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F gas regulation in Great Britain

Assessment report

December 2022

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Executive summary

This report has been prepared on behalf of the UK, Scottish and Welsh governments. Its focus is to provide a comprehensive review of the retained European Union (EU) regulation on fluorinated greenhouse gases (the F gas Regulation) ((EU) No 517/2014), as it applies in Great Britain, and to identify possible opportunities for further abatement. The F gas Regulation includes measures to reduce use and emissions of fluorinated greenhouse gases (F gases) and includes a legal requirement (set out in Article 21(2)) to review the Regulation by 2022.

The main objective of the F gas Regulation is to reduce F gas emissions by:

- establishing rules on containment, use, recovery and destruction of F gases
- imposing conditions on the placing on the market of specific products and equipment containing F gases
- imposing conditions on the specific uses of F gases
- establishing quantitative limits for the placing on the market of hydrofluorocarbons (HFCs)

The F gas Regulation has succeeded in its objective to reduce estimated cumulative emissions in Great Britain by 13.6-24.3 MtCO2e (million tonnes of carbon dioxide (CO2) equivalent).[1] Monetised gross benefits were measured at £1.9-8.5 billion and total costs at approximately £118 million.[2] This success is mainly the result of the HFC phasedown, by curbing low value uses and helping to drive the transition from high global warming potential (GWP) HFCs to lower GWP alternatives. In addition, it was found that this is due to the market incentives created by the increased price of HFCs.

Although the Regulation has been an overall success, there are certain aspects which could be strengthened, revised or amended. This includes, but is not limited to, extending the HFC phasedown to ensure continued compliance with the Kigali Amendment to the UN Montreal Protocol. Further measures could be considered to strengthen containment,

[1] Emissions lag consumption meaning that emissions reductions due to the Regulation differ from emissions reductions that occurred during the period the Regulation is in force. UK F gases emissions have declined by 2 MtCO2e per year from 2015 to 2020, as shown by the final UK greenhouse gas emissions national statistics: 1990 to 2020. Using data from the final greenhouse gas emissions 2020 – Table 1.1. The bulk of estimated emissions reductions from the F gas Regulation result from lower future emissions, because of placing less gas (by CO2e) in equipment.

[2] At a 1.5% discount rate. Using a 3.5% discount rate we find gross benefits of £1.8-8.1 billion. Total costs fall to £107 million.

including more transparent record keeping of leak checking and recovery to better inform emissions estimates.

This report reviews the current state of technology and the ongoing need for F gases, looking at possible alternatives and taking into account considerations of feasibility and energy efficiency. The report also provides a demand forecast based on currently available and likely to be available technologies through to 2050. Modelling suggests there may be space for further cost-effective abatement above already established targets.

Following this report, further work will be undertaken to assess potential future policy proposals to address these aspects and other measures. Subject to agreements between UK, Scottish and Welsh governments, these will be published in a joint consultation in due course.

1. Introduction

The purpose of this report is to comply with a legal duty to undertake a comprehensive review of the F gas Regulation.

F gases are a family of manufactured gases used in a range of industrial, commercial and domestic applications. F gases were often introduced as a replacement for ozone-depleting substances (ODS), following the requirement to phase out ODS under the UN Montreal Protocol on substances that deplete the ozone layer.[3] While not ozone-depleting, F gases are powerful greenhouse gases, with a GWP that can be many thousand times higher than CO2.[4] Annex 1 of the F gas Regulation includes a list of F gases (as defined in the Regulation) and their GWP values (see Appendix A).

F gases accounted for 3.02% of UK greenhouse gas emissions in 2020 and fall into four groups: HFCs, which form 95.1% of UK 2020 F gas emissions; sulphur hexafluoride (SF_6) – 3.25%; perfluorocarbons (PFCs) – 1.63%; and nitrogen trifluoride (NF_3) – negligible quantities.[5] F gases (HFCs, SF_6, PFCs and NF_3), alongside CO2, methane and nitrous oxide, are the seven direct greenhouse gases under the Kyoto Protocol and are monitored and reported on under the UK Greenhouse Gas Inventory. When considering the relative impact of F gases in comparison to other greenhouse gases, CO2e is used as a measure of how much a gas contributes to global warming, relative to CO2.[6]

F gases are used in refrigeration, air-conditioning and heat pumps (79.5% of emissions in 2020), medical inhalers and aerosols (9.8%), electrical switchgear (4.1%), closed-cell insulation foams (3.3%), fire protection systems (2.5%) and other specialist applications (0.8%), such as semi-conductor manufacture, solvents and tracer gases.[7]

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[3] Some fluorinated gases, such as CFCs and HCFCs, are classified as ozone-depleting substances and not considered F gases for the purpose of the F gas Regulation. These have been phased out in the UK.

[4] GWP figures used in this report are based on 100-year values from the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change.

[5] Final UK greenhouse gas emissions national statistics: 1990 to 2020. Final greenhouse gas emissions 2020 – Table 1.1.

[6] How to calculate the carbon dioxide equivalent quantity of an F gas

[7] Final UK greenhouse gas emissions national statistics: 1990 to 2020. Final greenhouse gas emissions table 2020 – Table 1.6.

Regulation (EU) No 517/2014[8] (F gas Regulation) replaced Regulation (EC) No 842/2006[9] (2006 F gas Regulation), which aimed to contain, prevent and reduce emissions of F gases. The current F gas Regulation built on the foundation set out in the 2006 F gas Regulation and aims to protect the environment by reducing F gas emissions through establishing rules on containment, use, imposing conditions on the placing on the market of specific products and equipment and on the specific uses of F gases, as well as establishing quantitative limits for placing on the market of HFCs.[10]

The F gas Regulation requires a 79% cut in the use of HFCs between 2015 and 2030. This is achieved by phasing down the amount of HFCs that can be placed on the market, for the first time, by allocating steadily reducing quotas to HFC producers and importers. The reduction in F gas emissions, resulting from the HFC phasedown (the phasedown schedule is shown in Appendix B), is a key commitment for meeting UK climate change goals under the Climate Change Act 2008[11] and contributing to future carbon budgets.

The F gas Regulation bans the use of F gases in certain applications and sets requirements for leak checks, leakage repairs and recovery of used gas. In addition, the F gas Regulation requires that all technicians handling F gases must be trained in their safe use and certified.

The F gas Regulation came into force on 1 January 2015. Until 31 December 2020, the F gas Regulation applied in the UK as directly applicable EU law. Following EU Exit, the F gas Regulation applies in Great Britain as 'retained EU law' and the requirements remain the same as under EU legislation. Secondary legislation was introduced to enable operation in Great Britain and to implement the Protocol on Ireland / Northern Ireland.[12,13]

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[8] Regulation (EU) No 517/2014

[9] Regulation (EU) No 842/2006

[10] The Great Britain F gas Regulation defines 'placing on the market' as supplying or making available to another party in any part of Great Britain for the first time, for payment or free of charge, or using for its own account in the case of a producer and includes customs release for free circulation in any part of Great Britain.

[11] Climate Change Act 2008

[12] The Ozone-Depleting Substances and Fluorinated Greenhouse Gases (Amendment etc.) (EU Exit) Regulations 2019

[13] The Ozone-Depleting Substances and Fluorinated Greenhouse Gases (Amendment etc.) (EU Exit) Regulations 2020

F gas and ODS policy is devolved, however, the UK, Scottish and Welsh governments have agreed to work together and arrangements are in place, underpinned by a Common Framework for F gases and ODS,[14] to jointly run a Great Britain wide F gas system in relation to quota allocation and reporting. The Environment Agency are responsible for administering and operating this Great Britain F gas system on behalf of the UK, Scottish and Welsh governments. Other regulators also have roles in ensuring compliance and undertaking enforcement across Great Britain.[15]

Since commencement of the F gas Regulation, further international action has been taken to address the use of F gases, specifically HFCs. The Kigali Amendment to the Montreal Protocol was adopted in 2016, under which Parties to the Protocol agreed to reduce global production and consumption of HFCs. Under this Amendment, developed countries such as the UK are required to reduce HFC production and consumption by 85% by 2036. The end target of the phasedown under the Kigali Amendment therefore goes further than the current F gas Regulation, although the phasedown under the Regulation means the UK is currently well ahead of the schedule set by the Kigali Amendment.

Review of the F gas Regulation in Great Britain

The F gas Regulation includes a legal requirement to publish a comprehensive report on the effects of the Regulation (Article 21(2)) by the end of 2022, including in particular:

(a) a forecast of the continued demand for HFCs up to and beyond 2030
(b) an assessment of the need for further action in light of existing and new international commitments regarding the reduction of F gas emissions
(c) an overview of domestic and international standards, national safety legislation and building codes in relation to the transition to alternative refrigerants
(d) a review of the availability of technically feasible and cost-effective alternatives to products and equipment containing F gases for products and equipment not listed in Annex 3 of the F gas Regulation, taking into account energy efficiency

The review of the Regulation has been jointly undertaken by UK, Scottish and Welsh governments, as a Great Britain wide exercise, with Defra leading this work. The focus of this report is a retrospective assessment of the implementation of the F gas Regulation in Great Britain. It also fulfils the requirements set out in Article 21(2)(a-d).

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[14] ODS and F gases: provisional common framework

[15] Scottish Environment Protection Agency (SEPA) in Scotland, Natural Resources Wales (NRW) in Wales, Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) for offshore oil and gas operations and local authorities.

Following this assessment report, further work will be undertaken to assess potential policy proposals and subject to agreements, these will be published in a joint consultation in due course. The consultation will provide the vehicle for forward looking policy and set out policy proposals to be more ambitious on F gases, in support of the UK's net zero commitments and to take account of technological developments.

The European Commission have also undertaken a review of the EU F gas Regulation, in line with Article 21(2) and published a legislative proposal to update it.[16] Under the current Protocol on Ireland / Northern Ireland,[17] any future F gas legislation in the EU would apply in Northern Ireland.

2. Engagement

A variety of methods were used to gather data and evidence from relevant stakeholders to assess the implementation of the F gas Regulation. This varied approach enabled engagement with a range of stakeholders and sectors. The UK, Scottish and Welsh governments thank stakeholders for their engagement and input. The feedback received has been invaluable in supporting the development of this assessment report and initial thinking for policy proposals.

Sector groups

Three sector-specific groups were established covering the main F gas sectors and priority areas for the review. These sectors were – refrigeration, air-conditioning and heat pumps (RACHP), metered dose inhalers (MDIs) and power (for example, electric power transmission and distribution grids). RACHP and MDIs both use HFCs, while the power sector relies on SF_6.

When establishing these groups, it was important to ensure there was a balance of stakeholders and key individuals (Appendix C lists the stakeholders involved in each of the sector groups). To ensure this, the groups were initially set up with known, key stakeholders and ahead of the introductory meeting a list of the organisations invited was circulated and stakeholders were asked to flag any important organisations/individuals not included. The RACHP sector group included industry representatives, equipment manufacturers, trade bodies and relevant regulators from across government. The power

[16] EU Commission proposal to replace Regulation (EU) No 517/2014

[17] Protocol on Ireland/Northern Ireland

sector group had a similar mix of stakeholders. Given the nature of the MDI sector, in addition to manufacturers, trade bodies and relevant policy teams from across government, this group also included clinical and patient representatives. The sector groups included stakeholders from across the UK and EU, given the pan-European nature of F gas markets.

The aim of these groups was to gather evidence and feedback on the implementation of the Regulation and, where appropriate and applicable, support the development of options for future legislation. There were several sector group meetings, which considered specific issues relating to those sectors, both in the current regulations and for policy proposals. This included containment, phasedown, bans, training and certification, trade and legal loopholes. These groups were well attended, and stakeholders fed back positively on the transparency and open engagement.

Meetings with individual organisations

In addition to sector-wide group meetings, one-to-one meetings were held between Defra and stakeholders. Most of these meetings were as a result of stakeholder requests, but some stakeholders were contacted for meetings – these were typically large trade associations, key market players or those associated with a sector not covered by the sector groups, for example fire protection and anaesthetics. For sectors where groups were established, one-to-one meetings provided an opportunity to build on the discussion from the group meetings and consider specific issues and perspectives in more detail, for example NGO views and electronic logbooks for reporting on leaks and top-ups. These meetings also included discussions on topics not covered in sector group meetings, for example the use of flammable gases in restricted environments, such as in airports and railway stations. These meetings allowed for the exchange of commercially sensitive information and information that stakeholders may not have felt comfortable sharing in a wider sector group setting.

To support the assessment of the effectiveness of the F gas Regulation and more detailed information on future policies, position papers were also welcomed from stakeholders. Most of the papers received covered the three sector group areas. These papers helped provide an evidence base for the assessment report.

