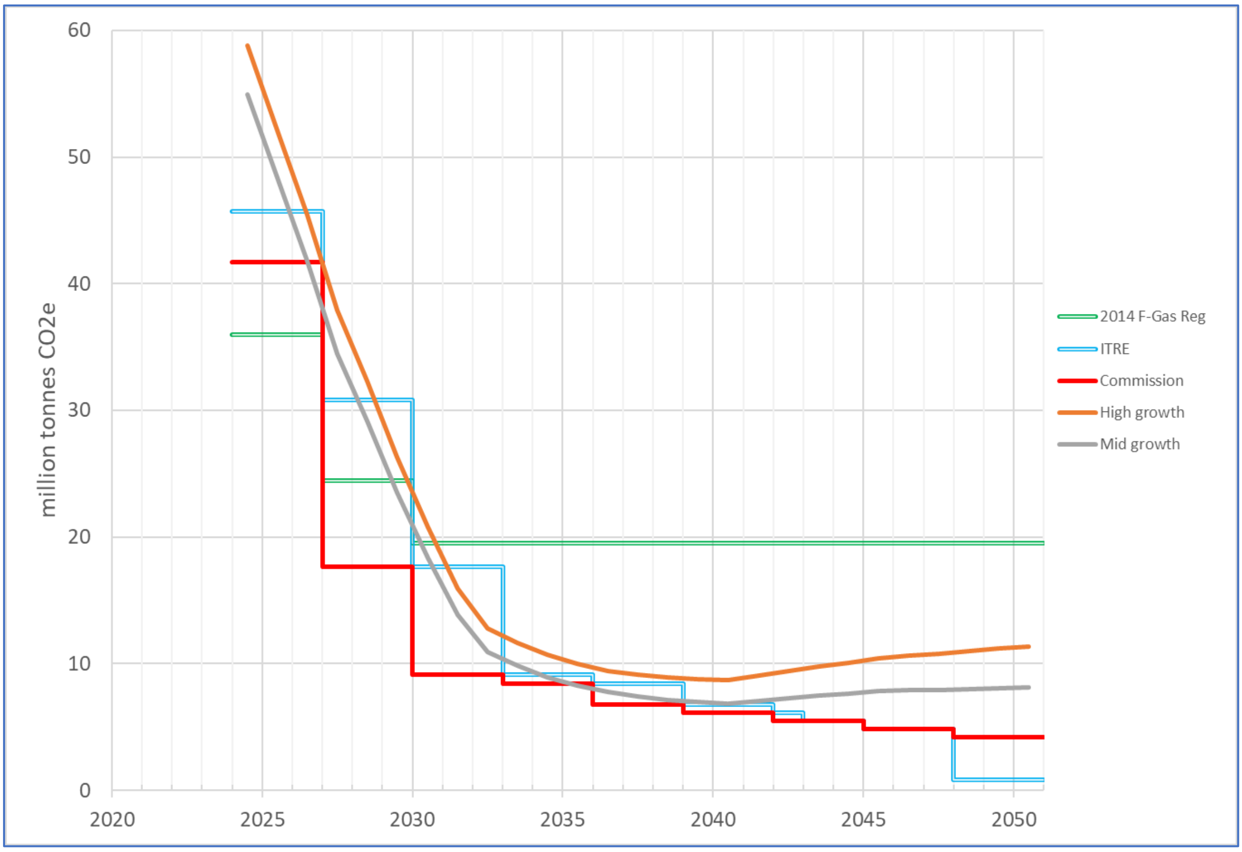


Figure 8 shows that for the Future Technology Scenario:

a) During the period 2024 to 2034 the Commission proposal is impossible to achieve, even with high levels of gas re-use and use of banked authorisations. This is because the technology transition to low GWP refrigerants will take longer than is assumed by the Commission.

b) During the period 2024 to 2034 the Commission proposal is impossible to achieve, even with high levels of gas re-use and use of banked authorisations. This is because in several sectors different technology transitions to lower GWP refrigerants are assumed and the transition time is estimated to take longer than is assumed by the Commission. Also some sectors are included in the EPEE model which are not properly analysed in the AnaFgas model, such as multi-split air to air heat pumps below 12kW, which already represent a high share of the heat pump market (40% on EU level based on EHPA statistics, in some member states the share is up to 80% such as Finland)

c) During this period the ITRE and Czech proposals are closer to our modelled estimates although they are still very challenging.

d) From around 2034 to 2042 the mid-growth forecast under this scenario is in approximate compliance with the Commission proposal.

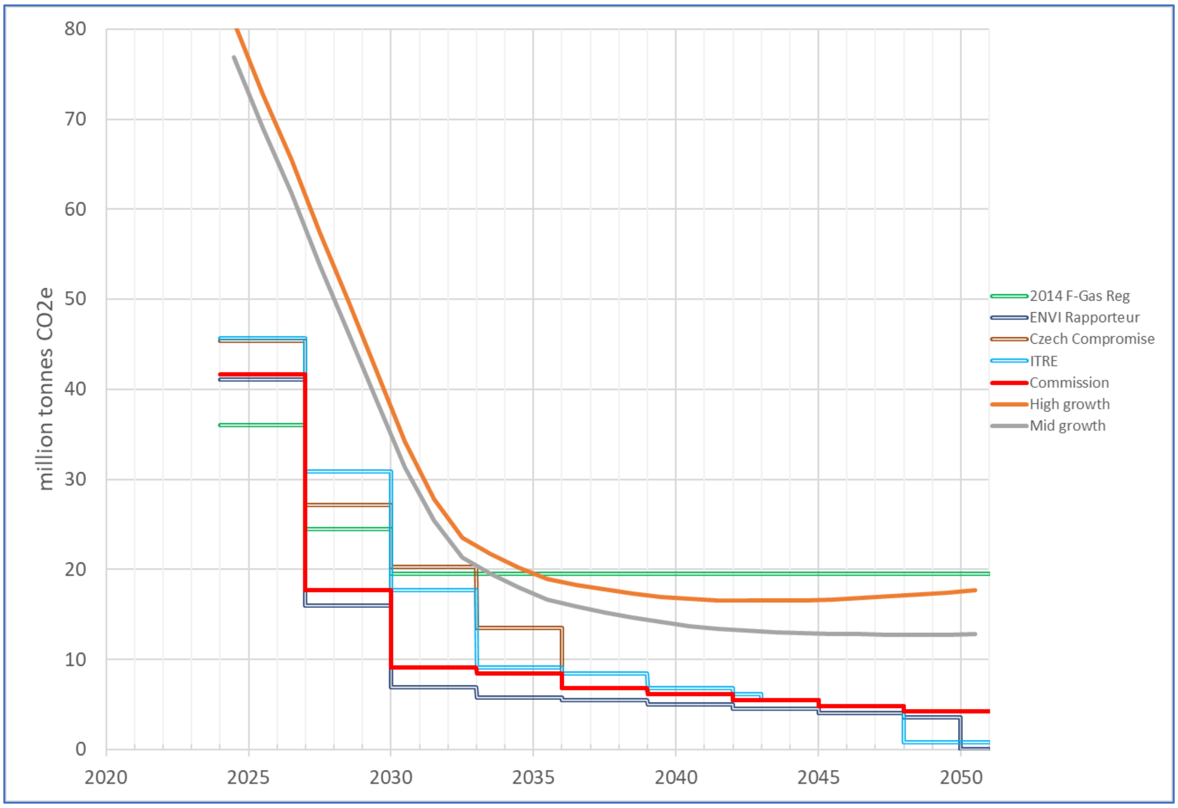
e) From 2042 onwards the mid-growth forecast becomes non-compliant due to continued growth of the heat pump market.

f) Under the high-growth forecast it is more challenging to achieve the Commission proposal.

The net demand forecast takes account of estimates of the re-use of HFCs recovered from RACHP equipment reaching end-of-life. There is significant uncertainty over these gas recovery figures, as discussed in Section 6. Further adding to the uncertainty of the forecast is the potential PFAS restrictions under the REACH Regulation, currently under assessment.

Figure 9 shows the Gross Demand forecast for the Future Technology Scenario. This assumes a worst case in which there is no re-use of recovered HFCs. Figures 8 and 9 clearly show the importance of gas re-use – without it (Figure 9) the proposals are impossible to achieve, but with high levels of gas re-use (Figure 8) the forecast demand for HFCs is fairly close to the Commission proposal between 2034 to 2042. A revised regulation needs to include strong measures to ensure that end-of-life gas recovery rules are complied with and that where possible this recovered gas should be reused.

Figure 9: HFC Gross Demand Forecast Based on Future Technology Scenario (including MDIs, assuming no re-use of HFCs)



5. Factors Influencing HFC Phase-down Trajectories

Heating decarbonization

Most existing heating systems (for building space heating, for water heating and for industrial process heating) use fossil fuels and make a significant contribution to EU CO_2 emissions. The decarbonisation of heating is a crucial aspect of the path to net zero in the EU.

Based on data published by DG Energy[10], around 6,000 TWh of heat was supplied in the EU in 2015. Most of this heat is provided from fossil fuels, mainly natural gas. Figure 10 shows a breakdown of the heat supplied, split by application. Over 70% of this EU heat demand is at a temperature low enough to be supplied using electric heat pumps. This is the most efficient way of providing low temperature heat, as heat pumps make use of "free heat" in a waste heat stream or from the environment (from air, water or the ground). Low temperature heating with heat pumps makes use of renewable electricity with an efficiency that is **6 to 8 times greater**[11] than using that electricity to create green hydrogen and using the hydrogen for low temperature heating.

Around 30% of the heat supplied in the EU is for high temperature process heating (e.g. for manufacturing steel, cement, etc.). This cannot be supplied by heat pumps; other solutions such as hydrogen or direct electric heating are required for these high temperature heat demands.

The heating markets that are well suited to heat pumps include:

a) **Residential**: space heating and sanitary water heating

b) **Service**: Commercial and public sector buildings, space heating and sanitary water heating

c) **Industrial**: low temperature process heating (below 130^{o}C) and industrial building space heating

EPEE estimate that the loads suited to heat pumps represented a total heat demand of about 4,300 TWh in 2015. An important element of the path to net zero will be to reduce these heat demands, for example by improving the levels of building insulation. Figure 10 shows that by 2050 this heat demand might fall to around 3,200 TWh (a 25% reduction from 2015 levels).

HFC Outlook EU includes a rapidly growing stock of heat pump equipment, ranging from small domestic systems to large systems for industrial heating and district heating. Figure 10 includes a forecast of the amount of heat delivered by the heat pumps in the *HFC Outlook EU* model, using the mid-growth scenario. By 2050 we estimate that around 3,000 TWh of heat is delivered with heat pump technology – making a very substantial contribution to decarbonisation of heating.