Government engagement

Since 1 January 2021, the Environment Agency has had responsibility for administering and operating the Great Britain F gas system on behalf of the UK, Scottish and Welsh governments, with oversight through the governance arrangements defined in the Common Framework. Prior to this, the UK was part of the EU F gas system administered by the European Commission and European Environment Agency. By way of the

Fluorinated Greenhouse Gases Regulations 2015,[18] compliance and enforcement throughout the implementation of the F gas Regulation has been the responsibility of the Environment Agency, Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW), Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) and local authorities. The experience of regulators was an important consideration as part of this assessment, given their interactions with the Regulation.

UK, Scottish and Welsh governments agreed to undertake this assessment report jointly, with Defra leading the work on behalf of all three. Under the Common Framework for F gases and ODS, established by the four governments of the UK, a Working Group and Governance Group have been established to manage the effective implementation of the Framework. These groups were used to provide routine oversight on progress and for decision-making in relation to the review and the joint approach to this work. While Northern Ireland remains subject to and in the EU F gas Regulation and system, the Northern Ireland Executive was involved in discussions and updates between the other three governments specific to the F gas Regulation review.

As part of the wider work considering future policy options, there was engagement with various policy teams from across government departments and bodies, which interact with F gas policy. This included collaborative work in relation to existing policy and future ambition on MDIs, anaesthetics, heat pumps, the power sector and training and certification. As part of this engagement on future policies, evidence was also gathered to support the assessment of the Regulation.

Consultancy

To support this work, Gluckman Consulting were contracted who have extensive experience related to the use and emissions of F gases, as well as expertise on the application of the F gas Regulation and the Kigali Amendment. They provided support in preparing and delivering the sector groups, as well as technical input and background papers to support the assessment of the Regulation. Gluckman Consulting also prepared the Great Britain model for HFC use and emissions which forms the basis for the demand forecast in section 9.

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[18] The Fluorinated Greenhouse Gases Regulation 2015. This instrument applies in full to Great Britain but to Northern Ireland only in respect of certain import, export and trade provisions, which are reserved matters.

3. F gas related policies and initiatives

UNFCCC

In addition to the Montreal Protocol, there are also international obligations under the United Nations Framework Convention on Climate Change (UNFCCC) for reporting on F gases. The UNFCCC's Kyoto Protocol requires Parties to report annually on emissions of seven greenhouse gases. F gases, specifically HFCs, PFCs, SF_6 and NF_3, are included in this group of greenhouse gases.

The 2020 UK Greenhouse Gas Emissions Final Figures report[19] sets out that while emissions from F gases had significantly increased as HFCs replaced ODS, this trend has reversed in recent years. This has been driven by the HFC phasedown under the F gas Regulation. Since the peak of F gas emissions in 2016, F gas emissions have decreased by 11%.

Domestic F gas policy

In accordance with the F gas Regulation, the UK government implemented domestic regulations to enforce necessary provisions, such as Article 10 and Article 25. The Fluorinated Greenhouse Gases Regulations 2015[20] were implemented and amended by the Fluorinated Greenhouse Gases (Amendment) Regulations 2018.[21] These Regulations apply in Great Britain and also provide enforcement in respect of import and export controls and trade in Northern Ireland.

These domestic regulations provide powers for authorised persons in England, Scotland and Wales to enforce the F gas Regulation, prescribe offences and penalties, enable data sharing between HMRC and regulators, designate certification and training bodies and include a power for appointing bodies to undertake certification, evaluation and attestation of F gas handlers.

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[19] 2020 UK Greenhouse Gas Emissions – final figures

[20] The Fluorinated Greenhouse Gases Regulation 2015

[21] The Fluorinated Greenhouse Gases (Amendment) Regulations 2018

Net zero

In 2019, the UK government and the devolved administrations committed to legally binding targets to bring greenhouse gas emissions to net zero by 2050. All parts of the UK have an integral role in delivering the UK-wide carbon budgets on the path to net zero by 2050, as set out in the UK's net zero strategy.[22] This builds upon the Climate Change Act 2008,[23] which committed the UK to reducing greenhouse gas emissions by 80% by 2050. The UK net zero target requires a 100% reduction in net emissions. The Climate Change Act includes three F gases (HFCs, PFCs and SF_6) in the definition of greenhouse gases and sets emissions reduction targets on these gases.

F gases have a role to play in ensuring the UK meets net zero and further ambition on F gases will be needed. The UK's net zero strategy sets out plans to continue to reduce emissions of F gases. The strategy commits the UK to meet the Kigali Amendment target of reducing HFC consumption by 85% by 2036, as well as the F gas Regulation target of a 79% reduction by 2030.[24]

Following this report on the F gas Regulation, an assessment will be needed to consider what additional reductions in F gas use and emissions can be made to help the UK meet net zero by 2050. That could involve action beyond meeting the Kigali Amendment target.

In addition to UK-wide net zero targets, Scotland and Wales also have independent targets. Scotland has one of the most ambitious legal frameworks for emissions reduction in the world, with a headline net zero target of 2045 and a commitment to reduce carbon emissions by 75% from 1990 levels by 2030. Scotland's climate change plan, finalised in March 2021,[25] sets out a comprehensive package of policies and proposals to reduce carbon emissions across all sectors of the economy over the period to 2032.

In March 2021, the Welsh Senedd formally committed Wales to achieving net-zero emissions by 2050. Following on from 'Prosperity for All: A low carbon Wales', 'Net Zero Wales: Carbon Budget 2 (2021-2025)' sets out how Wales will meet its second carbon

[22] UK net zero strategy: build back greener

[23] Climate Change Act 2008

[24] The Kigali Amendment uses a baseline period of 2011-2013, whereas the EU F gas Regulation used a period of 2009-2012 and the Great Britain F gas Regulation uses 2015-2019.

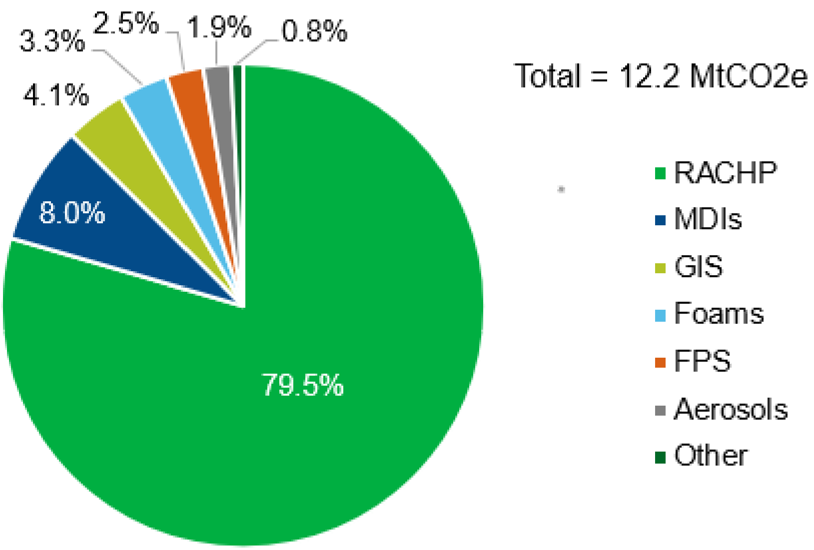
[25] Scotland climate change plan

budget and looks beyond to start building the foundations for Wales Carbon Budget 3, 2030 target, and net zero 2050 target.[26]

4. F gas markets and sectors

F gases are used across a range of sectors and applications (Figure 1). The main use of F gases are HFCs as a refrigerant within the RACHP sector. This sector is also the most significant source of F gas emissions, contributing to 79.5% of F gas emissions in 2020.

Figure 1: UK F gas emissions in 2020, split by main sectors (% tCO2e)[27]



Other key uses of F gases (and therefore sources of emissions) include as a propellant in medical inhalers (MDIs) and in technical aerosols, as a blowing agent in closed-cell insulating foams, as a suppressant in fire protection systems (FPS) and as an insulating gas in switchgear equipment on the power grid (gas-insulated switchgear (GIS)). There are some other smaller uses of F gas, including in semiconductor manufacturing, precision cleaning, the magnesium industry, radar systems, particle accelerators and tracer gas. In addition to these uses there are fugitive emissions of F gases from aluminium smelting and fluorochemical manufacture.

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[26] Net zero Wales carbon budget 2

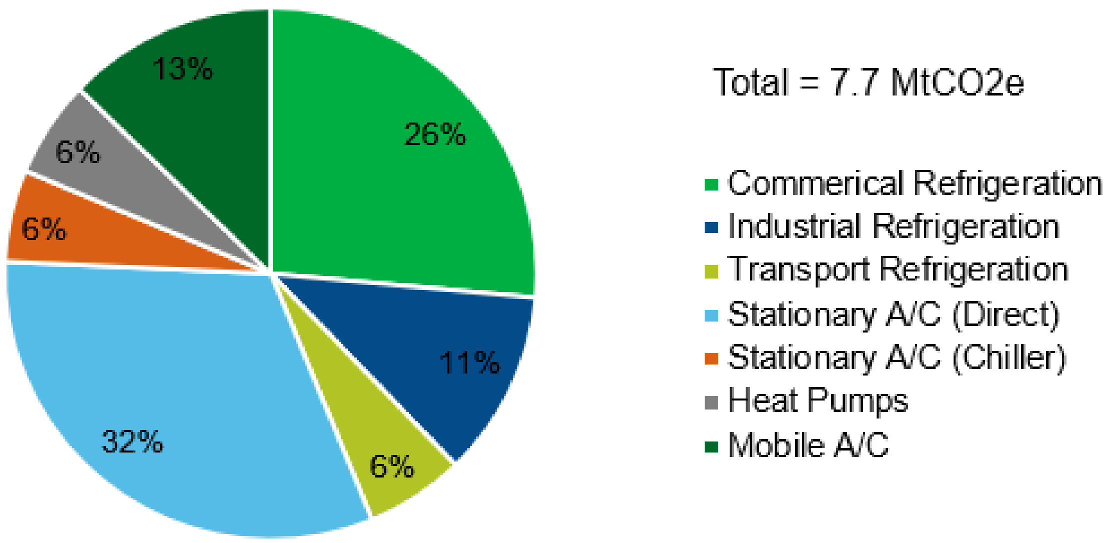
[27] Final UK greenhouse gas emissions national statistics: 1990 to 2020. Final greenhouse gas emissions 2020 – Table 1.6. MDI emissions estimated from UK 2020 NHS prescription data.

Some F gas applications are intrinsically emissive, including MDIs and technical aerosols. Other applications such as RACHP and GIS need the F gas to be well contained in a piece of equipment to ensure effective operation. Emissions from these applications are largely unintended, for example through leakage during operating life or from inadequate gas recovery at end-of-life.

RACHP

The use and emissions of HFCs in the RACHP sector is split across a number of sub-sectors (Figure 2). The main sub-sectors contributing to F gas emissions are commercial refrigeration, mobile air-conditioning and stationary air-conditioning systems. In light of the phasedown under the F gas Regulation, the use of HFCs in the RACHP sector should continue to reduce, as this is the main sector consuming HFCs placed on the market through the HFC phasedown quota mechanism. Emissions reductions are predicted to follow a similar trajectory to the phasedown, but there may be a lag between consumption and emissions reductions given that gases are held within equipment and emissions are not an intended part of the functioning of that equipment.

Figure 2: UK RACHP emissions in 2021, split by main sub-sectors (% tCO2e)[28,29]



[28] Data estimated by the Great Britain model (see Chapter 9 for a more detailed description of the model).

[29] It is worth noting that heat pump emissions in 2021 were only 6% of the total. The relative importance of heat pump emissions could grow considerably as heat pumps are rolled-out as a key technology to reduce the reliance on natural gas fired boilers for domestic and commercial building heating.

Non-RACHP applications

As a result of the phasedown under the F gas Regulation, while total emissions are forecast to fall, this is predominantly driven by a reduction of emissions from the RACHP sector, in response to the HFC phasedown. The proportion of remaining emissions represented by non-RACHP sectors is projected to increase (in the absence of further controls or external intervention) – even though overall emissions will reduce. Some of the non-RACHP sectors do not rely on HFCs and are therefore not subject to the phasedown, or rely on HFCs, but are exempt from the phasedown. The following is a summary of those sectors.

MDIs

Under the F gas Regulation, the supply of HFCs to an undertaking producing MDIs for delivery of pharmaceutical ingredients is exempt from the requirement for quota and the HFC phasedown (Article 15(2)). This exemption was agreed as there were no low GWP propellant alternatives available at the time. It was acknowledged that the process for developing alternatives would take time and ensuring supply of HFC propellants for medical uses was sufficiently critical for an exemption from quota.

This exemption came into force from 1 January 2018, which coincided with the second phasedown step (to 63%).[30] Between 1 January 2015, when the Regulation came into force, and 31 December 2017, quota was needed to place HFCs on the market for use as MDI propellant. As a result of the exemption (from 1 January 2018), under the F gas Regulation there are currently no controls on the quantity of HFCs supplied for use in MDIs. This means that control of emissions from this sector falls to the NHS, which has various levers with which to influence the market. Unlike the F gas Regulation, under the Kigali Amendment there are no exemptions from the HFC phasedown. As such, if HFC consumption for use in MDIs remains uncontrolled the UK could eventually become non-compliant with the Kigali Amendment. Controls on consumption across all sectors will need to be considered to ensure the UK is able to comply and meet the Kigali phasedown schedule.

[30] Appendix B shows the HFC phasedown schedule under the F gas Regulation.

Power

Switchgear equipment is an important component in the operation of the power grid. Nearly all high voltage switchgear currently on the Great Britain grid and commercially available relies on the use of SF_6 as an insulating gas. SF_6 has the highest GWP of all F gases controlled under the F gas Regulation, with a GWP of 22,800 (Appendix A includes the GWP values of F gases, as set out under Annex 1 of the F gas Regulation).

Emissions from switchgear accounted for 4.1% of UK 2020 F gas emissions. While the F gas Regulation encourages best-practice maintenance in this sector, better regulation could further reduce emissions from this sector. SF_6 is not subject to the phasedown mechanism and there are currently few incentives to move away from its use. There are some alternatives available (discussed in more detail in section 8 – state of technology), but intervention may be needed to drive innovation and promote the transition to alternatives to SF_6.

5. Application of the F gas Regulation

This section summarises the main provisions of the F gas Regulation and includes a brief description of the costs and benefits for the UK, as predicted when the 2014 F gas Regulation was developed. The latter is included as Great Britain specific estimates, which were not published at the time and are useful to measure the success of the Regulation.

The F gas Regulation (517/2014) superseded and replaced the earlier 2006 F gas Regulation. In 2011, Schwartz et al. produced a retrospective analysis of both the 2006 Regulation and the separate 2006 Mobile Air Conditioning (MAC) Directive.[31,32] The report found that the combined effect of the two regulatory actions had stabilised overall F gas emissions but that the existing rules were insufficient to reduce emissions.[33]

Schwartz' analysis formed the basis of the European Commission's 2012 retrospective analysis, which doubled as an impact assessment, for the 2014 F gas Regulation.[34] Both

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[31] Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

[32] Directive 2006/40/EC

[33] Although the bulk of emissions today come from HFCs, in 2006 emissions were dominated by HCFCs (a group of ozone-depleting gases used during the transition from CFCs to HFCs). Although HFC emissions increased between 2006 and 2014, this increase was driven by the phase out of HCFCs.

[34] Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

these analyses, as well as the European Commission's 2022 retrospective analysis of the F gas Regulation,[35] noted that economic impacts varied between Member States but did not break down costs by country.

Although there was no requirement to produce a separate analysis, Defra commissioned Jacobs Consulting to produce a separate impact assessment focused exclusively on the UK.[36] As the report was commissioned prior to EU Exit, it considers the UK whereas the current Regulation applies only to Great Britain.

In producing a retrospective analysis it is useful to consider the UK and EU studies together. The UK study permits a more direct comparison of estimated and observable costs but, as the UK did not create the Regulation, the analysis only assesses likely impacts without attempting to provide a rationale. By contrast, the European Commission provides a more comprehensive criteria by which to judge the success of the F gas Regulation.

Implementation of the Regulation

While both the EU and the UK analysis have been used to evaluate the F gas Regulation, the UK report has been primarily depended on to determine which provisions required retrospective analysis. Some articles had a marginal or no real effect on the UK market.[37] As the UK's analysis was not published, a summary of the relevant findings is provided.

Replicating the view of the European Commission, Defra consultants found that the combined effect of the 2006 F gas Regulation and the MAC Directive would hold HFC emissions at 2012 levels, halting projected growth but not reducing emissions.[38] Analysis used the 2006 F gas Regulation as the baseline for calculating costs and benefits (costs and benefits were not calculated from provisions that were carried over to the 2014 F gas Regulation). When provisions were modified the analysis looked at the change. For

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[35] Öko-Recherche support contract for an evaluation and impact assessment for amending Regulation (EU) No 517/2014 on F gases.

[36] Unpublished, but with findings summarised here.

[37] Some uses may already have been prohibited under domestic law while other industries were not present. For example, the use of SF_6 in double glazing or magnesium diecasting facilities with consumption under 850 kg per year and industries such as stationary air-conditioning were much smaller than in some other Member States.

[38] This is a slightly higher level that the 2015 baseline used to set quota for the F gas Regulation in Great Britain.

consistency, and to permit comparison with initial estimates, this approach was maintained in the retrospective analysis supporting this report (which is detailed in section 6).

The HFC quota system was the most notable new measure: limiting the quantity of bulk gas HFC gas suppliers could place on the market.[39] From 2017, importers also required quota for HFCs contained in pre-charged RACHP equipment (Article 14(1)).[40] Like almost all new measures in the 2014 F gas Regulation, the quota system targeted consumption rather than emissions of F gas. Given that quota is fixed, this meant that all other demand-based measures only shifted consumption to other uses provided that all quota was used.

Some measures, such as leak testing, have a direct impact on emissions as well as demand. However, reducing leakage would have increased the available quota to other uses which may or may not be emissive. As it is difficult to determine how gas will be used, analysis attributed all emissions savings to the quota system, assuming that emissions would fall in 1:1 proportion to consumption reductions.

Despite this there are still costs associated with individual measures. In some cases analysis found negative net costs due largely to energy savings (summarised below).

This section summarises the main provisions of the F gas Regulation, including the regulatory justification where known.

Chapter 1 – general provisions

Chapter 1 set out the objective of the F gas Regulation, which is to protect the environment by reducing emissions of F gases. The subsequent chapters and annexes set out measures to deliver this objective. Chapter 1 also includes definitions of terms.[41] The articles in this chapter did not impose any costs or benefits.

Chapter 2 – containment

Chapter 2 focused on the prevention of F gas emissions, through containment during installation, use and at end-of-life of equipment. This chapter is specific to gases listed in

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[39] Based on CO_2e – see Appendix A.

[40] Quota cannot be used directly for pre-charged equipment; the importer must obtain sufficient quota authorisations from a quota holder.

[41] Feedback from stakeholders and regulators has highlighted the need for greater clarity for some defined terms, for example “placing on the market”.

Annex 1 of the F gas Regulation or mixtures containing these substances. One group of substances not covered by this chapter is hydro-fluoro-olefins (HFOs). HFOs are listed as 'other fluorinated greenhouse gases' in Annex 2 of the F gas Regulation (as shown in Appendix D).

HFOs

HFOs, sometimes known as unsaturated HFCs, have considerably lower GWPs than HFCs and are exempt from quota and the phasedown, so have provided a useful alternative. HFOs are more likely to be flammable than HFCs and are typically more expensive.[42] Total UK HFO consumption is estimated to be ~0.01 MtCO2e per year currently and as such their inclusion in total UK emissions would not materially alter the results of the analysis.

HFOs are less stable than saturated HFCs meaning they break down more quickly in the atmosphere, a key reason for their lower GWPs. However, some HFOs photodegrade into trifluoracetic acid which then quickly breaks down into trifluoroacetate which accumulates in water and soil, is persistent and can be harmful to human and animal health in sufficient quantities. Trifluoroacetate does occur naturally and although the UN Environment Programme finds that levels are rising, it does not bioaccumulate and does not exist in sufficient quantities to currently pose a risk to humans.[43] Trifluoracetic acid is also produced by the photodegradation of HFC-134a and the overall impact of the Kigali Amendment may be to reduce accumulation of trifluoroacetate.[44]

There are ongoing discussions relating to the ecological impact of PFAS (per- and polyfluoroalkyl substances) and the most appropriate regulatory framework under which to address use. Some HFCs and HFOs are classed as PFAS.

Article 3 prohibited the intentional release of F gases to the atmosphere. This prohibition was carried over from the 2006 F gas Regulation and therefore imposed no new costs.

Articles 4 and 5 covered leak checks and leakage detection systems and altered the threshold for mandatory leak checks and mandatory leak detection equipment from a

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[42] For example, in 2014, Defra estimated that replacing HFC134a with HFO1234yf would cost an additional £50 per kilogram.

[43] Solomon KR, Velders GJ, Wilson SR, et al. Sources, fates, toxicity, and risks of trifluoroacetic acid and its salts: Relevance to substances regulated under the Montreal and Kyoto Protocols. *J Toxicol Environ Health B Crit Rev*. 2016;19(7):289-304.

[44] Bornman, J.F., Barnes, P. and Pandey, K., (2021) "Summary Update 2021 for Policymakers: UNEP Environmental Effects Assessment Panel"

requirement based on the physical quantity of gas in equipment (as set in the 2006 F gas Regulation, Article 3) to one based on the CO2e value. Table 1 shows the impact of the 5 tCO2e leak check threshold (in the current F gas Regulation) and the quantity (kg) of refrigerant contained within the equipment. In addition, leak checking requirements were expanded to include refrigerated trucks, GIS used in power distribution, and Organic Rankine Cycles (ORC) which generate power from waste heat.

Table 1 highlights the quantity (kg) of refrigerant contained within the equipment, as a result of the 5 tCO2e leak check threshold.

Refrigerant	GWP	kg for 5 tCO2e
R-404A	3922	1.3
R-410A	2088	2.4
HFC-134a	1430	3.5
HFC-32	675	7.4
HFC-152a	124	40.3

Article 4 replaced the leak checks thresholds in the 2006 F gas Regulation of 3, 30 and 300 kg to 5, 50 and 500 tCO2e. These thresholds set the frequency of leak checks required (frequency increases with the quantity of F gas contained in the equipment).

The analysis noted that effective leak testing, maintenance and repair can also improve the energy efficiency of equipment. Although most equipment will continue to function with less than a full charge of refrigerant, it will be less efficient. Inspections for leak testing may also identify other inefficiencies such as blockages. Energy savings of 3-6% were estimated in Great Britain, resulting in annual savings of £5-25 million and 25-125 ktCO2e.

An additional cost of £3-7 million was estimated to result from expanding the scope of requirements to include trucks but counterbalanced with offsetting energy savings of £1-7 million. There were a very small number of ORC systems currently in use in the UK (<10), so the estimated cost of leak testing these systems is in the range £5-10 thousand per year.

Article 4(1) set out exemption conditions from leak checks for GIS if it:

(a) has a tested leakage rate of less than 0.1% per year
(b) is equipped with a pressure or density monitoring device

(c) contains less than 6 kg of F gases

If using the leakage rate exemption, appropriate labelling is required, but analysis concluded that very little equipment at the time had compliant labelling. However, the less than 6 kg threshold means that most primary and secondary equipment at medium voltage will be exempt from leak checks. Larger equipment at high voltage is almost always fitted with automatic leak detection equipment and would also be exempt. As a result, analysis concluded that there were no costs for GIS.

Article 5 set out leakage detection system requirements and retrospectively applied the requirement to install mandatory leak detection hardware to existing installations. The threshold for requiring a permanently installed leak detection system was changed from 300 kg (in the 2006 F gas Regulation) to 500 tCO2e. A retrospective analysis showed that this resulted in a cost of £13-60 million for the RACHP sector, with an additional £2-8 million to expand requirements to fire protection systems. The analysis did not separate the one-off cost associated with retrofit from the ongoing costs associated with installation in new equipment, but it seems likely that the former was the dominant expense.

Article 6 required all operators of equipment which require leak checks to establish and maintain records of this activity (as set out in Article 6(1)). Although the F gas Regulation carries over this provision from the 2006 F gas Regulation, the change to leak checking thresholds under Article 4 created additional administrative costs estimated at £6-16 million per year initially, falling to zero by 2030. Extending the leak checking provisions to trucks imposed further costs of £1-2 million per year. As set out in Articles 6(1) and 4(1), the reporting requirement threshold is for equipment containing 5 tCO2e or more of F gases. Some stakeholders have suggested that this threshold could be extended to cover HFOs.

Article 7 imposed new requirements on producers to take all necessary precautions to limit emissions of F gases in their production, transport, and storage. There is no HFC production in Great Britain, but there is one PFC manufacturer. Furthermore, this provision overlaps with the Industrial Emissions Directive and imposed no new requirements.[45] Analysis estimated a small total administrative burden of £20-60 thousand per year for imports of F gas from outside the EU. This cost will have increased for businesses based in Great Britain following EU Exit but will likely remain small.

Article 7 also required producers or importers, if placing on the market F gases or substances listed in Annex II, to provide evidence of the capture and destruction of any HFC-23 produced as a by-product in the manufacture of F gases, where relevant.

[45] Directive 2010/75/EU, this was retained in UK law following EU Exit.