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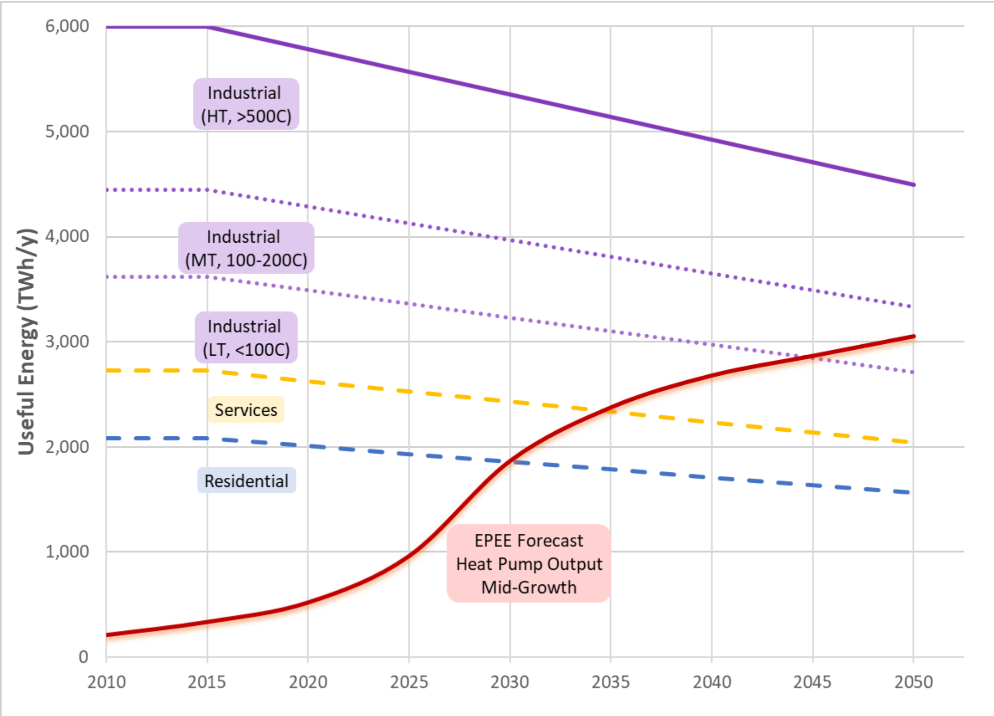
[10] Thermal Heat Demand Figures are taken from the EU Buildings Database, and Heat Roadmap Europe. Demand reduction until 2050 due to energy efficiency are EPEE's own estimates.

[11] https://h2sciencecoalition.com/blog/hydrogen-for-heating-a-comparison-with-heat-pumps-part-1/

Figure 10: EU Heating Requirements (TWh heat supplied) and forecast of heat supplied by heat pumps



To assess the net benefit of using heat pumps it is necessary to estimate the emissions from the installed heat pumps and compare these to the emissions abated by avoiding the use of fossil fuels.

The emissions from heat pumps include (a) the direct refrigerant emissions plus (b) the indirect energy related emissions. The fossil fuel emissions abated depend on the type of fossil fuel used (e.g. natural gas, oil or coal) and the efficiency of the boilers or other heating devices.

Figure 11 shows *HFC Outlook EU* estimates of heat pump emissions and abated fossil fuel. The abated fossil fuel is assumed to be natural gas used in boilers that are 95% efficient (these are conservative assumptions as other fossil fuels emit more CO_2 per kWh than natural gas and 95% efficiency is optimistic). In 2050 it is forecast that:

- 640 million tonnes CO_2e of fossil fuel emissions will be abated.
- The total direct and indirect emissions from heat pumps will only be 5.2 million tonnes CO_2e.

This shows that the abated fossil fuel emissions in 2050 are **120 times greater** than the total heat pump emissions.

In 2030 the benefits are less as there are far fewer heat pumps and the electricity grid is not yet fully decarbonised. Despite the higher grid carbon factor in 2030 and the greater proportion of higher GWP refrigerants, the heat pump benefits (in terms of abated fossil fuel emissions) are still 6 times higher than the direct and indirect heat pump emissions.

This analysis shows it is crucial that the roll-out of heat pumps is not compromised by constraints on the choice of the refrigerant used, which must be selected to (a) maximise efficiency, (b) ensure safety and (c) facilitate rapid roll out. The gas choice trajectories in the EPEE model make use of a range of lower GWP refrigerants (including lower GWP HFCs and HFC blends, HFOs and non-fluorinated refrigerants) to ensure that efficiency and safety are optimised.

Figure 11: Avoided GHG Emissions through use of Heat Pumps[12]

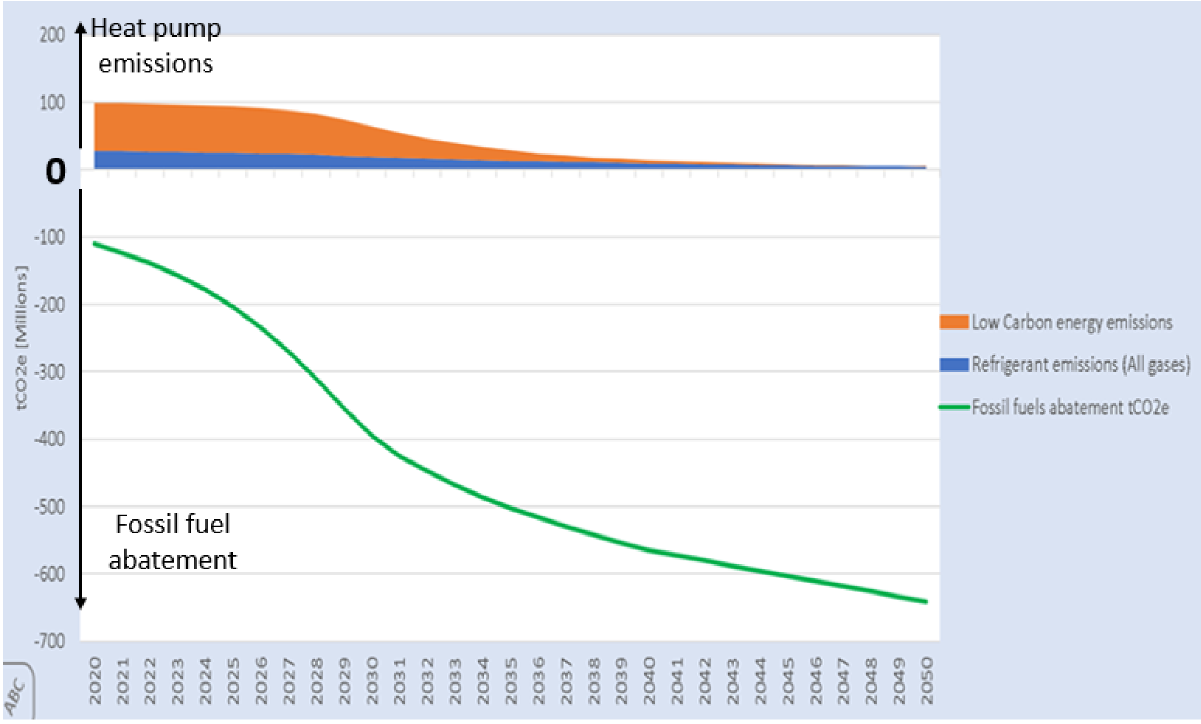
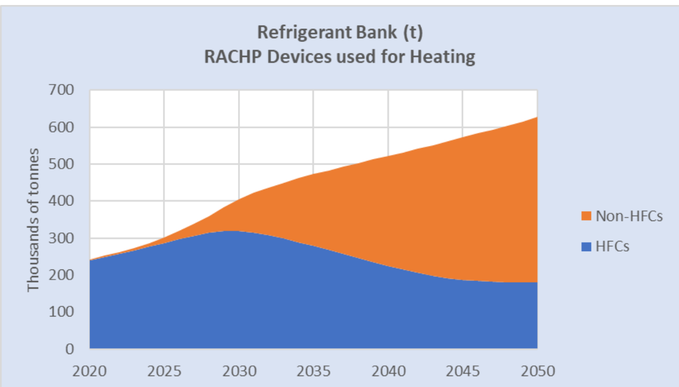


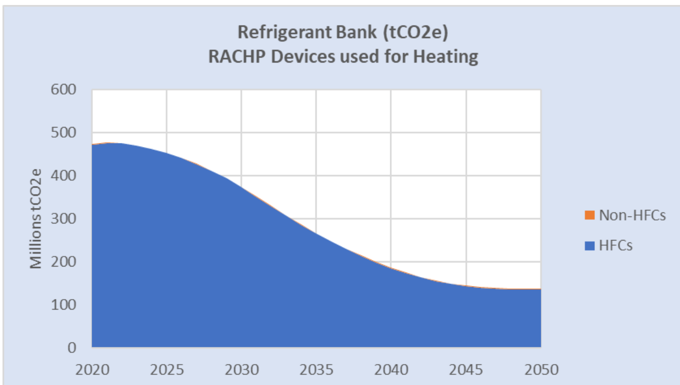
Figure 12 shows the bank of refrigerant used in all equipment that can provide heating; the data is plotted in both physical tonnes and tonnes CO_2e. This includes some "heating-only" heat pumps (e.g. for industrial process heating) but largely includes reversible devices that provide both cooling and heating (e.g. split air-to-air units, VRF systems and hydronic systems). Whilst non-fluorocarbon refrigerants such as propane are suited to small monobloc hydronic heat pumps installed outdoors, HFC and HFC/HFO blends will remain necessary to maximize efficiency and maintain safety in split type hydronic heat pumps, in multi-split air-to-air systems and in monobloc hydronic heat pumps installed indoors.

Figure 12: Refrigerant Bank in RACHP Devices Used for Heating

(a) Physical tonnes



(b) tonnes CO_2e



12 "Low carbon energy emissions" refers to an EU average electricity grid emissions factor that transitions from 0.26 kg CO_2 per kWh in 2020 to zero emissions in 2050.

Figure 12a shows around 30% of the 2050 refrigerant bank (in physical tonnes) for heat pumps will be HFCs and HFC blend components. The remaining 70% will be either non-fluorocarbons (e.g. propane) or HFOs. Figure 12b shows that the 2050 HFC bank in tonnes CO_2e is only 30% of the bank in 2020, despite the fact that amount of heat delivered by heat pumps has risen 6-fold during that period.

Energy Efficiency First

A very important consideration when selecting RACHP equipment is energy efficiency. Minimizing energy demand is a key objective in the EU "Energy Efficiency First" principle. In the growing RACHP market there will be increasing electricity demands that will make the transition to decarbonised electricity more challenging. Minimising the impact of growth of RACHP electricity demand is a key objective. Also, a significant cost to end users of RACHP systems is the lifetime energy cost.