Article 8 was carried over without significant amendment from the 2006 F gas Regulation and required recovery of F gases from equipment at end-of-life “to the extent that it is technically feasible and does not entail disproportionate costs”. Specific language was added to cover refrigerated trucks and trailers, but these were previously included under a “catch-all” provision and therefore assumed to add no additional cost.

While there were no additional costs relative to the 2006 F gas Regulation, it was not possible to produce a detailed picture of the impact of recovery provisions. This is in part because venting gas is illegal and thus not reported. Existing reporting provisions do not show how much gas is available for recovery, or how much is recovered unless it was sent to a reclamation or destruction facility.

Nevertheless, the lack of analysis in 2011 was partly due to inconsistent and incomplete application of the law across Member States. At the time of analysis, the provision was relatively new and as a result some Member States had yet to fully implement the provisions. Despite an overall lack of data, survey evidence from the UK and France showed low levels of recovery suggesting ineffective application of this article.

RACHP sector stakeholders have suggested that there needs to be greater awareness of this article, particularly in the construction sector. This is because there have been reports of instances of venting when the recovery obligation should have applied.

Recovered gas must either be destroyed (for example through incineration) or reused via reclamation[46] or recycling.[47] If virgin HFCs are cheaper than recycled or reclaimed HFCs there is little financial incentive to recover gas and illegal venting is more likely. Increases in the price of HFCs, because of the phasedown, are likely one of the most significant drivers increasing the portion of HFCs recovered. The phasedown increased the economic incentives for reclaimed R-404A, R-410A and HFC-134a. However, other stakeholder feedback suggested that for some gases it can be cheaper to buy virgin refrigerant than paying for recycling or reclamation.

Stakeholders suggested that incentives, or effective policy and penalties are needed to motivate end-of-life recovery, otherwise venting will likely continue as the cheaper option. Incentives are particularly important for gases that no longer have a market value, such as HCFC-22 and, in time, high GWP HFCs such as R-404A. Recovery of these gases is needed as well as those with market value, especially given the high GWP of HCFC-22

[46] ‘Reclamation’ means the reprocessing of a recovered fluorinated greenhouse gas in order to match the equivalent performance of a virgin substance, taking into account its intended use.

[47] ‘Recycling’ means the reuse of a recovered fluorinated greenhouse gas following a basic cleaning process.

and R-404A (1,810 and 3,922 respectively). Appendix E sets out the GWP for common F gases not included in Annex 1 (Appendix A) or Annex 2 (Appendix D) of the F gas Regulation.

Some concerns were raised around how recycling is defined in the F gas Regulation and potential loopholes, as clarity is not provided on who can use recycled gas. There is general agreement that there is a place for both recycling and reclamation in ensuring recovery and reuse. Whether a refrigerant is recycled or reclaimed is dependent on the sector, application and individual contractor preference. If recycling were prohibited in favour of reclamation, this could result in venting rather than reclamation. Feedback suggested that better education on recovery would be beneficial.

Article 9 encouraged the development of producer responsibility schemes for the recovery of F gases. This provision did not set a legal requirement for implementing such a scheme and the UK did not implement domestic legislation to establish one.

Some companies operating on the Great Britain market have implemented takeback/return schemes for pre-charged equipment, but feedback from the RACHP sector group suggests the uptake of these schemes is very low. This is concerning given that within the RACHP sector HFC recovery is mandatory. The MDI sector has introduced industry led takeback schemes, but also experienced low uptake (around 3%). Without financial incentives, it is difficult to encourage return of MDIs.

Article 10 expanded the training requirements set out in the 2006 F gas Regulation for F gas engineers and required the establishment or adaptation of certification programmes and training for natural persons who install, service, maintain, repair, or decommission equipment that is subject to leak checks, carry out leak checks and/or recover F gases. It also required that government publish guidance making this information available to new engineers but did not mandate retraining. The provision also expanded training requirements to cover MAC. Analysis estimated a one-off cost of £1.3-£3.5 million associated with the time taken for existing engineers to read the new guidance, plus an additional £50-100 thousand to prepare and circulate guidance. Training for new engineers added £100-200 thousand per year and the expansion to MAC an additional £0.25-£1 million per year. Within the UK there are over 50,000 engineer technicians and 7,500 companies registered to work with F gases.[48]

In response to the phasedown and bans set out in Annex 3, the choice of refrigerant used in equipment has and is transitioning from high GWP HFCs to lower GWP HFOs, blends and non-F gas alternatives, such as propane. Many of these lower GWP alternatives

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[48] Based on stakeholder feedback.

(including non-F gases) have flammable properties and stakeholders have consistently fed back that the F gas Regulation should therefore include training on them to overcome concerns about safety that can be seen as a barrier to deployment.

Chapter 3 – placing on the market and control of use

This chapter set out provisions for controlling the use and placing on the market of F gases, through restrictions, requirements for labelling and extending controls to pre-charged equipment.

Article 11 restricted the placing on the market of products and equipment containing F gases and includes reference to Annex 3 in the F gas Regulation, which set out placing on the market prohibitions for certain products and equipment. Placing on the market prohibitions were carried over from the 2006 F gas Regulation and expanded to include additional bans. Further information on the impact these prohibitions have had on the market is set out in section 7 – state of technology.

Most of the costs from bans were relatively small. Importantly, there were no ongoing costs associated with adopting new technologies (such as higher manufacturing costs or reduced energy efficiency). All costs were from the use of more expensive (lower GWP) alternatives.

In some cases, there were readily available substitutes, most notably HFC-32 (GWP 675) which is also cheaper than the gases it replaced, such as R-410A. In other cases, non-HFC alternatives have been used, such as CO_2, hydrocarbons, or ammonia which are cost-effective but not always suitable alternatives, often due to flammability or toxicity concerns. In some instances, analysis predicted industry would switch to HFOs. Consequently, refrigerant manufacturers often use HFOs to create lower GWP HFC/HFOs blends. Analysis predicted that more widespread adoption of HFOs would see their price fall, leading to lower costs over time, which is being reflected in recent market prices.

The prohibition on domestic refrigeration, using HFCs with a GWP of 150 or more, resulted in a small cost. Domestic refrigerators previously used HFC-134a as a refrigerant and an HFC foam blowing agent. Manufacturers have transitioned to use hydrocarbon refrigerants in domestic refrigerators, which are less expensive but are limited in charge size due to flammability. Prior to the F gas Regulation, less than 10% of refrigerators (mostly larger units imported from the U.S.) still used HFC refrigerants. Consultants predicted these would switch to HFO-1234yf, adding £20 per unit at a total cost of £0.6-£1.2 million per year halving by 2025.[49]

Analysis predicted a further £1.5-3.3 million per year for hermetically sealed commercial refrigerators,[50] as a result of the prohibition on commercial refrigeration with around half that expense being the amortised cost of developing non-HFC systems. For other stationary refrigerators there were already cheaper refrigerants that complied with the ban and were more energy efficient.[51] Analysis estimated no cost from adopting the new refrigerants but a saving of £13-30 million a year in energy costs and CO2 reductions of 70-150 kt per year.

Analysis estimated an additional £370-700 thousand for hermetically-sealed movable air conditioning including amortised development cost.[52] There was an additional £300-600 thousand for extruded polystyrene (XPS) foam (used in building insulation).[53] Analysis estimated a further £3.5-7 million for technical aerosols, including any aerosol not considered "novelty" (for which a total ban already existed) and where flammable hydrocarbons are not suitable (for example lubricants and air dusters).[54] These costs are entirely from the higher cost of HFO propellants.

The remaining bans imposed neutral or very small costs. As well as new equipment bans there were additional costs of £0.5-1.5 million per year associated with the requirement that F gas only be sold to appropriately trained and qualified individuals and companies.

Article 11 included exemptions from the Annex 3 prohibitions. Military equipment is exempt from all prohibitions. Equipment that has lower lifecycle CO2e emissions than equivalent equipment meeting ecodesign requirements and containing HFCs is also exempt from the bans set out in Annex 3. No requests have been made under these exemption conditions. In addition, Article 11(3) enabled a temporary (up to four years) exemption to a ban to be

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49 This was based on an assumption of HFO-1234yf costing an additional £20 per unit falling to £10 by 2025. Since implementation, evidence has not been provided of any refrigerators on the market that switched to HFO-1234yf. Instead, it is assumed that all units now use hydrocarbon refrigerants.

50 Ban 11 restricted HFCs with a GWP over 2,500 from 2020 and HFCs with a GWP over 150 from 2022.

51 Ban 12 restricted refrigerants with a GWP > 2,500 in stationary refrigeration (except products cooling to below 50°C) from 2020.

52 Ban 14 restricted HFCs with a GWP > 150 in portable air conditioners from 2020.

53 Ban 16a restricted HFCs with a GWP > 150 in XPS foam (typically used in building insulation or laminated boards) from 2020.

54 Ban 17 restricted the use of HFCs with GWP > 150 in technical aerosols from 2018.

granted in response to requests that demonstrate that no alternatives are available or cannot be used for technical or safety reasons or the use of technically feasible and safe alternatives would entail disproportionate costs. No exemptions have been granted under this provision thus far.

Article 11(4) specified that distributors can only sell to certified undertakings and that F gases can only be purchased by certified undertakings for the purpose of installation, servicing, maintenance or repair of equipment containing F gases or relying on F gases. Concerns have been raised around the implementation of this provision with regards to the automotive sector. Undertakings within this sector can purchase HFC-134a, but the MAC Directive under which these undertakings hold qualifications does not cover charging or handling of refrigerants and there are concerns that this leads to leakage.

Stakeholders highlighted concerns with Article 11(5), which states that end-users can only purchase pre-charged systems where evidence is provided that the installation will be carried out by a certified individual. There are no requirements for retaining that evidence to allow for compliance checks. Stakeholders feel this is a loophole that could be closed if sellers were required to keep records of who equipment was sold to, especially given the projected increase in heat pump sales. Concerns have also been raised about end-users accessing public registers of certified individuals/companies and falsely claiming individuals/companies named on those registers are installing the equipment.

Article 12 expanded the labelling requirements in the 2006 F gas Regulation to include: newly added categories of equipment (solvent systems, aerosols, ORC, and foams), labelling of exempted products under derogations, tCO2e on labels, recycled and reclaimed gases, labelling of F gas placed on the market for a variety of uses and labelling information in descriptions used for advertising. These additional requirements support other new requirements in the F gas Regulation, such as the quota system and exemptions. Without these additional labelling requirements, it would not be feasible to enforce the F gas Regulation.

Analysis showed a £50-150 thousand total one-off cost for the new labelling requirements. Amending labels to include tCO2e added a £2-6 million one-off cost for redesign and an additional £400-800 thousand per year thereafter. There was a one-off cost to design labelling for reclaimed F gas of £0.3-1 million and £300-750 thousand per year thereafter. Finally, the analysis found a small cost £25-75 thousand per year for labelling special purposes and no further cost associated with labelling exempt purposes or the advertising requirement.

Article 13 extended restrictions on the use of SF_6 in magnesium diecasting. The 2006 F gas Regulation already imposed a ban on SF_6 in magnesium diecasting facilities with annual consumption over 850 kg per year and there were no facilities in the UK under that limit. There were therefore no costs for these measures.

This article also banned the use of F gases with a GWP of 2,500 or more for servicing or maintenance of refrigeration equipment with a charge size of 40 tCO2e or more from 1 January 2020. Exemptions to this prohibition are provided for military equipment or equipment intended for applications designed to cool products to temperatures below -50°C. This prohibition only covers the use of virgin F gases – reclaimed or recycled F gases can continue to be used until 2030.

Analysis projected a very substantial one-off cost of £100-280 million to replace or retrofit existing systems prior to 2020 in response to this ban but did not predict any ongoing costs. Projections also indicated it would be necessary to eliminate HFCs with a GWP over 2,500 to meet phasedown targets. While Jacobs' prospective analysis chose to separate the impacts of equipment bans from the phasedown the finding strongly implies that most of the costs can be combined.

Stakeholders suggest the 40 tCO2e threshold is outdated and should be removed since it acts as loophole for the ongoing use of virgin R-404A. It is noted that the threshold was intended to address the concern at the time the F gas Regulation was brought in that it was not thought cost-effective to retrofit small condensing units and transport systems. However, retrofit costs have proved lower than expected and the transport sector has been retrofitting R-452A into trucks for several years.

Article 14 introduced, from 1 January 2017, the requirement that RACHP equipment pre-charged with HFCs must not be placed on the market without being accounted for within the quota system. It also introduced the need for manufacturers and importers of such equipment to draw up a declaration of conformity to evidence that equipment placed on the market has been accounted for within the quota system. Article 18 set out the means through which quota can be used to enable the placing on the market of pre-charged equipment.

Chapter 4 – reduction of the quantity of hydrofluorocarbons placed on the market

This chapter set out measures to reduce the quantity of HFCs placed on the market. The primary mechanism through which this is achieved is the HFC phasedown.

Article 15 introduced the phasedown which aimed to reduce the quantities of HFCs placed on the market. Annex 5 of the F gas Regulation set out the phasedown schedule (shown in Appendix B), which introduced steps reducing the quantities of HFCs placed on the market over time, reaching a 79% reduction compared to 2015 by 2030. The phasedown was implemented through quota allocation given to producers and importers, which set an annual limit on the quantity of HFCs they could place on the market (Article 16).

Analysis predicted the bulk of costs and benefits from the F gas Regulation would arise from the HFC phasedown. Overall, the phasedown was expected to contribute 58% of costs (£658-1,508 million) and 68% of benefits (£2,513-7,542 million).[55]

The phasedown is calculated in relation to the baseline period. The European Commission implemented a baseline set as the annual average of the total quantity of HFC placed on the market from 2009 to 2012. This formed the basis of initial analysis which also assumed that in the absence of further regulation emissions would remain at 2012 usage levels. To calculate a baseline for the Great Britain F gas Regulation, the baseline period 2015-2019 was used, as data were more readily available for placing on the market from the implementation date of the F gas Regulation.

To calculate achievable phasedown steps, the European Commission looked at the technologies likely to be available by 2030 and identified cost-effective abatement opportunities (defined as technologies with a cost no greater than €50 per tCO2e abated).[56] The Commission then assessed how much HFC consumption could be reduced if industry adopted all cost-effective technologies by 2030.[57] They then set intermediate targets based on the end goal.

It is noted that the phasedown steps do not directly translate into the maximum quantity of HFCs available through quota. When calculating the maximum quantity for placing on the market, first the percentage reductions are applied to the baseline and then the quantity of reported quota exemptions (as set out in Article 15(2)) are subtracted. This method of calculation has caused some concern among stakeholders, particular those in the RACHP sector, as it creates uncertainty around how much quota would be allocated in future years. This is because it leaves open the possibility that quota would be reduced even more should the quantity of HFCs for exempted uses increase.

Article 15(2) set out exemptions to the phasedown, which include producers or importers placing less than 100 tCO2e of HFCs on the market a year and HFCs destined for the following uses: imports for destruction, feedstock applications, export, military equipment, semiconductor industry and pharmaceutical MDIs. The MDI exemption came into force from 1 January 2018, while the others were implemented from the date the F gas Regulation entered into force (1 January 2015).

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[55] Costs and benefits are for the period 2015-2035, discounted to 2015 net present value. Costs include the impact of articles 16-18 described in more detail in the next section.

[56] Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

[57] With a further caveat that such technologies should be energy efficient.

In addition to the exemptions laid down by Article 15(2), Article 15(4) allowed an exemption to the HFC phasedown and requirement for quota to be granted for up to four years where it can be demonstrated that no alternatives are available or cannot be used for technical or safety reasons and that a sufficient supply of HFCs cannot be ensured without disproportionate cost. No such exemption has been granted under either the EU or Great Britain F gas Regulation.

Articles 16, 17 and 18 detail the administrative procedures for quota allocation and transfer in conjunction with Annex 6 which sets out the quota allocation mechanism. Annual administrative cost to business was assessed to be £100-350 thousand. From 1 January 2015, any HFCs (bulk gas) placed on the market (through production or import) needed to be accounted for under the quota system. From 1 January 2017, this also applied to imports of pre-charged equipment.

Quota was initially allocated to producers or importers who placed HFCs on the market from 2009 to 2012 and reported data under the 2006 F gas Regulation (Article 16(1)). Undertakings that received quota through this mechanism are considered to be incumbents. In addition to the allocation of incumbent quota based on historic activity, a portion of the total annual quota is reserved (11%) for producers or importers that have not previously placed HFCs on the market. Any undertakings wishing to receive quota allocation from this reserve pot must declare their intention to place on the market the following year (as set out in Article 16(2)). These undertakings are referred to as new entrants. Incumbents may also request additional quota from this reserve. Reference values are re-calculated every three years, as set out in Article 16(3), and Annex 6 includes the mechanism through which quotas are allocated (Article 16(5)).

Quota is allocated in tCO2e, providing flexibility to producers and importers as to the type of HFCs that can be placed on the market. Article 18 enables incumbent quota holders to transfer quota to another producer or importer or to authorise an undertaking to use its quota for placing pre-charged equipment on the market (Article 14).[58] New entrants may not transfer quota but can grant an authorisation if they physically sell the corresponding amount of gas when the authorisation is made (Article 18(2)).

[58] If incumbents fail to use quota in a given year, this is reflected in the reference value recalculation (as set out in Annex 6 of the F gas Regulation) and they would lose some of their original quantity in subsequent years. Consequently, they may prefer to import bulk gas on behalf of another company rather than sell their quota.

Quota authorisation

At the time the EU introduced the F gas Regulation and the HFC phasedown it was the first of its kind. This created a problem that while European equipment manufacturers were forced to reduce consumption of HFCs, they would still be in direct competition with equipment manufacturers outside the EU who would not face these constraints.

It would also result in 'carbon leakage', whereby costly domestic abatement is offset by increased emissions elsewhere.[59] In other words, domestic producers would spend resources developing newer technologies to comply with phasedown and consumers would respond by purchasing imported equipment which used higher GWP gases. This would not only harm domestic industry but result in higher emissions.

The European Commission responded to this challenge by creating a closed system for bulk gas and pre-charged equipment. Importers of pre-charged equipment must obtain quota authorisation and they must have sufficient authorised quota for the quantity of gas within the imported equipment. This protected manufacturers within the domestic market by ensuring a level playing field for EU and non-EU manufacturers. It also ensures the integrity of the phasedown mechanism.

While necessary under the circumstances at the time, the closed system is imperfect. Stakeholders note that the system can be bureaucratic and quota authorisation only addresses gas in equipment and not the more conventional form of carbon leakage where CO_2 emissions are embedded in the manufacture of imported goods. For example, if HFCs are used as a cover gas then only the end-product enters the domestic market. But there are still emissions associated with that import and domestic manufacturers may face a disadvantage.

The Kigali Amendment to the Montreal Protocol introduced an alternative mechanism by which all Parties agreed to a global HFC phasedown. While the Kigali Amendment does not require countries to use a quota system it does place a cap on the quantity of HFC consumed and produced. This means that overseas manufacturers cannot gain a competitive advantage over domestic industry by lowering their standards.

While the Kigali Amendment is not incompatible with the system of quota authorisation, there are tensions between the two approaches. While inward processing[60] can be used to

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[59] Although in the case of gas in pre-charged equipment most emissions would still take place within the EU/ Great Britain. This is slightly different to most instances of carbon leakage where CO_2 emissions are associated with manufacture of equipment overseas.

[60] Using inward processing to process or repair your goods

import bulk gas and pre-charge equipment for export without the need for quota, the gas used to pre-charge the equipment is still counted under the Kigali Amendment concept of consumption.

It is not always possible to avoid using quota, even if using inward processing. This is especially true where manufactured goods cross borders. Some stakeholders have indicated that they ship goods manufactured in Great Britain to the EU for distribution, including back to the Great British market. As both markets operate separate quota authorisation systems, this inherently causes double counting. There is therefore a risk that the system of quota authorisation could disrupt supply chains and reduce trade with other markets, including the EU and Northern Ireland.

The Kigali Amendment does not immediately eliminate the rationale for the current system. At present the Kigali Amendment imposes a less restrictive phasedown than the F gas Regulation and will not become more restrictive until 2034. It may be decided to further tighten the quota system in Great Britain in that time. As part of this, policymakers should continue to monitor the effectiveness of the system of quota authorisation to ensure that it continues to serve a purpose.

The supply constraint, caused by the phasedown, was expected to increase HFC prices, resulting in reductions in use. Charging for quota is not a measure contained within the F gas Regulation, but has been introduced by some EU Member States, for example as part of a deposit and refund scheme.[61] The UK did not implement such a scheme.

To assess costs for quota, Defra analysis considered capital costs and the increased cost of switching to more expensive refrigerants. The higher cost of gas does not measure the costs associated with quota, in part due to existing gases becoming more expensive, because these costs to end-users are also increased revenue for quota holders. Rather it is the cost of switching to gases such as HFOs which have a higher associated manufacturing cost. While analysis noted that some alternative gases would be cheaper, they predicted an average increase of £5-12/kg for refrigerant gases with a total annual cost of £40-100 million in 2030.

Although some refrigerant gases, such as CO2, are cheaper than their HFC equivalents, the analysis assumes that there may still be additional capital costs. Such costs are estimated at £25-55 million annually including amortised research and development costs. It is assumed that in the long-term, low carbon technologies may be no more expensive than existing equivalents.

[61] See also discussion on recovery in section 6.

Although there is no quantification of the benefits from requiring quota authorisation, the requirement was introduced to prevent imported F gas equipment from displacing European manufacturers. As the quota requirement increases the cost of HFCs there was a risk that overseas manufacturers of pre-charged equipment, who were not then subject to any restrictions, would be able to sell at lower cost. This would have both undermined the effectiveness of the F gas Regulation and caused damage to domestic manufacturing.

As quota can be used either for bulk gas or, in the form of quota authorisation, for pre-charged equipment, analysis attributes the majority of costs and emissions savings to the HFC phasedown. This left relatively small costs associated with compliance and documentation: £100-£300 thousand annually for manufacturers of pre-charged equipment and £300-£750 thousand each year for importers. These numbers were however calculated prior to the UK leaving the EU. As the UK imports a substantial quantity of equipment from the EU, it is likely that these underestimate present costs.

Article 17 set a compulsory requirement for relevant importers, producers and undertakings to be registered in the F gas system in order to receive quota. Relevant undertakings include incumbent producers/importers (Article 16(5)), new entrants (Article 16(2)), undertakings who have been transferred quota (Article 18), exporters of F gases, importers of equipment containing HFCs and undertakings supplying or receiving exempted F gases (under Article 15(2)). Valid registration is considered to be a trade licence for HFCs, as required under the Montreal Protocol.

Chapter 5 – reporting

Article 19 set out the requirement for annual reporting on production, imports, exports, feedstock use and destruction. Producers, importers, exporters or undertakings must report on bulk gas and pre-charged equipment and reporting covers substances listed in Annex 1 and Annex 2 of the F gas Regulation. Thresholds for reporting are included and differ between the reporting activity. Analysis estimated an annual £40-£160 thousand in reporting costs for exporters.

Undertakings which placed 10,000 tCO2e or more (in bulk gas) on the market must have their report verified by an independent auditor for accuracy. Analysis estimated a total cost of £200-£500 thousand for importers and a further £120-£400 thousand per year associated with 43 new gases requiring reporting found in Annex 2.

It was also estimated that a small number of companies responsible for the destruction of gas would incur an additional £12-£40 thousand reporting cost. Producers and importers of pre-charged equipment, placing more than 500 tCO2e would need to provide additional details at an annual cost £0.4-1.6 million.

In addition to placing on the market reporting (which is used for reporting on consumption to the Ozone Secretariat of the Montreal Protocol), Article 20 requires the establishment of emissions data reporting. F gas emissions are required for reporting under UNFCCC, although in comparison to placing on the market data, emissions are mainly calculated based on estimates.

Chapter 6 – final provisions

This chapter includes a number of final provisions. This includes Article 21 which requires a comprehensive review of the F gas Regulation which this assessment report seeks to provide.

Article 23 required there to be a balanced participation of stakeholders when implementing the Regulation. In preparation for the Great Britain F gas Regulation and through its implementation there has been regular engagement with stakeholders across F gas sectors. As part of the review, sector group meetings and one-to-ones were held to ensure feedback from across stakeholders, sectors and uses.

Article 24, in the Great Britain F gas Regulation, sets out the Committee Procedure. This relates to devolved competences and includes how functions are exercised. This Article allows Scottish and Welsh Ministers to consent to functions being exercised by the Secretary of State or to direct the appropriate regulator to perform functions on their behalf. This Article enables the Great Britain F gas system to operate across Great Britain.

Article 25 sets out the requirement for penalties. Article 25(1) addresses penalties relating to the Regulation as a whole. As set out in section 3, the UK government implemented domestic regulations to enforce the necessary provisions in Article 25.[62] Article 25(2) specifically addresses penalties for undertakings in relation to exceeded allocated quota or placing on the market breaches (in accordance with Article 16(5)) and only relates to bulk gas quota.

Annex 3 – placing on the market prohibitions

Annex 3 sets out placing on the market prohibitions (from specified dates) for listed products and equipment. Most of the Annex 3 prohibitions have already come into effect, however, there are still some prohibitions that will become effective in the coming years. Some of the prohibitions were carried over from the 2006 F gas Regulation and some were introduced with the 2014 F gas Regulation. This section focuses on the prohibitions introduced under the 2014 F gas Regulation.