The "Energy Efficiency First Principle" is an important part of the EU policies that support the journey to net zero CO_2 emissions. It means "*taking utmost account of cost-efficient energy efficiency measures in shaping energy policy and making relevant investment decisions. It is a far-reaching guiding principle that should complement other EU objectives, in particular sustainability, climate neutrality and green growth*".

This principle is highly relevant to RACHP equipment as a large part of GHG emissions from RACHP is from the energy used to operate the equipment. The global warming impact of RACHP equipment consists of two main contributions:

a) **Direct emissions**: from refrigerant emitted due to operational leakage or at end-of-life.

b) **Indirect emissions**: from CO_2 emitted by the power stations that supply the electricity used.

To minimise the total global warming impact of RACHP it is essential to consider both these contributions. Efforts to reduce emissions of refrigerants must go hand-in-hand with efforts to maximise energy efficiency through good design and also through good operation and maintenance. This not only minimises indirect emissions, but also minimises peak electrical demand created by RACHP equipment, which reduces the required investment in decarbonised electricity generation. This is a key aspect of the Energy Efficiency First principle.

HFC Outlook EU provides estimates of energy use and the related indirect GHG emissions from RACHP equipment. The model includes scenarios for different levels of energy efficiency improvement. It is assumed that there will be efficiency gains in the future, but the gains achieved depend on the level of ambition and the application of the Energy Efficiency First principle.

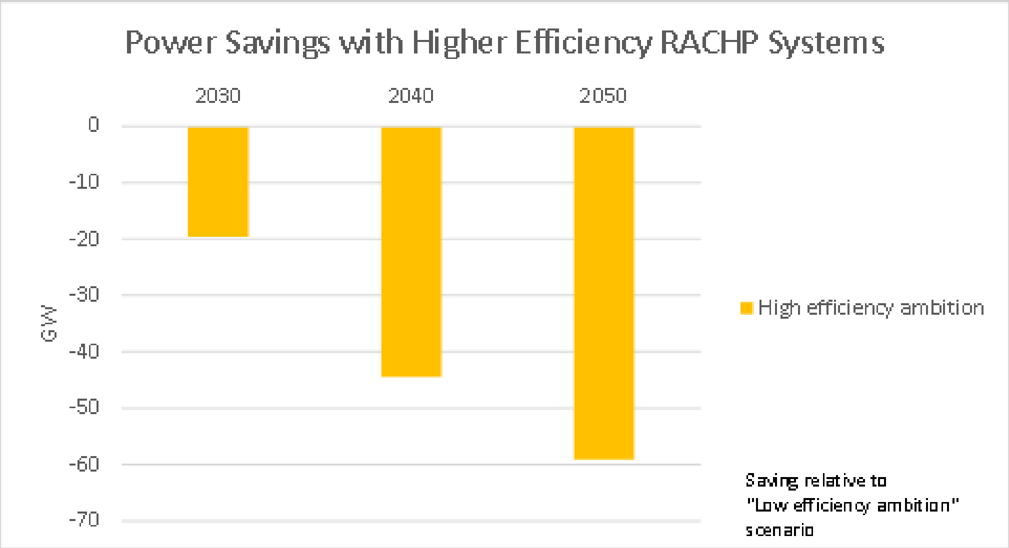
Figure 13 shows an estimate of the power savings that will be achieved if the "high efficiency ambition" scenario is achieved rather than the "low efficiency ambition" scenario in *HFC Outlook EU*. High efficiency gains are needed to achieve the Fit-for-55 targets by 2030 and are considered in the ongoing revision of EU energy efficiency policies, such as the Energy Performance of Buildings Directive (EPBD), relevant product-group implementing regulations under the Ecodesign Directive[13], and the Energy Efficiency Directive (EED).

By 2030 it is estimated that there could be a 170 TWh annual electrical energy saving, equivalent to an average 20 GW power saving. This has a massive impact in terms of indirect CO_2 emissions and electricity costs for end users. It also has a significant impact on the investments required to produce zero carbon electricity. To produce an extra 20 GW would require 20 large nuclear power stations or

[13] Under revision in respect to the Commission's proposal for an Ecodesign for Sustainable Products Regulation (ESPR).

approximately 13,000 wind turbines (each of 5 MW capacity allowing for a 30% wind turbine load factor). By 2050 the average power savings are estimated to be nearly 60 GW.

Figure 13: Savings Achievable Under "High Efficiency Ambition" Scenario



In the switch to lower GWP refrigerants, the EU must maximise the potential for energy efficiency gain. Energy efficiency is one of the key pillars to meet the EU's climate objectives, to ensure that only the necessary energy is produced and stranded investments are avoided. The review of the EU F-Gas Regulation should not contradict this energy efficiency principle. While there are some applications where a combination of non-HFC refrigerant and higher energy efficiency can go together, this is not always the case. This is mainly due to safety considerations that constrain the quantity of flammable and/or toxic refrigerants that can be used in some applications.

A particular concern relates to the efficiency of comfort cooling and heating equipment in all multi-splits and single split air-to-air units in the size range 6 to 12 kW). These parts of the market are expected to grow considerably in response to both the decarbonisation of heating and also the rise in average summer temperatures. The Commission analysis assumes that propane (HC-290) can be safely used for all applications in this size range <u>at equal efficiencies</u> to HFC systems. This view is not supported by data from manufacturers that show that the highest levels of energy efficiency cannot be achieved with propane because of the safety restrictions on the permitted maximum refrigerant charge (see next section) or the complex installations of multi-splits in light of the latest safety standards.

Safety

A crucial factor in the selection of refrigerants is safety. It is essential that refrigerant choice maintains or minimizes the overall level of risk for a RACHP system to an acceptable level. This is relevant to both end users and to technicians supporting the RACHP lifecycle (manufacture, transport, installation, maintenance and end-of-life treatment). All the previously popular high GWP HFC refrigerants (mainly R-404A, R-410A and HFC-134a), which are still in use today, are non-flammable and have low toxicity, as were the CFC and HCFC refrigerants phased out under the EU Ozone Regulation. These refrigerant characteristics simplified the safe design of RACHP used in many applications. Lower GWP alternative refrigerants can bring increased risk related to flammability, toxicity or pressure. This can create barriers to their use in certain applications.

RACHP safety standards, including product standards such as EN 60335-2-40 or EN 60335-2-89 and generic standards such as EN 378 and ISO 5149, recognise the importance of refrigerant flammability and toxicity and set out rules for the maximum refrigerant charge allowed for different types of RACHP application. In relation to flammability, refrigerant designation and classification standard ISO 817 defines four different levels of flammability as shown in Table 2. In product and generic safety standards, the maximum refrigerant charge allowed is greater for non-flammable refrigerants and smaller for higher flammability refrigerants.

Table 2: Refrigerant Flammability Levels

Level	Description	Examples
1	Non-flammable	R-404A, R-410A, R-407C, HFC-134a, R-744 (CO_2), HFO-1336mzz, HFO-1233zd
2L	Lower flammability	HFC-32, R-717 (ammonia), HFO-1234yf, R-454C, R-455A
2	Flammable	HFC-152a
3	Higher flammability	HC-290 (propane), HC-600a (iso-butane)

Whilst flammability is a key issue, other safety issues such as toxicity and high operating pressure are also relevant. Toxicity is defined in RACHP safety codes as either A (low toxicity) or B (high toxicity).

An example of an application specific complexity is the use of flammable refrigerants in high rise buildings. In France, this is currently not allowed. In Italy, higher flammability refrigerants (Level 3) are not allowed in a wide range of public buildings. Some airports and railway stations do not allow any flammable refrigerants in general occupancy areas, which prevents the use of many of the lower GWP alternatives with flammability levels 2L and 3.

RACHP safety standards recognise three occupancy categories, shown in Table 3. They also take into account the system location classification shown in Table 4.

Table 3: RACHP Occupancy Categories

A General Occupancy	B Supervised Occupancy	C Authorised Occupancy
e.g. residences, shops, hospitals, hotels, restaurants	e.g. offices, laboratories	e.g. factories, machine rooms, outdoor locations with limited access

Table 4: RACHP System Location Classification

I All refrigerant containing parts in the occupied space	II Compressor, pressure vessel in machinery room or open air	III All refrigerant containing parts in machinery room or open air	IV Ventilated enclosure
e.g. refrigerators	e.g. split AC, VRF unit, split heat pump	e.g. water chiller, monobloc heat pump	Special design products

The maximum quantities of refrigerant permitted in safety standards for each type of RACHP application take into account many factors including: (1) the occupancy category, (2) the system location classification, (3) the flammability and toxicity of the refrigerant and (4) the volume of the space into which refrigerant could leak. In addition, local legislation, building codes and fire prevention codes may set even stricter standards. Some examples:

a) **Occupancy Category A, System Location Classification I:** Typical examples include residential refrigerators, heat pump tumble driers, movable air conditioners and stand-alone refrigerated retail displays. These usually have very small refrigerant charges in the range of 0.05 to 0.5 kg. The refrigerant circuit is a factory pre-assembled hermetically sealed unit. Use of appropriate safety measures (such as ensuring electrical connections cannot create a spark in an area where refrigerant could leak) allow usage of A2L and A3 flammable refrigerants with acceptable risk.

b) **Occupancy Category A or B, System Location Classification II:** Typical examples are split air-to-air systems for comfort cooling and heating (e.g. single split, multi-split, VRF), split hydronic heat pumps and retail refrigeration display cases connected to a remote condensing unit. These can be single split systems with one indoor unit connected to one outdoor unit or multi-splits where at least two indoor units are connected to each outdoor unit. Indoor units and outdoor units are connected by site-installed pipework. Pipework length can range from a few metres for a single split to more than 100 metres for some complex VRF systems. These systems have refrigerant charge ranging from <1 kg for a small single split to 80 kg for a large VRF. The direct use of refrigerant circulating inside a building in Occupancy Category A or B leads to a limited permitted charge depending on flammability and/or toxicity characteristics and the volume of the space in which the indoor unit is installed. For A3 refrigerants (such as propane) used in these applications the permitted charge is only a few hundred grammes in small rooms, up to a maximum of 980 grammes in larger spaces. Allowed quantities for A2L refrigerants (such as HFC-32 and HFO-HFC blends) are considerably higher, which enables A2L refrigerants used in this type of system to achieve high levels of energy efficiency in much larger sizes than for A3 refrigerants. Due to their direct heat exchange design, air-to-air split and VRF systems offer higher energy efficiency potential than alternatives such as chilled water systems.

c) **Occupancy Category C, System Location Classification III:** Typical examples are monobloc hydronic heat pumps located outdoors and water chillers used for comfort cooling and heating or for process cooling. These systems can have refrigerant charge ranging from <10 kg to >1000 kg. The fact that all refrigerant containing parts are located in a machinery room or outdoors in authorised occupancy areas makes it easier to cope with flammable or toxic refrigerants. It should be noted that although refrigerant charge is less restricted, several requirements are set to ensure safety such as avoidance of leakage to occupied spaces, exclusion of ignition sources, fencing and restricted access, ventilation, leak detection and alarms for machinery rooms. The maximum allowed charge for propane is just below 5 kg per circuit.