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[62] The Fluorinated Greenhouse Gases Regulation 2015 and The Fluorinated Greenhouse Gases (Amendment) Regulations 2018

Fire protection

The F gas Regulation introduced a placing on the market prohibition on fire protection equipment containing HFC-23 (GWP 14,800) from 1 January 2016 (Annex 3 No 3). It also retained a previous prohibition on equipment containing PFCs from the 2006 F gas Regulation.

Fire protection systems using F gases are a small part of the overall fire protection market and are mainly used when water-based fire protection could cause damage to building contents, for example in computer centres or art museums. Fire protection systems can be long lasting, approximately 15 years, so there are existing systems within Great Britain still relying on HFCs. Following HFC-23 ban, the two remaining and commonly used HFCs in this sector are HFC-227ea and HFC-125, (with GWPs of 3,500 and 3,220 respectively).

Industry have fed back that the price pressure created by the HFC phasedown has encouraged end-users to move away from the use of HFCs, particularly in new fire protection systems. The impact of quota and the HFC phasedown has effectively phased out the use of HFCs in this industry, particularly since 2018 with the introduction of the 63% phasedown step.

The available alternatives to HFCs are broadly split into two categories. These are the use of in-kind solutions or inert gases. In-kind solutions have similarities to HFCs in how they operate and are stored. This includes the use of fluorinated ketones (fluoroketones), such as FK-5-1-12. There are commercially available fluoroketones on the Great Britain market for use in this sector and other agents are being developed. Inert gas systems work by reducing oxygen levels in a space within safe limits. Inert gas suppression systems often use mixtures containing argon and nitrogen (and may contain CO2). Not-in-kind water-based solutions remain a viable alternative, but gas systems are often preferable given the potential for water damage.

RACHP

The RACHP sector can be divided into two main categories. These are refrigeration and comfort cooling and heating. Within these two categories there are a number of sub-sectors. For refrigeration these include residential, commercial, industrial and transport. Comfort cooling and heating includes direct and indirect systems, as well as MAC. The technologies and gases used across these sectors has changed over the duration of the F gas Regulation. One driver for this has likely been the placing on the market prohibitions set out in Annex 3 of the F gas Regulation. Additionally, and in parallel, the phasedown has increasingly restricted availability and accessibility of HFCs.

The F gas Regulation included a number of prohibitions on refrigeration systems using high GWP F gases. From 1 January 2015 the placing on the market of domestic refrigerators and freezers containing HFCs with a GWP of 150 or more was prohibited (Annex 3 No 10). This prohibition acted as a backstop for this sub-sector which was already transitioning away from HFCs (such as HFC-134a) to hydrocarbons, typically isobutane (R-600a).

Prohibitions also targeted commercial refrigeration, used in food retail and food services. Commercial refrigeration systems are usually located in public spaces and includes the use of stand-alone units, condensing units and central systems. The F gas Regulation includes a prohibition on refrigerators and freezers for commercial use, specifically hermetically sealed equipment, containing HFCs with a GWP of 2,500 or more from 1 January 2020 (Annex 3 No 11). This prohibition was extended to equipment containing HFCs with a GWP of 150 or more from 1 January 2022. In addition, there is also a prohibition on multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more containing F gases with a GWP of 150 or more (Annex 3 No 13, from 1 January 2022).

These prohibitions impact the placing on the market of new equipment. Existing equipment already on the market can continue to be used. The main HFCs typically used in this sub-sector have been R-404A, R-507A and HFC-134a. Much of this sub-sector has already transitioned away from these high GWP HFCs and there are a number of alternatives being used within Great Britain, including hydrocarbons (typically isobutane, propane (HC-290) and CO2 (R-744). There are also a number of new HFC/HFO blends with a GWP of less than 150, which are well suited to this sub-sector.

Industrial refrigeration includes direct expansion cooling (DX) systems, flooded systems and chillers, which have previously made use of HFCs such as R-404A and HFC-134a. There is a prohibition in the F gas Regulation on stationary refrigeration equipment containing HFCs with a GWP of 2,500 or more (from 1 January 2020) (Annex 3 No 12), which impacted this sub-sector. Unlike domestic and commercial refrigeration, industrial refrigeration is often in restricted access locations, which provides opportunity for the use of flammable refrigerants and other alternatives. One such alternative is ammonia, which has a safety category of B2L due to its high toxicity (B) and lower flammability (2L).[63] Where ammonia is not suitable, other alternatives for industrial applications include CO2 and HFO/HFC blends with a GWP of less than 150 (particularly in smaller systems).

The F gas Regulation also includes prohibitions relating to comfort cooling and heating sub-sectors. These have been targeted at direct comfort cooling and heating systems. Movable systems have been impacted by the prohibition on the use of HFCs with a GWP of 150 or more since 1 January 2020 (Annex 3 No 14). As a result, these systems have transitioned away from HFCs (typically R-410A, GWP 2088) to hydrocarbons.

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[63] UNEP/ASHRAE refrigerant factsheet and ASHRAE designation and safety classification of refrigerants

The F gas Regulation also contains an upcoming ban on small split air-conditioning systems (those containing less than 3 kg of F gas) using F gases with a GWP of 750 or more, from 1 January 2025 (Annex 3 No 15). Within this sub-sector there has already been a significant transition away from the use of R-410A to HFC-32 and HFO/HFC blends. There is some use of propane, but this is very limited within Great Britain. HFC-32 has proved to be an important alternative to R-410A, it has a GWP of 675 and is a high-pressure refrigerant with similar characteristics to R-410A, apart from flammability. R-410A is an A1 non-flammable refrigerant, whilst HFC-32 is an A2L lower flammability refrigerant.

Foams

HFCs, such as HFC-134a, HFC-152a, HFC-245fa, HFC-365mfc and blends of these, have been used as foam blowing agents. Under the F gas Regulation the placing on the market of extruded polystyrene foams using an HFC blowing agent with a GWP of 150 or more was banned from 1 January 2020 (Annex 3 No 16). For other foams, the F gas Regulation sets out the same prohibition from 1 January 2023. Alternatives within this sub-sector include hydrocarbons, HFOs and CO2.

Aerosols

The F gas Regulation refers to another use of HFCs as “technical aerosols”. The use of HFCs in aerosols is fully emissive. In order to reduce emissions from this use, placing on the market of technical aerosols using a propellant with a GWP of 150 or more was banned from 1 January 2018 (Annex 3 No 17). This sub-sector previously relied mainly upon the use of HFC-134a. The use of HFCs in technical aerosols and the emissions from this sector has reduced because of this ban. Alternatives for aerosol propellants include hydrocarbons, HFOs and compressed gas (CO2, air, nitrogen and nitrous oxide). There are also not-in-kind alternatives such as hand-pumped sprays, powders and roll-on liquids/sticks.

Summary of projected impacts

While the F gas Regulation covers F gases broadly, measures applying to HFCs generated most of the costs and benefits. Of this, most costs and benefits can be directly attributed to the HFC phasedown, including reductions in HFC emissions.

Overall, the UK analysis projected discounted costs of £1.6-2.7 billion and discounted benefits of £3.8-11.2 billion from 2015 to 2035, at 2014 prices (see Appendix F). Total benefits exceeded total costs in every scenario, including comparing the lowest benefit estimate to the highest cost estimate. Most of these benefits came from reduced CO2e emissions, largely from lower usage of HFCs but with some additional savings from reduced energy usage. However, costs are heavily frontloaded, while benefits are largely measured towards the end of the studied period. This reflects the high initial investment outlay to develop new technologies and replace existing capital equipment. Delayed benefits reflect both the time required to bring new technologies to market and the time lag between reducing consumption and reducing emissions as gas sits in banks of equipment.

The EU did not estimate total discounted costs and benefits but estimated annual costs at €1.7 billion per year (plus an additional one-off administrative cost of €1.9 billion) across the EU. They estimated total emissions reductions at 70.7 MtCO2e annually by 2030, with an average cost of €16/tCO2e abated.[64] Although the EU did not calculate an average cost, the rule capped marginal cost at €50 and Schwartz estimated that more than 75% of reductions would cost less than €20/tCO2e.[65]

Impacts of EU Exit on analysis

In evaluating the success of the F gas Regulation, comparison of the outcomes from the F gas Regulation and the original projections was undertaken. The UK's exit from the EU since the introduction of the F gas Regulation may substantially impact not only the costs associated with the Regulation but also the "business as usual" counterfactual envisaged in the initial analysis.

Initial Defra cost estimates were for the UK market. As this report is only reviewing the implementation of the F gas Regulation in Great Britain, costs are only assessed for Great Britain.[66] Neither the EU nor UK analysis considered Great Britain specifically. Defra's own cost estimate is for the UK's cost share of the EU F gas Regulation. It measured the impact on Great Britain of both the UK and EU adopting the F gas Regulation against a base case of neither adopting it.

This is no longer a realistic counter factual, as any future Great Britain action would be taken independently with implications for costs and benefits. While the UK does import and export outside of Europe, and in some cases UK manufacturing is aimed solely at the domestic market, a large portion of manufacturers have indicated to Defra that they produce for both the EU and UK markets. While there is considerable heterogeneity across these markets, it is likely that manufacturers serving Great Britain will be heavily influenced by the European market.

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[64] Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

[65] Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

[66] Northern Ireland remains subject to EU F gas legislation in accordance with the Northern Ireland Protocol.

EU findings

As the current law is retained EU legislation, the European Commission has a matching review obligation to the UK's. The European Commission has already published its own retrospective analysis which found the EU F gas Regulation to have been a success in reducing emissions at significantly lower average cost than predicted.[67]

The European Commission did not attempt to separate the impacts of the phasedown from those of other measures aimed at HFCs. Instead, they measured the impact of the F gas Regulation as a whole. Overall, the EU found average cost of abatement (per tCO2e) was only €6 with a marginal cost of €16: compared to €16 and €50 respectively.[68]

While the European Commission did not breakdown costs by Member State, they found that southern Member States had lower average costs of abatement but a higher relative burden overall. This is consistent with the aim of tradeable quota which shifts effort share to the lowest abatement cost. The report attributed the north/south difference to higher usage of air-conditioning in warmer climates. This would imply that average abatement costs in Great Britain would be more similar to other northern European nations, and thus higher than the EU average, but without the ability to shift effort share to countries with lower average abatement costs.

Overall, the European Commission found that the EU F gas Regulation has been a success but also highlight some concerns. In recent years industry has not used the full quota allotment and has instead stored excess quota as quota authorisation. The European Commission estimate banks of quota authorisation equal to seven years of normal annual demand for imports of pre-charged equipment.[69] Such imports comprise approximately 10% of total HFC demand, suggesting that the stored quota authorisations equate to roughly 0.7 years of total HFC consumption.

This raises a concern that although the EU F gas Regulation met absolute targets for emissions reductions, based on previous estimates of feasibility and cost effectiveness, it did not achieve all possible emissions reductions up to the target €50/tCO2e marginal abatement cost, taking into account innovation. Most consumers will only interact with quota through the impact on prices. If those prices do not reflect the cost of carbon the

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[67] Öko-Recherche support contract for an evaluation and impact assessment for amending Regulation (EU) No 517/2014 on F gases.

[68] Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases and Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases.

[69] EEA F gas report 2021

consumers will likely fail to consider the full impact of CO2e emissions in their buying decisions.

The report also raised a concern regarding the scale of illegal HFC trade. A study by the Environmental Investigation Agency (EIA) found significant increases in imports of HFCs in countries bordering EU states.[70] This included the UK although the European Commission concluded this was likely a consequence of EU Exit with suppliers choosing to import directly to the UK rather than ship HFCs via the EU. The authors concluded that illegal imports accounted for as much as 20-30% of HFCs sold in the EU and argued this was a leading cause in the decline in HFC price. While troubling, it is unclear to what extent this finding is relevant to Great Britain.

6. Costs and benefits

The analysis within this section considers the impact of the current F gas Regulation and does not seek to evaluate future policy measures. It was found the F gas Regulation reduced overall emissions in Great Britain by 13.6-24.3 MtCO2e cumulatively across the period 2015 to 2021, generating net benefits of £1.8-8.4 billion.[71] Total cost was estimated at approximately £118 million, indicating the Regulation has generated significant net benefits.[72]

An average cost per tCO2e emissions abated of £4.10-7.40 (€4.80-8.60) was estimated.[73] This estimate is consistent with EU estimates of €6. It is also considerably less than initial estimates of an average abatement cost of €16. A maximum marginal abatement cost is also estimated, recorded in 2017, of £23.60-28.30 (€27.40-32.90) as compared to a maximum abatement cost of €50 proposed in the impact assessment produced ahead of the EU F gas Regulation.