A mandatory certification system for refrigerant handling does not yet exist for HFO or non-fluorinated refrigerants, which increases safety risks and the potential for poor energy efficiency. Equipment manufacturers and importers have a duty to place safe products on the market, but in many cases are not able to control who will do the final installation, servicing and end-of-life treatment of the equipment (which can be many years after the first sales). This is an important market barrier for introducing non-HFC alternatives, which could be partially addressed by a mandatory certification system that covers non-HFC alternatives (see Section 6).

Impact of market sector granularity on the refrigerant transition

It is important to recognise the complexity of the RACHP market when making decisions about HFC phase-down ambition and supporting policies such as bans. These complexities include general factors such as equipment size and application-specific factors such as use of equipment in sensitive locations. If these complexities are ignored, there is a risk that policies lead to unintended consequences and the need to make provision for exemptions.

An example of a general factor is the over-simplification of a sector such as industrial refrigeration. The 2022 Oeko Recherche Impact Assessment[14] uses 2 sub-sectors ("small" and "large") to represent industrial refrigeration and goes on to state that refrigerants such as ammonia or CO_2 could be used for all industrial systems. Small is defined as 270 kW. EPEE does not consider this size to be representative of small industrial systems as many industrial systems are well under 50 kW. Ammonia is an excellent refrigerant for large industrial systems and has been widely used throughout the last 100 years, but it is not suitable for small industrial systems. The industrial sector has equipment ranging in size (in terms of cooling capacity) from <10 kW to >1000 kW. Industrial refrigeration systems are used for a wide range of temperature levels from -80°C to >20°C. With such a large size range of temperature and capacities it is not surprising that different refrigerants are required for different equipment sizes and that HFCs or HFO-HFC blends could provide the most energy efficient option for small systems.

Another important market over-simplification is for split air-conditioning systems used in residential and commercial buildings. Again, the size range is significant, from around 1.5 kW to over 100 kW. The size affects the amount of refrigerant required and hence the risks associated with each refrigerant type. Furthermore the Commission analysis makes no distinction between single splits (where the system is built with one single indoor unit and a refrigerant charge proportional to the single cooled space) and multi-split systems (where the system is built with several indoor units serving different spaces and where the system total charge is proportional to the sum of all conditioned spaces and the complex piping network connecting them to the outdoor unit). The maximum charge allowed for a flammable refrigerant will be dictated by the smallest space served with an indoor unit – this makes it very difficult to use A3 refrigerants in any size of multi-split system.

Any categorisation will hide some of the complexity of the RACHP market, but sufficient sub-categories need to be considered, to ensure that policies take account of the most important "intersections" of size and application. The EPEE model uses 8 main RACHP market sectors and splits them into 40 RACHP technology sub-sectors to create reasonable granularity. Tables 5 and 6 summarise characteristics and transition pathways for refrigeration sub-sectors and for comfort cooling and heating sub-sectors. For the purposes of this summary document, we have slightly simplified the categories by aggregating the sub-categories for frozen and chilled refrigeration applications, hence there are only 31 RACHP sub-sectors shown in Tables 5 and 6.

While this kind of granularity in the *HFC Outlook EU* model helps to estimate the future HFC needs, in reality, even 40 sub-sectors is a considerable simplification of the market. There is a continuous spectrum of RACHP solutions from the smallest to the largest and a range of application-specific and location-specific issues that can constrain refrigerant choice in some circumstances. In addition, new design solutions are still evolving (for example: multifunctional solutions which combine comfort cooling/heating with refrigeration and/or hot water production; hybrid heat pumps; electric car heat

[14] Support contract for an Evaluation and Impact Assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gas, CLIMA.A2/ETU/2019/0016 Impact Assessment Final Report – ANNEXES 14 March 2022

pumps). Hence, Tables 5 and 6 are not suitable for defining policy measures for a particular technology sub-sector as in reality the boundaries are not so clear. However, the tables provide a good insight into the general trajectories for the refrigerant transitions that can be expected to take place as the HFC phase-down continues to reduce the GWP-weighted quantities of HFCs available on the EU market.

Shifts to lower GWP alternatives are reflected in *HFC Outlook EU* and they create a very significant cut in HFC consumption by 2030. The timing of the shifts vary, based on the availability of suitable commercially available equipment. For example:

a) The use of HC-600a in new residential refrigerators was already widespread by 2010 and by 2030 there are virtually no HFC-134a refrigerators left in the installed bank.

b) In the car air-conditioning sector, the big shift away from HFC-134a to HFO-1234yf in new cars occurred in 2016 / 2017. There will still be a demand for servicing existing cars with HFC-134a for the next decade, but by 2030 most passenger cars on the road will be using non-HFCs such as HFO-1234yf.

c) As shown in Table 6, for water chillers there are already a number of lower GWP alternatives, so the trajectory leads to considerable reductions in HFC usage.

d) For hydronic heat pumps we expect massive market growth as discussed in Section 3. Whilst some of this growth can use propane (in particular, certain monobloc air-to-water systems provided that relevant installation conditions are met), the optimum refrigerant choice for split units (to maximise efficiency and safety) or monoblocs installed indoors is a lower GWP HFC or HFC/HFO blend. Hence we predict growth of lower GWP HFC use in these market sub-sectors.

e) For air-to-air split units used for both cooling and heating there will be some use of propane in small systems, but HFCs and HFC/HFO blends will be needed to maximise efficiency and meet safety requirements in small, medium and large sized single splits and in nearly all multi-split, VRF and rooftop systems.

Table 5: Review of Refrigeration Sub-Sectors

Main Sector	Sub-sector	Reference Gas[15]	Cooling Capacity kW		Refrigerant charge kg		Comments and Transition Pathways
			Nominal[16]	Range[17]	Nominal[12]	Range[13]	
Residential refrigeration	Refrigerators and freezers	HC-600a	0.2	0.1 - 0.5	0.05	0.03 - 0.15	Small and medium size factory made units. Often hermetically sealed, already using ultra-low GWP HC-600a and HC-290.
Commercial refrigeration	Stand-alone units	R-404A	0.8	0.5 - 3	0.25	0.2 – 1	
	Condensing units	R-404A	5	1 - 20	4	1 – 20	Usually located in general occupancy areas. Widespread use of CO_2 in central systems and CO_2 condensing units becoming available. Efficiency during warmer outdoor temperatures is a challenge. New A2L HFO/HFC blends with GWP < 150 are well suited to condensing units and small central systems.
	Central systems	R-404A	75	20 - 200	150	20 – 400	
Transport refrigeration	Vans, light trucks	R-404A	3	2 - 5	1.5	1 – 3	R-452A (GWP 2140) has become widely used in place of R-404A (GWP 3922). There is relatively slow progress towards other lower GWP options. Special rules related to flammable refrigerants and cooling performance apply to transport e.g. (UN ATP rules).
	Trailers, containers	R-404A	9	5 - 15	6	3 – 10	
Industrial refrigeration	DX[18] small	R-404A	25	10 - 50	40	15 – 70	Most industrial equipment can be in authorised occupancy locations, giving scope for the use of flammable refrigerants. Ammonia is safety class B2L. It is used in large systems in factory locations – the 2L flammability is not a constraint. The size spectrum for industrial systems is very wide. Small food processing operations often use several small DX systems. These are not suited to ammonia. CO_2 is a possibility, although due to the wide range of sizes and temperatures required, there is not much suitable CO_2 equipment available for small and medium DX industrial applications. New A2L HFO/HFC blends with GWP < 150 are well suited to small and medium sized industrial applications.
	DX medium	R-404A	100	50 - 300	140	70 – 400	
	DX large	R-404A	400	300 - 750	500	400 - 1000	
	Flooded systems	R-717	1000	500 - 5000	3000	1000 - 5000	
	Chillers medium	HFC-134a	200	100 - 500	100	50 – 250	
	Chillers large	HFC-134a	1000	500 - 5000	500	250 - 2000	

[15] The reference gas is the most commonly used gas in 2014, before the impact of the EU F-Gas Regulation

[16] The nominal cooling capacity and refrigerant charge is the value used for each technology sub-sector in the *HFC Outlook EU* model.

[17] The range of cooling capacity and charge indicates the overall size range of each technology sub-sector

[18] DX refers to direct expansion systems

Table 6: Review of Comfort Cooling and Heating Sub-Sectors

Main Sector	Sub-sector	Reference Gas[7]	Cooling and/or heating Capacity kW		Refrigerant charge kg		Comments and Transition Pathways
			Nominal[12]	Range[13]	Nominal[12]	Range[13]	
Comfort heating and cooling Stationary applications Direct	Stand-alone	R-410A	2.5	2 - 3	0.5	0.3 - 0.7	Movable units already subject to >150 GWP ban and most now use HCs.
	Split systems small	R-410A	3.5	2 - 5	1.2	0.7 - 1.5	Usually located in general occupancy areas. Significant size range for single split and small multi-split systems. There will be some use of HC-290 (propane) in small systems, but HFCs and HFC/HFO blends will be needed to maximise efficiency and meet safety requirements in small, medium and large systems. For small systems energy efficiency is an important consideration – the charge limitations for A3 refrigerants like HC-290 are likely to restrict efficiency improvements.
	Split systems medium	R-410A	7	5 - 10	2.5	1.5 - 4	
	Split systems large	R-410A	14	10 - 20	5.5	4 - 8	
	Split systems ducted	R-410A	7	5 - 15	2.5	1.5 - 5	
	Roof-top units small	R-410A	25	10 - 50	6	3 - 13	Usually located in general occupancy areas. RTUs and VRFs are too large to allow direct use of A3 refrigerants. A2Ls are already being used in small RTUs and small VRFs. There is significant on-going development work to extend the size range for using A2Ls through the use of "additional safety measures" that are defined in safety codes. Switching to water chillers leads to a loss of energy efficiency in this size range. Chillers are more appropriate for larger cooling loads.
	Roof-top units large	R-410A	150	50 - 250	40	13 - 60	
	VRF systems small	R-410A	40	20 - 60	20	10 - 30	
	VRF systems large	R-410A	100	60 - 150	50	30 - 75	
Comfort heating and cooling Stationary applications Indirect	Water chillers small	R-410A	100	50 - 200	30	15 - 60	Chillers are usually located in authorised occupancy areas. There are 3 different technologies used for chillers. Small chillers and some medium chillers currently use high pressure refrigerants such as R-410A. Use of HFC-32 and HFO/HFC blends is now common. Large chillers use medium pressure refrigerants and very large chillers can use low pressure refrigerants. A range of ultra-low GWP refrigerants are already used in chillers including HFOs, ammonia and propane.
	Water chillers medium	HFC-134a	400	200 - 800	150	60 - 250	
	Water chillers large	HFC-134a	1200	800 - 2000	700	250 - 1200	
	Water chillers very large	HFC-134a	2500	2000 - 5000	1500	1200 - 3000	
	Hydronic HPs, domestic	R-410A	10	5 - 30	5	2 - 10	Some hydronic heat pumps (e.g. air source monobloc domestic sized systems) are located outdoors. Monobloc ground source heat pumps are mostly located indoors. Other hydronic heat pump types are of a split design, with an outdoor unit and an indoor refrigerant condenser in what is usually a general occupancy area. HCs are becoming used in air source monobloc designs and rarely in ground source monoblocs. A2L blends are suited to ground source monobloc and split systems.
	Hydronic HPs, small	R-410A	50	30 - 100	15	10 - 30	
	Hydronic HPs, medium	R-410A	150	100 - 300	50	30 - 100	
	Hydronic HPs, large	HFC-134a	500	300 - 2000	150	100 - 750	
Mobile air-conditioning	Cars, vans, trucks	HFC-134a	4	3 - 6	0.6	0.4 - 0.8	HFC-134a banned from 2017. HFO-1234yf already in widespread use.
	Buses, trains, ships	HFC-134a	25	10 - 50	10	4 - 25	Rules for transport applications might limit use of flammables.

f) In commercial refrigeration the picture is more complex. Equipment varies in size from very small units (capacity <1 kW) to large central systems (capacity >100 kW). Two distinct temperature levels are required (for chilled and for frozen products). This has led to a quite varied range of equipment designs and refrigerants to suit the different application and design requirements. The market for new installations has moved away from R-404A and HFC-134a, through a number of lower GWP transitional refrigerants to a future where R-744 (CO_2), HC-290 (propane) and HFC-HFO blends with a GWP under 150 are the dominant refrigerant choices.

Figure 14 illustrates the forecast trajectory for the bank of refrigerants in commercial refrigeration, using the Future Technology Scenario. The total refrigerant bank in this fairly mature market sector is expected to grow by 17% between 2020 and 2050, in terms of physical tonnes of gas. However, in terms of tonnes CO_2e the bank falls by 99% due to the modelled refrigerant transition.

Figure 14: Transition of Refrigerants for Commercial Refrigeration

(a) tonnes (b) tonnes CO_2e

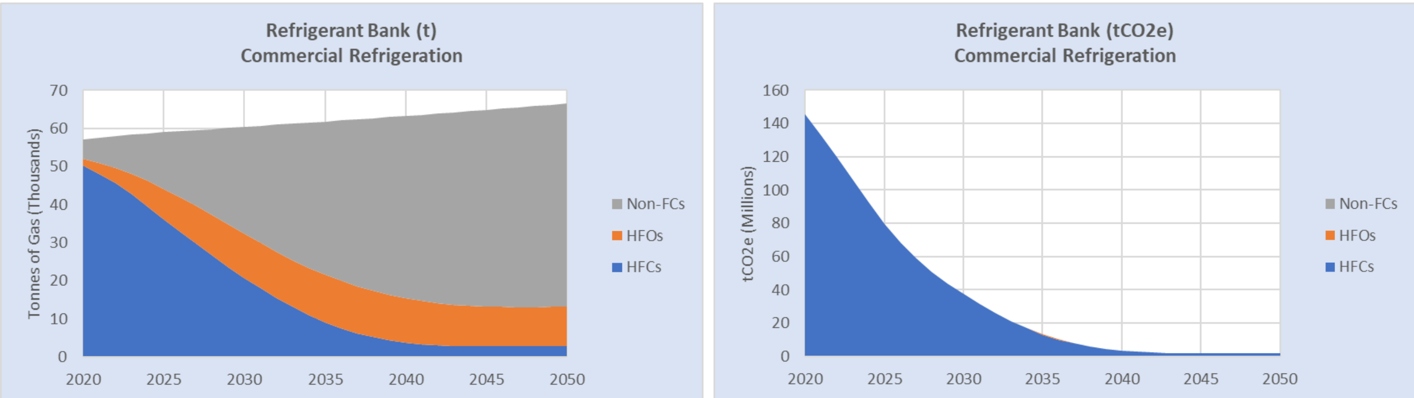
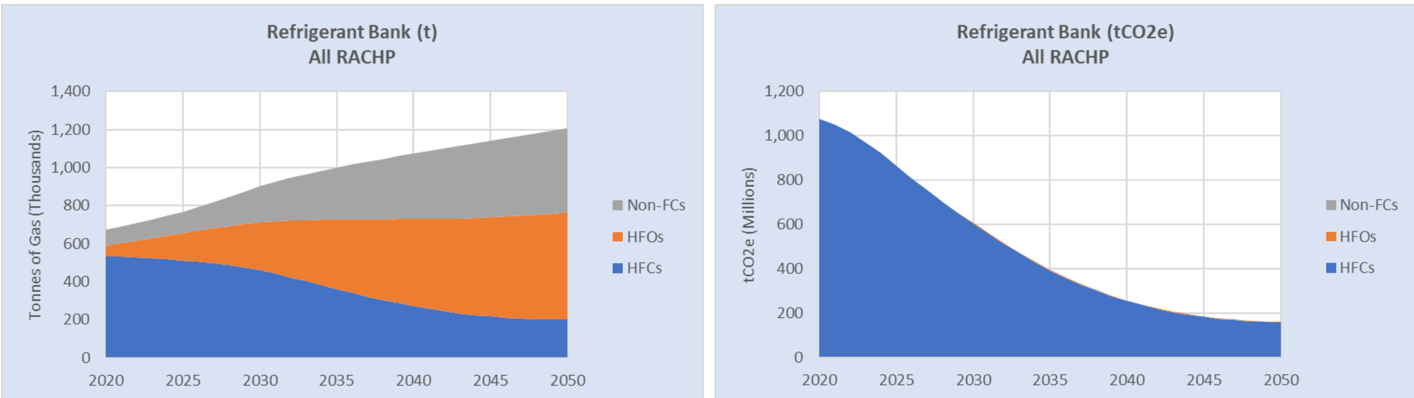


Figure 15 shows a similar forecast for the bank of refrigerants for all RACHP sectors, using the Future Technology Scenario. In physical tonnes the bank grows by around 80% between 2020 and 2050, the growth being mainly driven by the heat pump and comfort cooling sectors. Despite this significant growth, in terms of tonnes of CO_2e, the bank falls by 85%.

Figure 15: Transition of Refrigerants for all RACHP Sectors

(a) tonnes (b) tonnes CO_2e



Pre-charged product exports

To ensure a fair and equal treatment of equipment and product manufacturers inside and outside the EU, the EU F-Gas Regulation envisaged to treat pre-charged equipment the same way as bulk gas: imported pre-charged equipment are included in the phase-down quota since 2017 while all the exports of pre-charged equipment would be exempted from the HFC phase-down quotas. However, in practice, the EU Commission made the exemption of pre-charged equipment exports only partially possible by using the Inward Processing Relief (IPR) customs procedure, which presents certain limitations concerning its actual application and therefore not all EU factories can use it. The EU F-Gas Regulation revision creates the opportunity to simplify and facilitate the existing exemptions, as well as to add measures that support European manufacturers to maintain their production in the EU. If exemptions cannot be used in practice, the HFC quota needed will be higher.

Additionally, several non-EU countries have their own F-Gas Regulation in place (e.g. UK, Turkey) and include imports of pre-charged equipment in their own quota system. Hence, if exports of pre-charged equipment are not excluded from the EU F-Gas Regulation, there is double counting of HFC quota. To ensure a fair situation for EU manufacturers exporting to these countries, export of pre-charged equipment should be fully excluded or another type of bilateral agreement needs to be made between such countries to avoid double counting.

A stricter phase down with no or limited exemptions for product exports weakens the competitiveness of the EU industry in the export market. It is important to note here that we are not necessarily referring to exports of the higher GWP solutions – although such export demand exists as long as the non-EU countries do not have an equally ambitious HFC phase down regime. We would like to stress that the EU industry also needs to be able to export products with lower GWP HFCs or HFO-HFC blends. If the EU wants to be a world leader in decarbonized cooling and heating solutions, we should also be able to export those solutions to other countries.

The export market often fluctuates, hence it is difficult to predict the future growth. There is only one certainty: if the phase down becomes so strict that no HFCs would be available for producing equipment inside the EU, the only option for the EU industry is to relocate their manufacturing to non-EU countries where sufficient HFCs would still be available.

Brexit impact

The Commission has made adjustments to the phase-down schedule to take Great Britain (GB) out of the EU phase-down process (Northern Ireland remains in the EU HFC phase-down to enable free trade with the Republic of Ireland). The modelling for *HFC Outlook EU* assumed that GB represented 10% of EU-28 in case of the RACHP sector.

An important issue that needs consideration during the F-Gas Regulation review is trade with GB. Prior to Brexit there was significant trade between GB and EU-27 for both bulk HFCs and pre-charged equipment containing HFCs. It is important that this trade is allowed to continue without burdensome administrative procedures and without the impact of double regulation because the HFC use is controlled in both the EU phase-down and the GB phase-down.

6. Other Opportunities to Reduce HFC Emissions

Gas recovery and reuse

The ultimate goal of the EU F-Gas Regulation is to reduce emissions. An important measure that has been in force since the 2006 Regulation is the requirement to recover refrigerants from RACHP equipment during servicing and at end of equipment life, and treat this recovered refrigerant properly, through recycling, reclamation, conversion or destruction.

The EEA data reports on gas destruction and gas reclaim are not sufficient to judge whether the EU F-Gas Regulation rules for gas recovery at end-of-life and during servicing are being properly complied with. In the period 2015 to 2019 the EEA report the following quantities:

a) **HFCs destroyed**: average of 8 million tonnes CO_2e per year, of which around 75% is HFC-23[19]. This means that around 2 million tonnes CO_2e per year of the four main HFCs used in RACHP (R-404A, R-410A, R-407C and HFC-134a) are reported as being destroyed.

b) **HFCs reclaimed**: average of 3.5 million tonnes CO_2e per year reported as being reclaimed (earlier years showed higher values for EU-28 up to 4.8 million tonnes CO2e per year; the drop is due to a UK reclaimer that was no longer obliged to report). The average GWP of gases reclaimed is 2,500 which is consistent with the four main HFCs listed above being reclaimed.