Despite the uncertainty present there is a high level of confidence that the phasedown produced positive net benefits. This would also have been true at the lower estimated marginal benefit (€50) from abatement calculated when the F gas Regulation was implemented. There is also high certainty that marginal cost did not exceed marginal

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70 EIA's report on illegal trade ("Europe's Most Chilling Crime: The illegal trade in HFC refrigerant gases")

71 All numbers quoted in the text are at a 1.5% discount rate unless stated otherwise. At a 3.5% discount rate net benefits are £1.7-8.0 billion.

72 Costs are £107 million at both the 1.5% and 3.5% discount rate.

73 £4.40-7.90 at a 3.5% discount rate.

benefit using current valuations of carbon abatement, and it is likely that this would still be true at a marginal benefit of €50.

Overall the Regulation has been successful in its objective to accomplish (cost-effective) emissions reductions. It was further observed that the Regulation has promoted innovation and this has led to significantly lower abatement cost than initially predicted. However, this also suggests that the European Commission underestimated the ability of industry to reduce the usage of high GWP gases and that further action may be necessary to stimulate continued reductions.

It was found that the phasedown has been the most effective component of the Regulation and is responsible for almost all emissions reduction, and the large majority of costs.[74] The analysis indicates that the phasedown operates through price incentives and that this allows flexibility and promotes innovation. However, the decline in price of quota may have reduced incentives for continued innovation and that this may contribute to industry not developing or adopting better alternatives where available.

This assessment does not rule out the possibility that other measures may have imposed unquantified costs. For example, equipment bans may have led to additional costs without further reducing emissions, and that these may have distorted incentives leading to higher costs and potentially reducing the incentive to innovate. While the analysis finds that any costs are likely small, and would not alter the overall findings, there was not empirical support found for additional benefits originating from these bans beyond those as a result of the phasedown.

It is important to note the difference in approach, taken by this analysis and the European Commission, to evaluate the impact of the current Regulation. The European Commission considered the overall impact of the Regulation and evaluated the impact of specific measures in packages and did not present costs or benefits of specific measures in isolation. While this analysis evaluated the impact of measures separately. This difference in approach may explain some of the unexpected outcomes from the analysis, particularly the impact of the bans.

Additionally, the analysis indicates that while the phasedown has effectively targeted the use of gas, and has reduced emissions in this way, the Regulation does not adequately address emissions at end-of-life. There is significant evidence to suggest that gas is still vented where recovery is both possible and cost effective.

[74] The only emissions reductions not attributable to the HFC phasedown are those from regulation of non-HFCs (such as SF_6) which are too small to review.

HFC phasedown

The HFC quota and phasedown was found to be responsible for all reductions in the use of HFCs. Although other measures target the use of HFCs, the phasedown imposes a strict cap on usage meaning that targeted reductions in use would be offset by increases elsewhere.[75] While there is confidence that all emissions reductions derive from quota limits, it is not certain that there are no other costs. However, it is thought that this effect is small and does not affect the overall conclusions.

This issue, and other analytical limitations, is discussed at length in Appendix G. The Appendix also describes the methodology in calculating costs and benefits in greater detail. This section will only summarise the approach alongside the reported results.

To estimate the cost of phasedown, price data was used to infer a marginal abatement cost. This method does not calculate the additional price paid by users for quota, but rather the costs incurred to avoid using quota. This may include both expenditures to purchase alternative equipment but also loss of benefit from foregone activities.

The European Commission intended that the increased price of gas would alter consumer behaviour by encouraging substitution of high GWP gases and deterring low value uses. However, the quota system was designed in such a way that quota price would not reach the targeted marginal abatement cost.

Unlike some other quota systems, such as the Emissions Trading Scheme, HFC quota focuses purely on consumption, regardless of whether the gas is emitted to atmosphere. This means highly emissive uses, such as aerosols, require the same amount of quota as gas which is later recovered (although recovered gas could potentially be reused and then emitted).

The quota system does have some direct impacts on emissions. For example, the increased cost of gas creates an incentive to reduce leakage and to recover some gases from equipment reaching end-of-life. As discussed, the available evidence suggests that the price of gas has a greater impact than the targeted regulatory requirements. Measures to reduce leakage have a more immediate impact on emissions but in the long run it is expected that a higher portion of emissions reductions will come from placing less, or lower GWP, gas into systems.

[75] Provided all quota is used, however, this does not need to happen in the current year. It was observed that recently not all quota has been used in the current year. However, market participants have been storing quota authorisation which continues to trade at a non-trivial positive price. This suggests a response to anticipated future tightening rather a surplus. This is discussed in greater detail in Appendix G.

As the €50 target applies to emissions rather than use, the corresponding quota price should reflect average emissions. In other words, if on average half of all gas is emitted, quota should reach a price of €25/tCO2e across all sectors. Consequently, the price incentives may be too weak to encourage all cost-effective abatement, such as leak repair or effective recovery. While some Member States implemented deposit and recovery schemes to create a better alignment between price and emissions, the UK did not to implement any such measures.

To calculate total abatement it was assumed that consumption of HFCs would have remained at 2012 levels.[76,77] Using this approach, it was estimated that the F gas Regulation has reduced usage of HFCs in Great Britain by 40.4 MtCO2e between 2015 and 2021. Use abatement was converted to emissions abatement by assuming a fixed ratio of 50-60% of gas used being emitted (further information is provided in Appendix G). This equates to 20.2-24.3 MtCO2e of emissions abated in Great Britain. Using the most up to date financial values for abatement this implies a monetary benefit of £2.8- 8.5 billion.[78]

Our detailed modelling of use suggests that although industry has switched to lower GWP gases, the majority of this effect is driven by a shift away from HFCs whose use in metric tonnes halved from 2012 to 2021.[79] This mirrors the findings of the European Commission.[80]

It is not certain to what extent smuggling may have reduced the potential benefits. A report by the EIA found that 20-30% of all gas sold in the EU may have been imported without quota.[81] There is evidence to suggest this is an overstatement.[82] Moreover, most smuggling takes place across porous land borders which is less likely to affect the market in Great Britain. While this is not thought to be reflective of the current market situation in

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[76] The Great Britain model was used to produce 2012 levels of HFC consumption.

[77] This is consistent with assumptions made prior to the regulation.

[78] £2.7-8.1 billion at a 3.5% discount rate.

[79] Noting that the Great Britain baseline was calculated differently to the EU following EU Exit.

[80] The European Commission found a 47% decline in CO2e of HFCs and a 37% decline in metric tonnes of HFCs from 2015; Öko-Recherche support contract for an evaluation and impact assessment for amending Regulation (EU) No 517/2014 on F gases.

[81] EIA's report on illegal trade ("Europe's Most Chilling Crime: The illegal trade in HFC refrigerant gases")

[82] EEA report on indications of illegal HFC trade based on an analysis of data reported under the F gas Regulation, Eurostat dataset and Chinese export data

Great Britain, 30% was used as a sensitivity check to test the assumptions used. This would result in total abatement of 13.6-16.3 $MtCO_2e$ and total benefits of £1.9-5.7 billion.[83]

Using the implied cost approach (described in Appendix G), an average cost per tonne for abated emissions of £4.10-5.00 (€4.80-5.80), a maximum marginal cost of £23.60-28.30 (€27.40-32.90), and a total cost of £101 million (€117 million) were calculated.

This clearly shows significant net benefits from the Regulation. However, while the F gas Regulation has been successful, analysis also shows that the Commission underestimated the ability of industry to respond to the challenge of developing low GWP alternatives. While this suggests scope for greater ambition in future regulatory actions it also cautions about the difficulties in accurately forecasting demand.

It is an advantage of the structure of the Regulation that it encourages innovation not anticipated at the time of its drafting, which can lower the cost of abatement. However, this also makes it difficult to provide price certainty which may hamper investment in the long run.

The Regulation operates through price incentives in the market. Declining prices reduce the incentive to undertake efficient abatement. Price data and industry engagement indicate that the price of high GWP gases, such as HFC-134a, have fallen to the extent that they are cheaper than HFO blends. This reduces the incentive to use HFO blends where technology is available, but also to invest in developing technologies without certainty that there will be a market.

Stakeholders have expressed concern that rising prices may induce illegal activity. This could be particularly acute if prices reflect the updated estimated marginal benefits of marginal abatement (estimated at £248 in 2022, rising to £378 in 2050).[84] As prices remain pivotal to the function of phasedown, illegal activity is a significant concern. While it is difficult to work out the extent to which an inherently unreported activity could undermine the F gas Regulation, greater study might help more clearly understand the problem and identify solutions. It is possible that electronic record keeping, discussed in more detail below, would make it easier to identify illegal activity.

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[83] £1.8-5.5 billion at a 3.5% discount rate.

[84] Valuation of greenhouse gas emissions: for policy appraisal and evaluation. All figures stated in 2020 prices.

Leak testing

The F gas Regulation included new requirements for regular leak checks. At the same time the higher price of gas increased incentives to reduce leakage. There are also benefits to end-users in reducing leakage through improved energy efficiency when equipment operates with a full charge.

While the F gas Regulation imposed a requirement for engineers to keep records of leak checks, different Member States adopted different methods for record keeping. Poland and Slovakia adopted electronic logbooks with data reported directly to the national regulatory authority, while Germany operates a voluntary system run by a national association. Mandatory logbooks are discussed in more detail below and in the sub-section on recovery. The UK did not implement electronic reporting, meaning that service engineers may use electronic logbooks but there is no central collation of logbook data.

Since 2020, a UK private company has provided an electronic logbook, which service engineers may purchase. While Defra has seen anonymised data generated by this service there are limits in how it can be used to perform retrospective analysis. First, the service is relatively new, meaning that it can provide a snapshot into current practices but does not show how these have changed over time in response to the F gas Regulation. Second, its use is voluntary, meaning that it is unlikely those seeking to avoid detection would use it. It may therefore present an excessively favourable picture of compliance.

While data from other countries may not fully reflect the Great Britain market, it offers insight into the impact of the F gas Regulation. Data from Poland indicates a substantial reduction in leakage since the adoption of the F gas Regulation with annual leakage in equipment subject to mandatory checks declining from 12.6% to 3.12% from 2016 to 2019. However, the evidence suggests that the largest reductions in leakage coincided with increased quota price.[85] Data from other countries shows a similar trend although a less pronounced correlation between abatement and quota price.[86] Notably no countries show leakage increasing again after quota price began to fall. although there is substantial volatility in leak rates.[87]

Evidence indicates that the cost of gas is the main driver in reducing leakage. Leakage rates remaining low or continuing to fall after quota price declined does not necessarily indicate otherwise. HFC prices are still severalfold 2014 levels for high GWP gases. End-

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[85] Based on additional logbook data provided to Defra.

[86] Ibid.

[87] Ibid.

users may also be more aware of the benefits of effective leak checking on energy efficiency, or more sensitive to energy cost. Industry sources have reported that some equipment designed to measure energy efficiency of equipment may be used as automatic leak detection equipment.

While the specific provisions dealing with leak testing were found to have likely had minimal impact due to being pre-empted by the HFC phasedown, better information would be valuable.

There is a need to improve information about the types and causes of leakage. Industry sources suggest some leakage may be the result of untrained service technicians working (illegally) on F gas equipment. While it is difficult to determine the scale of this problem, industry suggest it is still prevalent and may require either better training or enforcement.

Control of use

The F gas Regulation introduced a series of bans on using high GWP gases in new equipment.[88] The assessment showed no additional benefits from these bans beyond those as a result of the phasedown, because of the supply constraint imposed by quota. Any reduction in use resulting from the new equipment ban would result in more gas being available for other uses.

Additionally, no costs were quantified on the basis that the new lower GWP technologies would be needed to comply with quota. The prospective analysis undertaken attributed both costs and cost savings to these bans, the latter coming from energy efficiency savings. It was concluded that if costs could be attributed to phasedown, then any cost savings should also be attributed to phasedown. Industry should consider any cost savings in making purchase decisions and these cost savings would lower marginal abatement cost and therefore be captured in the top-down approach used.

It is not possible to rule out the possibility that some equipment bans imposed a higher cost than the marginal abatement cost. This would have resulted in higher costs for industry but without any additional abatement. By comparing these findings with those of the EU, it was concluded that it is unlikely there is a significant effect from new equipment bans. However, it is worth evaluating whether equipment bans serve a valuable purpose.

Some stakeholders have argued that prohibitions could serve as signposts for users to move to alternative gases and create an incentive for producers and manufacturers to develop alternative gases and equipment. Although the Regulation sets out phasedown

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[88] See section 5.

steps in advance, end-users are not affected by the overall amount of quota available, but by price increases created by the supply constraint which can be hard to predict. Firms may be reluctant to invest in new technologies without knowing if there will be a market for their product. However, while prohibitions could provide a degree of certainty in specific markets, stakeholders have fed back concerns around inflexibility, for example where the GWP limits are arbitrary.