HFC Outlook EU forecasts the quantity of HFCs available for recovery each year – this is based on the quantity of HFCs banked in old equipment reaching end-of-life and also any HFCs that are being retrofitted with a lower GWP alternative. The annual average forecast of gas available for recovery in period 2015 to 2019 is 52 million tonnes CO_2e. The EEA reports indicate an average of only 5.5 million tonnes CO_2e per year being either destroyed or reclaimed – which is only about 10% of the amount of gas that could be available for recovery. Note, this excludes the destruction of HFC-23 which is not modelled in *HFC Outlook EU*. This discrepancy can be explained in three different ways:

1) The amounts being destroyed or reclaimed are significantly under-reported, because not all entities that do destruction or reclamation have a reporting duty or because some destruction facilities are unaware of their reporting responsibilities.
2) A significant amount of gas is being recycled and reused by contractors (who do not need to report to the EEA)
3) Refrigerant is being emitted at end-of-life, in contravention to the gas recovery requirements specified in the EU F-Gas Regulation and EU MAC Directive.

It is likely that all of the above are occurring, but the weighting between them is very hard to estimate. High levels of gas recovery and re-use should be considered best practice, creating compliance with the gas recovery rules and using the circular economy to supply reclaimed HFCs that might otherwise have been emitted. The phase-down regime and subsequent refrigerant price increases have already incentivised the market to re-use refrigerants. It is important that the Commission and Member States consider ways to ensure that gas recovery is maximised. Improved reporting is vital and better interaction with other policy mechanisms such as WEEE and EU waste legislation should be used to try and close the 90% gap illustrated in the analysis above.

Web-based electronic logbooks

Article 6 of the 2014 F-Gas Regulation requires various records to be kept by both end users and RACHP contractors. Record keeping applies to RACHP equipment above a 5 tonnes CO_2e threshold. No format for

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[19] HFC-23 is a by-product of HCFC-22 production and is destroyed at all EU HCFC-22 production plants.

records is specified and records do not need to be passed to a Competent Authority unless requested. It is possible that the quality of record keeping is very poor.

A few Member States have implemented electronic centralised reporting databases (e.g. Poland, Hungary, Italy) while in some countries contractor associations have set up their own voluntary initiatives (e.g. UK, Germany). These ensure that good records are kept and provide significant benefits to support compliance checking and also to provide a platform for the analysis of data that would be of enormous help to the RACHP industry, to DG CLIMA and to Member State Competent Authorities.

EPEE support the mandatory use of web-based electronic reporting systems. These could be mobile phone apps to be used on a regular basis by service technicians to record the required data. A system that is harmonised across the EU would provide the best results. Some of the most valuable data that could become available through analysis of large quantities of electronic records would be a much improved understanding of:

a) Leakage rates from different sub-sectors of the RACHP market.

b) Gas recovery rates.

c) The destination of recovered gas (i.e. re-used as recycled, sent for reclaim or sent for destruction).

EEA Reporting Gaps

The discrepancy between modelled estimates of gas available for recovery and reported data for reclaim and destruction could be improved with better reporting obligations. In particular:

a) All reclaimers should be required to report. Currently only companies that are importers or producers of bulk HFCs need to report reclaimed HFCs.

b) Efforts should be made to ensure that all destruction facilities are aware of the obligation to report F-Gas destruction. The low quantities reported could mean that not all destruction facilities are aware of this obligation.

c) There is no obligation to report recycled gas. Getting more data on recycling would be very helpful. One option would be to include recycling in reporting requirements under Article 19, but this could create a big administrative burden as the number of small RACHP contractors that would need to submit an annual report would be very high. EPEE recommend that analysis of recycling is done via the mandatory use of web-based reporting of records under Article 6.

Reducing refrigerant leakage

HFC Outlook EU forecasts show that leakage represents a significant proportion of HFC consumption. Figure 16 shows a forecast of the average leak rate from all RACHP equipment. It shows how both the 2006 and 2014 F-Gas Regulations have led to significant reductions in leakage rates and that continuing leak reduction is possible.

The available national data do indicate a significant improvement in leakage rates. Table 7 gives a summary of the available data and although not complete, shows the positive evolution.

It is crucial that the measures in the EU F-Gas Regulation that help to reduce leakage are strengthened across Europe, as leakage reduction is an effective action to reduce HFC consumption and emissions. Reduced leakage is also likely to lead to improved energy efficiency and reduced energy-related GHG emissions. As discussed above, the current end user record keeping requirements could be strengthened by requiring use of an electronic reporting database. This could provide powerful information about leakage rates that would be available to support initiatives to reduce leak rates.

Figure 16: HFC Leakage Rates, Future Technology Scenario

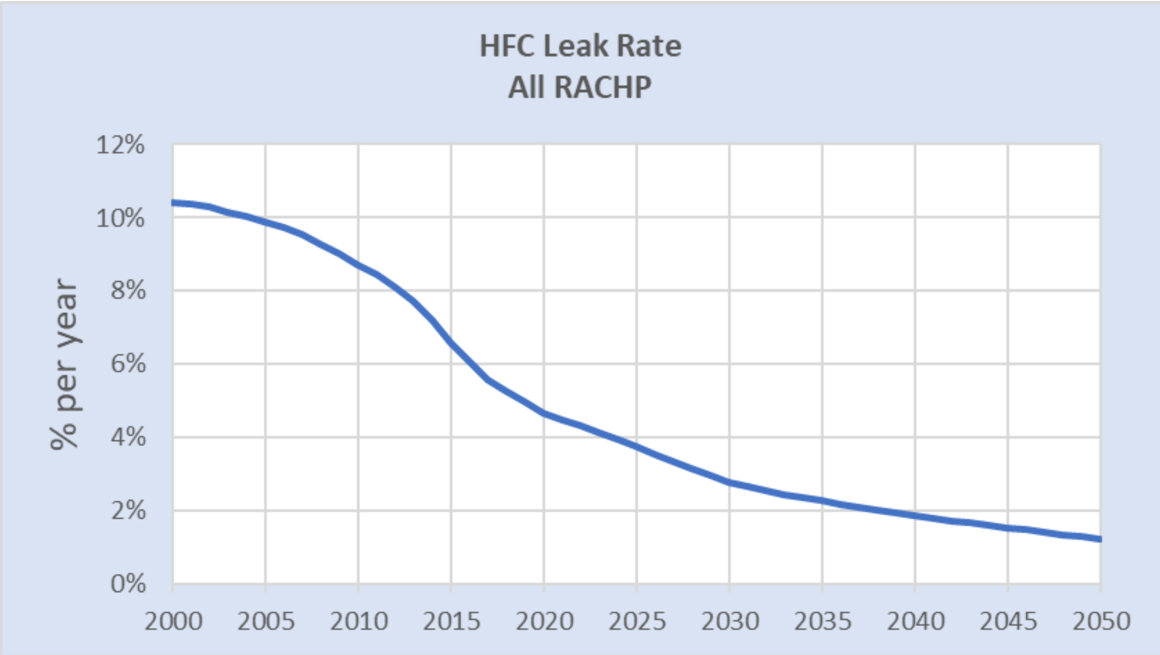


Table 7: Leakage rates evolution according to electronic logbooks sources

Product group		Data source[20]	2010	2015	2020
Air conditioning equipment	All	Poland		5.6%	1.7%
		Slovakia	5.0%	2.5%	2.0%
	VRF systems	Germany		1.8%	1.5%
	Split systems	Germany		1.6%	1.2%
	Water chillers	Germany		1.4%	1.3%
Hydronic heat pumps		Poland		6.7%	1.7%
Commercial refrigeration		Poland		16.2%	3.7%
		Germany		4.0%	3.4%
		Slovakia	4.5%	8.0%	5.0%
Industrial refrigeration		Poland		16.2%	3.7%
		Germany		2.3%	2.5%
		Slovakia	6.5%	4.0%	3.5%

Circular Economy

The Circular Economy is one of the main building blocks of the EU Green Deal. In a RACHP context this is also of geopolitical importance, as the EU is largely dependent on HFC and HFO imports. Maximising refrigerant recovery and re-use aligns well with Circular Economy policies.

[20] Poland: mandatory electronic logbook; Germany: VDKF voluntary electronic logbook; Slovakia: voluntary electronic logbook

The HFC phase-down mechanism is the main driver for re-using HFC and HFC blend refrigerants. The RACHP standards ISO 5149 and EN 378 recommend the conditions for appropriate use of recycled or reclaimed refrigerants. EPEE recommends that Member States or the EU F-Gas Regulation make reference to these recommendations, to ensure a harmonised approach to the re-use of refrigerants.

EPEE supports extended producer responsibility schemes as a tool to facilitate recovery and reuse of refrigerants. While such schemes are already in place for RACHP equipment under the WEEE directive, they are not in place for bulk gases in many EU countries, although the current F-Gas Regulation encouraged Member States to do so. An example of good practice is in France (ADC3R).

Training and certification for handling of all refrigerants

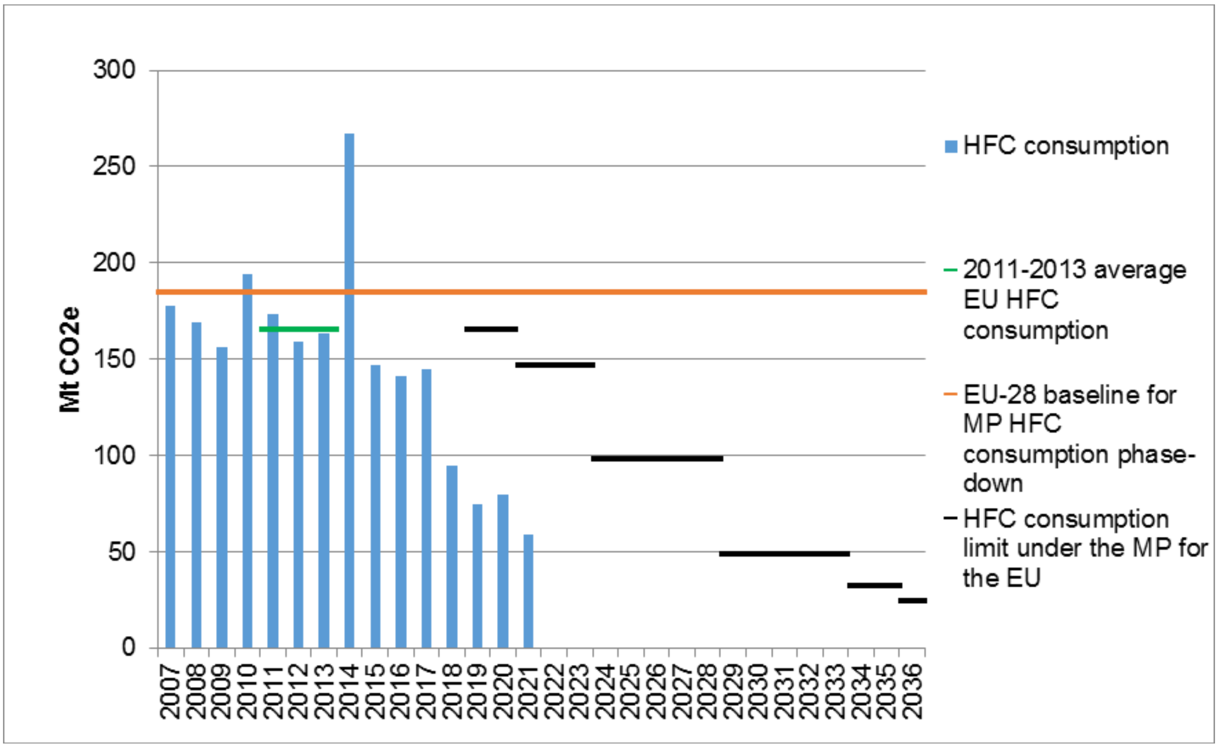
Article 10 of the current Regulation requires all technicians that carry out activities that could lead to leakage of HFCs (e.g. installation, maintenance, leak checking, gas recovery) to have an appropriate F-Gas training certificate and the companies they work for must hold a company certificate. These requirements have significantly improved the quality of installation and maintenance activities. Technicians must be able to safely handle flammable, high-pressure and toxic refrigerants, whether these refrigerants are fluorinated or not, including HFOs, ammonia, CO_2 and HCs.

7. Compliance with the Kigali Amendment

The Kigali Amendment to the Montreal Protocol sets HFC phase-down targets for all countries in the world (197 countries agreed the Kigali Amendment in 2016; by December 2022 there are 145 countries that have ratified).

The Kigali Amendment HFC phase-down schedule for developed countries (non-Article 5 countries) and the EU schedule are shown in Figure 17. The EU phase-down is well in advance of Kigali. In 2023 the requirement under Kigali is for a 10% cut from baseline. The EU has already achieved a 55% cut.

Figure 17: EU Progress towards Kigali Amendment Targets



However, it is very important to note that the way in which the Kigali Amendment phase-down is calculated is different to the EU phase-down. In particular:

a) The Kigali baseline is slightly higher (184.2 million tonnes CO_2e compared to 183.1)

b) The Kigali phase-down only relates to bulk HFCs placed on the market whereas the EU phase-down also takes account of HFCs in pre-charged RACHP imports.

c) The Kigali phase-down takes into account the deduction of any HFCs that are destroyed. This is not deducted in the EU phase-down.

These 3 factors make the 2036 Kigali target easier to achieve.

However, there are also some factors that make the Kigali target slightly harder to achieve:

a) The export of pre-charged equipment has some credit in the EU Regulation, if the exported products contain bulk HFCs that were imported using IPR (Inward Processing Relief). That credit is not available under Kigali. However, if the balance between the amount of imported pre-charged equipment and export pre-charged equipment is in balance, there is no risk for the EU to comply with their Kigali commitment.

b) The EU phase-down has some exemptions which are not currently available in Kigali. In particular, MDIs (metered dose inhalers for treatment of lung diseases) are exempt in the EU Regulation. This sector currently uses around 10 million tonnes CO_2e per year. If this continues to 2036 and there is no essential use exemption[21] then the EU might struggle to meet the Kigali target. There is significant development work taking place in the MDI sector for the introduction of lower GWP propellants and there are also not-in-kind alternatives such as dry powder and soft mist inhalers that do not use HFCs. It is likely that by 2036 there will be a significant reduction in MDI HFC use, but it is not yet clear how fast this can be done by when, and thus the amount of quota left for the RACHP sector is very difficult to predict.

Taking all these factors into account, our modelling shows that the current 2030 EU phase down target is sufficiently ambitious to comply with Montreal Protocol Kigali amendment, even in 2036.

[21] The Montreal Protocol has an Essential Use mechanism that was previously used to allow MDIs using CFCs to be used after the phase out date. That mechanism could be used if there are no alternatives available.

ANNEX 1: Glossary

Abated emissions	Heat delivered by heat pumps is assumed to replace heat that would have been delivered by natural gas boilers. The **abated emissions** represent the avoided CO_2 emissions from gas boilers through the use of heat pumps for building space heating, sanitary water heating and low temperature industrial process heating.
Air-to-Air Units	A commonly used configuration for reversible air-conditioning / heat pump units. In its simplest form an air-to-air unit has two heat exchangers, an indoor unit and an outdoor unit. In cooling mode the indoor unit is the refrigerant evaporator, and it directly cools the room air that is blown over it. The outdoor unit is the refrigerant condenser, with heat rejected to ambient air blown over it. In heating mode the roles of the heat exchangers are reversed. The outdoor unit becomes the evaporator and extracts heat from ambient air. The indoor unit becomes the condenser and heats the room air blown over it. More complex arrangements are often used with several indoor units connected to a single outdoor unit.
ATP	The ATP, "**Accord Transport Périssable**", is an international regulation for refrigerated transport at controlled temperatures of perishable goods.
Blend	Means a refrigerant mixture, i.e., a refrigerant composed of two or more substances.
Bottom-up stock model	Modelling of HFC use and emissions is done using a **bottom-up stock model** which breaks the market into multiple technology sectors. For each sector an estimate of the number of items of equipment (the stock) is used together with assumptions about key factors (such as refrigerant choice, leakage rates, end-of-life gas recovery rates) to estimate refrigerant use and emissions.
Bulk gas	Gases sold in cylinders or tanks are referred to as **bulk gas**.
Containment checks	Checks to evaluate whether the refrigerant in a RACHP equipment is still fully contained. The F-Gas Regulation specifies mandatory **containment checks,** the frequency depends on the size of the refrigerant circuit (in t CO2e).
Ecodesign	A group of EU product specific implementing regulations, under the **Ecodesign** Directive, that specify required minimum levels of energy efficiency and data disclosure for different types of energy related equipment, including nearly all the RACHP applications. Some of the products are also subject to mandatory energy labelling requirements.
Electronic logbook	The F-Gas Regulation specifies mandatory record keeping requirements for operators of certain equipment containing F-Gases. The type of information to be stored is specified, but not the method of storage. A few EU countries have adopted web-based **electronic logbooks** thatmust be used to enter the required data, either on a mandatory or voluntary basis. Mandatory systems have the significant advantage ofmaking the data available to users, industry and Government Competent Authorities to review the collected data and better understand compliance with the Regulation.
End-of-life recovery	The F-Gas Regulation requires **end-of-life recovery** of any HFCs in RACHP equipment. The recovery process can be done on site or in dedicated waste treatment facilities. Recovery requires specialised equipment (a refrigerant recovery machine) and must be carried out by certificated recovery technicians.
HFC phase-down schedule	A series of dates with specified maximum amounts of virgin HFCs that can be placed on the market (expressed in CO2e). There are different phase-down schedules and counting methodologies for the EU F-Gas Regulation and for the Kigali Amendment to the Montreal Protocol.
F-Gases	This refers to the fluorinated greenhouse gases listed in the EU F-Gas Regulation. The key gases covered by this Regulation are HFCs, PFCs and SF_6 listed in Annex I of the Regulation. The RACHP sector makes significant use of HFC refrigerants. Other fluorinated gases referred to in the Regulation include: unsaturated hydro(chloro)fluorocarbons, fluorinated ethers and alcohols, other perfluorinated compounds
F-Gas Regulation	The EU **F-Gas Regulation** specifies rules for the use of F-Gases with the objective of reducing the use and emissions of high GWP gases. Regulation (EC) 842/2006 was adopted in 2006 and later revised and replaced by (EU) 517/2014 in 2014
Gas reclamation	Refrigerants that are recovered from RACHP equipment can undergo a process of **gas reclamation**. This requires sophisticated gas reprocessing and testing equipment which enable reclaimed refrigerants to match the equivalent performance of a virgin substance, taking into account its intended use. Gas reclamation is always carried out by specialist reclamation companies.

Gas recovery	The process of removing refrigerant from a piece of RACHP equipment e.g. at end-of-life or during maintenance. The recovery process requires specialised equipment (a refrigerant recovery machine) and must be carried out by certificated recovery technicians.
Gas recovery rate	The **gas recovery rate** represents the proportion of gas in a system that is recovered.
Gas recycling	**Gas recycling** is a different process to gas reclamation. This is the reuse of a recovered gas followinga basic cleaning process. The quality may be sufficient for reuse in same or similar systems, depending on certain conditions (specified under EN and ISO standards) Gas recycling can be carried out by RACHP contractors or dedicated recycling companies.
Gas destruction	**Gas destruction** is the process of permanently transforming or decomposing all or most of a fluorinated greenhouse gas into one or more stable substances that are not fluorinated greenhouse gases.
Gas re-use	**Gas re-use** includes the reuse of recycled or reclaimed gas. .
GWP	**Global Warming Potential** means the climatic warming potential of a greenhouse gas relative to that of carbon dioxide, calculated in terms of the 100-year warming potential of one kilogram of a greenhouse gas relative to one kilogram of CO_2 which has a GWP of 1.
HCFCs	**Hydro-chloro-fluoro-carbons** are halocarbons containing carbon, hydrogen, chlorine and fluorine. HCFCs are ozone depleting substances and use of HCFCs has been banned in the EU in most new RACHP products since 2004 (some earlier). HCFC-22 was a widely used refrigerant and is still manufactured for use as a feedstock for certain chemical processes.
HCs	**Hydrocarbons** are carbon chain molecules containing only carbon and hydrogen. Propane (HC-290) and iso-butane (HC-600a) are typically used HC refrigerants.
Heat pumps	A device that absorbs heat at a low temperature and delivers useful heat at a higher temperature by using a vapour compression cycle driven by an electric compressor. In heating mode, the heat source can be air/water/ground and the heat sink can be indoor air or water or another fluid.
HFCs	**Hydro-fluoro-carbons** are halocarbons containing only hydrogen, fluorine and carbon. As HFC molecules have no chlorine they do not damage the ozone layer and they were introduced as alternatives during the 1990s to enable the phase-out of ozone depleting CFCs and HCFCs.
HFO	**Hydro-fluoro-olefins**. Also called unsaturated HFCs, these are carbon chain molecules containing carbon, hydrogen, and fluorine and they have a double bond between 2 of the carbon atoms. This makes HFOs less stable than HFCs and leads to very low GWPs (in the range of 3 to 7).
Hydronic heat pumps	Heat pumps where the heat sink is a water circuit (or other liquid). The hot water can be used for an additional heat exchange (hence also called “indirect” system) to the indoor air (through underfloor heating, convectors or radiators) and for sanitary hot water production.
IPR	**Inward Processing Relief** is an EU customs procedure that allows a component to be imported for processing (e.g., manufacturing of equipment) and later re-exported. Under IPR, the component is not considered to be placed on the EU market. IPR can be used to import bulk HFCs (without using any F-Gas quota) and use the HFCs in pre-charged equipment that is directly exported. IPR cannot be used when the HFC is purchased within the EU, nor can it be used when the equipment is not directly exported by the manufacturing company. IPR cannot be used if the export is to a country that has a bilateral trade agreement with the EU.
Leakage rate	The **leakage rate** is the percentage of the original refrigerant charge that leaks in a year. Leakage rates are usually defined as the average rate for a defined stock of equipment. An average leakage rate of 2% per year does therefore not mean that each piece of equipment is leaking at 2% per year, but it means that an amount equal to 2% of the refrigerant in the installed bank of all such equipment is estimated to leak in a year.
Low carbon heating	Supply of heat with lower CO_2 emissions than for fossil-fueled heating systems.
MAC	**Mobile air-conditioning** used in vehicles such as cars, vans, trucks, trains and buses. In the EU MAC directive, thescope is passenger cars and light duty vans only.
Market granularity	Modelling of refrigerant use and emissions is done using a bottom-up stock model which breaks the market into multiple technology sectors. Due to the complex nature of RACHP markets, it is important to split the market into a sufficiently large number of sectors to properly represent the different circumstances in which refrigerants are used. The EPEE *HFC Outlook* model uses a high level of **market granularity** with 50 different technology sectors.

MEPS	**Minimum Energy Performance Standards** are used to specify the minimum level of energyefficiency of new products. In the EU, the Ecodesign Framework Directive and implementing Regulations specify MEPS for many different types of energy using equipment. Products that are less efficient than the relevant MEPS level cannot be placed on the EU market.
Monobloc systems	**Monoblocs** are a type of RACHP design where the whole system is built as a single package, and the refrigerant circuit is filled in a factory. Monoblocs require no refrigerant handling when they are installed.
Multi-split systems	A type of split RACHP system that has several indoor heat exchangers connected with site-installed pipework to an outdoor exchanger. This is a common configuration for comfort cooling / heating of several rooms in a building. It is also a common configuration for food retail, where multiple refrigerated display cases are connected to an external compressor / condenser unit.
RACHP	**Refrigeration, air-conditioning and heat pump systems**. This is a common name for a sector which provides cooling and heating through a thermodynamic refrigeration cycle, typically used for comfort and cold chain applications. **Refrigeration cold chain** refers to systems that cool products below ambient temperature (e.g. chilled food at 4°C or frozen food at -20°C, with some applications requiring even lower temperatures). **Comfort applications** refer to systems that keep occupied spaces at a comfortable temperature (e.g. around 21°C).
Pre-charged equipment	Many types of RACHP equipment are **pre-charged** with refrigerant during factory manufacture. Some equipment can be partially pre-charged and requires some on site topping up, depending on the actual installation requirements.
RACHP contractors	Companies involved in the installation and maintenance of RACHP equipment. The F-Gas Regulation requires contractors to employ technicians with suitable F-Gas qualifications and to hold a company/people certification that ensures they adhere to F-Gas Regulation refrigerant handling requirements.
Refrigerant Bank	The **refrigerant bank** represents the total amount of refrigerant in the stock of equipment, either for a single technology type or for the whole RACHP market. For example, if there are 1,000 MACs each containing 0.6 kg of R-134a, the refrigerant bank is 600 kg of R-134a.
Refrigerants	**Refrigerants** are fluids used for heat transfer in RACHP systems, which absorbs heat at a low temperature and a low pressure and rejects heat at a higher temperature and a higherpressure usually involving changes of the state of the fluid. The F-Gas Regulation has created a shift towards lower GWP refrigerants including lower GWP HFCs, HFC-HFO blends, HFOs, ammonia, CO_2, HCs….
Retrofit	In some circumstances it is possible to remove an existing high GWP refrigerant from a refrigeration system and replace it with a lower GWP alternative. This is referred to as **retrofitting**. The most important retrofit opportunity relates to R-404A
RTU	**Rooftop Units** are a type of building air-conditioning system providing a supply of cooled air through ductwork, with the refrigeration system located on a flat roof. RTUs are driven by an electric compressor, of which the evaporator, compressor and condenser are integrated into a single package.
Split Systems	**Split systems** are refrigerating systems, comprising one or more factory-made indoor units in a space and one or more factory made units which are located outside the space and which are connected on site during installation with site-installed refrigerant pipework in accordance with the instructions of the manufacturers of the factory-made units. The most common example is the small single split air-to-air unit, with (a) an indoor unit that cools the air in a room and (b) an outdoor unitwith a compressor and air-cooled condenser (in reverse mode it is used for heating). Another common example is for food retail systems that have a cooling evaporator in a food display case inside a store, connected to a “condensing unit” (compressor and condenser) located outdoors.
Virgin gas	**Virgin gas** is a refrigerant that has not previously been used (unlike reclaimed or recycled gas which has been recovered from an existing system). Virgin gas is supplied to a quality standard that relates to the application e.g. HFCs can be refrigerant quality or medical quality (for use as a propellant in inhalers for treating lung diseases such as asthma).
VRF	**Variable Refrigerant Flow** systems are a sophisticated type of air-to-air or water-to-air split system used for building cooling and heating. A single VRF outdoor unit can be connected to up to 64 indoor units located in different rooms. A heat recovery VRF can reuse extracted heat from cooling some rooms and heat others, leading to very high system efficiency.

ANNEX 2: Background to EU Modelling with *HFC Outlook*

HFC Outlook EU, developed by Gluckman Consulting, builds on their initial modelling work done for EPEE in 2012, which modelled a trajectory for an HFC phase-down in the EU. The 2012 modelling helped EPEE assess the European Commission's phase-down proposals and showed that the phase-down steps in the 2014 EU F-Gas Regulation were challenging but considered achievable.

The *HFC Outlook EU* model was used to support EPEE's "Gapometer" project in 2016 which assessed progress towards the challenging HFC phase-down step in 2018 (a 44% cut from the baseline) and to provide the RACHP industry with clear signals about the actions required to achieve the required HFC consumption reductions.

The *HFC Outlook EU* model is highly regarded in the RACHP industry and parallel models are used beyond EU borders. The UN has worked with EPEE and Gluckman Consulting to create country specific models to help Montreal Protocol Article 5 countries prepare their F-Gas reductions plans.

Additional improvements to the *HFC Outlook EU* Model over the past 2 years include:

a) Updated HFC consumption trajectories taking account of the technical developments that have occurred since 2012

b) Revised market growth forecasts, especially related to heat pumps.

c) Modelling of the energy related GHG emissions from the RACHP market to provide a better understanding of the balance of direct and indirect GHG emissions from RACHP systems.

The latest model includes the HFC requirements for pre-charged RACHP products exported from the EU. These were not included in the 2012 model as it was expected that such exports would be exempted from the HFC phase-down, which is not the case.

The *HFC Outlook EU* projections are built bottom-up, providing an analysis of the stock of equipment in more than 50 HFC technology sub-sectors. This includes the RACHP sectors and also non-RACHP HFC applications such as MDIs, technical aerosols and foams. EPEE consider that this level of sub-sector granularity is essential for a model to properly take account of the complexity of the HFC market. Even a detailed model of this type simplifies the complex markets for HFCs, but it provides a reasonably comprehensive platform to assess future HFC needs.

HFC Outlook EU outputs can be analysed individually for each technology sub-sector or aggregated by:

a) Market types: residential; commercial; transport; industrial; non-RACHP

b) Technology types: refrigeration; comfort cooling and heating

c) Technology sub-types: stand-alone, direct expansion; chillers; flooded systems

Each sub-sector is analysed on an annual basis from 1990 to 2050. The various modelling input parameters (e.g. leak rates, gas choices for new equipment, gas recovery at end-of-life etc.) can be varied annually and are individually defined for each technology sub-sector. EPEE members, which include the leading global companies in the RACHP value chain, provide input and technological advice on the parameters used in the model.

Table A1 illustrates the wide range of different outputs available.

Table A1: Summary of Outputs from *HFC Outlook EU*

Output	Units	Examples
Gas[22] use	tonnes; tonnes CO_2e	Products manufactured; pre-charged imports; leakage top-up
Gas emissions	tonnes; tonnes CO_2e	During manufacture / installation; during operation; at end-of-life
Energy use	MWh, TWh	Electricity used for stationary cooling and heating. Vehicle fuels used for refrigerated transport and mobile air-conditioning
Energy emissions	tonnes CO_2e	Indirect GHG emissions from electricity and fuels used
Gas banks	tonnes; tonnes CO_2e	Gas in exisiting equipment; gas in new systems and retiring systems
Gas recovery	tonnes; tonnes CO_2e	Gas available for recovery; gas recovered and re-used; gas destroyed
Number of items	Number	Number of existing systems; number of new and retiring systems
Thermal capacity	MW	Cooling capacity and heating capacity for RACHP sectors

Two very important features of EPEE's modelling are:

1) **The assessment of energy use and indirect GHG emissions.** Energy usage is modelled separately for each RACHP sub-sector using the same stock model and stock growth assumptions that are used to model refrigerant consumption and emissions. Energy used in each sub-sector is estimated on an annual basis, which allows for an evolution of equipment efficiency in the RACHP stock. The GHG emissions associated with electricity use are assessed by taking account of the evolution of the EU's electricity generation carbon emission factors. The energy modelling also enables *HFC Outlook EU* to project the amounts of avoided emissions through the heat delivered from heat pumps, which would otherwise have been delivered by burning fossil fuels (mainly natural gas and oil in boilers).

2) **The level of granularity within the modelled sub-sectors.** *HFC Outlook EU* uses over 50 technology sub-sectors. The AnaFgas model used by the Commission for their April 2022 F-Gas Regulation Impact Assessment uses a less granular analysis with many less technology segments. This requires aggregation of sub-sectors that in practice require different refrigerant choices to be modelled. For example, industrial refrigeration was treated as two technology segments both of which are large enough to be suited to ammonia refrigeration. However, numerous industrial facilities are relatively small and they often use small industrial refrigeration systems that are not suited to ammonia. *HFC Outlook EU* uses 10 technology sub-sectors to model industrial refrigeration applications to ensure these complexities can be modelled.

Compared to the 2012 modelling work, the HFC Outlook EU has been extended to project not only greenhouse gas emissions from refrigerants, but also the electricity-related emissions from the equipment using these refrigerants.

[22] "Gas" refers to HFCs and alternative fluids including CO_2, ammonia, hydrocarbons and HFOs