One benefit of the phasedown is that it directs effort towards the lowest cost of abatement and provides far greater flexibility. It can also encourage innovation not foreseen at the time the Regulation was drafted, potentially going further than a ban. This happens when businesses respond to price incentives. Analysis suggests that industry was able to adopt low GWP alternatives more rapidly than originally anticipated. This highlights both the potential for further reductions but also the difficulty in making detailed predictions.

Some stakeholders have supported bans as a means of preventing the price of gas from rising in response to quota constraints.[89] End-users would prefer to prevent prices from rising, and imposing demand constraints which could be the impact of equipment bans. However, prices are a fundamental component of the operation of the phasedown. By potentially lowering HFC prices, bans risk reducing certainty for innovators and ultimately reducing overall investment.

Research by Porter argued that regulation can stimulate innovation and improve productivity.[90] However, this is only likely to happen when regulation sets broad outcomes-based standards.[91] Prescriptive technical mandates can reduce productivity. The research suggests that regulation should give industry the greatest possible freedom to attain desirable outcomes. Although product bans may stimulate innovation in specific areas, they can also lessen the market price signals created by the phasedown meaning it is not possible to calculate the net impact on innovation.

The analysis suggests that equipment bans likely had only a marginal effect due to being set below the level needed to meet phasedown targets. It is possible some bans shifted activity emphasis to more expensive abatement activities. Although this does not affect overall emissions savings this may lead analysis to underestimate costs. However, this effect is likely very small. This finding may be unexpected to some stakeholders and

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[89] It was noted that although higher HFC prices are a cost for end-users it is not an overall cost of the F gas Regulation because they generate additional revenue for suppliers.

[90] Porter, M.E. (1991) America's Green Strategy

[91] The Porter Hypothesis has been the subject of wide-spread study. For further information see Wagner, M. (2003). *The Porter hypothesis revisited: a literature review of theoretical models and empirical tests*.

sector group discussions. It is important to note that this reflects the analysis of the impact of the bans beyond the costs/benefits as a result of the phasedown.

Recovery

The F gas Regulation did not implement additional provisions regarding recovery but retained those from the 2006 F gas Regulation. This included a provision that "Member States shall encourage the development of producer responsibility schemes for the recovery of fluorinated greenhouse gases and their recycling, reclamation or destruction."

The UK did not introduce additional provisions but some other Member States did. For example, Denmark, France, and the Netherlands all developed "takeback" schemes. Denmark also introduced a deposit and refund scheme and Spain introduced a system of refrigerant tax rebates (recycled and regenerated refrigerants are taxed at half the rate of virgin refrigerants). There is little evidence on the success of these schemes but the European Commission reports favourable stakeholder feedback.

There is very little evidence regarding the adherence to recovery requirements. Industry is only required to report destruction and reclamation in a facility, the latter referring to gas that goes through an industrial cleaning process to return it to virgin quality.[92] Although service engineers are required to log onsite recovery and recycling – when an engineer removes gas and replaces it either in the same equipment following maintenance or uses recovered gas in other equipment – they are not required to report this information except on request.

Stakeholder feedback from both the power and RACHP sectors was consistent in recommending improvements to reporting on operating-life and end-of-life containment.

Within the power sector, there is variation in reporting between operators regulated by Ofgem and privately-owned equipment. Transmissions and distribution network operators must publish annual environment reports, as part of their reporting to Ofgem, which includes SF_6 emissions. Whilst power sector stakeholders recognised that reporting could be improved, particularly around end-of-life, they were clear that 'double reporting' (for example reporting under F gas and Ofgem regimes) would not be an optimal solution.

Within the RACHP sector, stakeholders suggested the introduction of a centralised electronic logbook system for containment reporting. This could help streamline reporting

[92] Only quota holders are required to report reclamation so these records may also be incomplete. Service engineers must keep logbooks of any onsite recovery and recycling but these are only available to regulators on request.

and be accessible to regulators to provide better data on emissions and to support enforcement. There is a data gap in relation to information gathered on containment, which could be mitigated by this kind of measure. Some Member States have introduced electronic equipment databases through national legislation. These databases are used to collect information on equipment, such as initial refrigerant charge and the amount of gas used to top up. Member States including Poland, Hungary, Slovakia, Czech Republic and Italy have established this kind of database.

Despite the lack of first-hand evidence, a mixture of independent studies and industry feedback (from the UK and EU stakeholders) suggests there may be significant non-compliance with recovery laws.[93] Furthermore, internal modelling suggests that improper recovery still contributes a significant portion of emissions and that this is likely to rise over time. It was also found that although recovery is mandated, where economically feasible, there are weak incentives to recover gases even when costs are low.

A study by the government of Flanders found that end-users are frequently unaware of the obligation to recover gases.[94] This means that engineers fulfilling a legal requirement are less competitive than those who ignore recovery obligations and may lose contracts. Furthermore, because it is difficult to track emissions, some operators will charge for recovery and then release the gas to atmosphere. Although these studies are based in the EU, industry feedback suggests these practices also exist in Great Britain.

Stakeholders have also indicated that, because of a lack of awareness by end-users around recovery, untrained construction workers may unintentionally vent HFCs to atmosphere before service engineers can recover the gas. In one example, a recovery crew arrived on site to find that construction workers dismantling a facility had severed the gas lines and allowed all the gas to escape the day before.

Where there is a market for recovered gas, this may create an economic incentive for more effective recovery. Industry representatives report a decline in reclamation and destruction which they attribute to increased recycling. By contrast, the Flemish study found reclaimed refrigerants still comprise less than 5% of the market but this number doubled between 2015 and 2016.[95] The same study found increased demand for

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[93] For example Dauwe, T., Altdorfer, F., Gschrey, B. (2018) "Waste and disposal emissions from F gas containing refrigeration and potential actions to improve recovery of F gases" *Department Of Environment & Spatial Development*

[94] Ibid.

[95] Ibid.

containers used for storage and transport of HFCs, supporting the likelihood of an increase in recycling.[96]

While it is likely that market incentives will increase recovery for some gases, this will depend on the individual market. Engineers typically extract gas from equipment that is 10-25 years old. The types of recovered gas therefore reflect HFCs that were used prior to the introduction of the phasedown. These may be higher GWP gases and sometimes cannot be used in new equipment due to the bans in Annex 3 of the Regulation. This reduces the incentive to recover some types of gas. Industry sources indicate that although there is a market for most types of reclaimed HFCs, service engineers may not be paid for returning the gas to a proper facility.

As the phasedown reduces the supply of virgin gases, there will be more gas available for recovery than available through quota (when measured in tCO2e). In some cases, this gas can only be used to refill leaks. The larger supply of high GWP gases could potentially create incentives for end-users to keep old and inefficient equipment rather than switch to new equipment that requires lower GWP gases. Older equipment is likely to have a higher leakage rate than newer equipment, resulting in greater emissions.

Some industry representatives have suggested allowing manufacturers to use recovered gas in new equipment. This could potentially solve the problem described above and also allow industry to reduce demand for virgin gas more rapidly. However, it would mean that high GWP gases would remain in service for much longer than under the current Regulation, although if those gases would otherwise be vented to atmosphere reusing the gas could still potentially reduce emissions.

At present there are no incentives, beyond the legal mandate, to destroy HFCs. Destruction is the only way of removing existing high GWP gases from the economy except for venting. While there is a lack of data, it is likely that the increased demand for recovered gas reduced total destruction. However, this effect was not quantified.

F gas emissions and exempted uses

The F gas Regulation includes a number of exemptions from quota for HFCs and placing on the market reductions (Article 15(2)). These include import for destruction, those used in feedstock applications, supply directly for export, use in military equipment, use for the etching of semiconductor material or the cleaning of chemicals vapour deposition chambers within the semiconductor manufacturing sector and supply for producing MDIs.

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[96] Ibid.

Of these exempted uses, supply for MDIs is the most significant in terms of the quantity of HFCs and emissions.[97] The use of HFCs as propellants for MDIs is fully emissive and UK MDI emissions in 2020 were 974 ktCO2e.[98]

Anaesthetic gases are another use of F gases resulting in emissions and are used commonly for surgical applications.[99] There are three anaesthetic gases that contain F gases, often referred to as volatile anaesthetic agents. These are desflurane, isoflurane and sevoflurane.[100] These anaesthetic gases are not HFCs, so are not exposed to HFC quota and the phasedown.

Emissions from volatile anaesthetic gases in 2020/21 accounted for 21.96 ktCO2e in England, 1.5 kt tCO2e in Scotland and 0.753 ktCO2e in Wales.[101] Even in the absence of action under the F gas Regulation there has been some reduction in the emissions from these gases. This has been driven by NHS England, Scotland and Wales actions and targets to reduce the use of desflurane as part of the transition to net zero.[102]

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[97] In 2019, the total placed on the EU-28 market for exempted uses was 21.6 MtCO2e. Of which, 10.3 MtCO2e was used for MDIs and the remaining 11.2 MtCO2e was spread across the remaining exempted uses. (EEA, Fluorinated greenhouse gases 2021, Annex to Public Briefing)

[98] Estimate of propellant emissions, estimated using UK 2020 NHS MDI prescription data. Considering MDI prescriptions by type, estimates of charge size and therefore propellant emissions.

[99] In the public and private healthcare and the veterinary sector.

[100] The EU F gas proposal, based on the Sixth Assessment Report adopted by the Intergovernmental Panel on Climate Change, includes the following GWPs: desflurane – 2590, isoflurane – 539 and sevoflurane – 195. These have been updated since the F gas Regulation, which included GWPs of 989 and 350, for desflurane and isoflurane, and did not include sevoflurane. However the NHS use Sulbaek Andersen 2013 GWPs: desflurane – 2540, isoflurane – 510 and sevoflurane – 130.

[101] Figures provided by NHS England, NHS Scotland (NHS Scotland climate emergency and sustainability strategy 2022 – 2026, Annex B, Table 7) and NHS Wales.

[102] In Wales, the NHS Wales Decarbonisation Strategic Delivery plan sets out the roadmap for the NHS Wales contribution to a collectively net zero public sector by 2030. This includes a number of commitments in respect to anesthetics.

7. Standards

This section sets out the classifications of safety standards as well as an overview of international standards for RACHP, relevant European standards, recent and ongoing updates of these standards, and relevant national codes and regulations.

When considering the use of F gases and the availability of alternatives, it is important to consider current international, regional and national standards, relevant safety codes and regulations as this will inform the potential usability of those gases.

Classification

Safety and adherence to set standards is particularly important in relation to the manufacturing, placing on the market and utilisation of F gases. The UK therefore applies voluntary standards developed through national, European and international standards bodies. International and European standards are adopted for the whole of the UK as British Standards, alongside a diminishing proportion of national-only standards that meet purely local needs.

The F gas Regulation is intended to encourage the transition to low GWP and zero GWP alternatives. This is achieved through limiting the use of high GWP F gases in certain applications, reducing the quantity of available HFCs, setting minimum training standards for technicians and as a result reducing F gas emissions. When considering the move to alternatives to F gases it is important to take into account flammability and toxicity, and to ensure additional technical knowledge and safety measures are in place in order for the gases to be used in a safe and energy efficient way. Standards use refrigerant flammability and toxicity properties to define refrigerant classifications and practical limits for different systems, as shown in Table 2.

Classifications also define toxicity, with two broad classifications for lower (A) and higher (B) toxicity. All the example refrigerants in Table 2 have a toxicity classification of A, apart from ammonia which has a higher toxicity classification of B.

Table 2 shows flammability classifications as defined in safety standards.[103]

Description	Classification	Examples
No flame propagation	1	R-404A, R-410A, R-407C, HFC-134a, R-744 (CO_2)
Lower flammability (burning velocity of < 10 cm/s)	2L	HFC-32, R-717 (ammonia), HFO-1234yf
Flammable (burning velocity of ≥ 10 cm/s)	2	HFC-152a
Higher flammability	3	HC-290 (propane), HC-600a (iso-butane)

International standards

International standards form the basis of regional and national standards. There are two organisations responsible for international RACHP standards in relation to F gases and alternatives to F gases. One is the International Organization for Standardization (ISO), which is an independent, non-governmental international organisation, with a membership of 167 national standard bodies and is responsible for developing international standards. The second is the International Electrotechnical Commission (IEC), which is a global not-for-profit organisation, whose work underpins quality infrastructure and international trade in electrical and electronic goods.

For F gases, international standards are typically not used directly but are adopted as national or regional standards. For UK national standards, modifications or deviations might be included. Group safety standards comprise safety aspects applicable to several products or systems (for example aerosol group standards include MDIs, as well as

[103] Refrigerant flammability levels – from ISO 5149 and EN 378 safety codes.

aerosol air fresheners), whilst product safety standards refer to a specific product or system.

The Technology and Economic Assessment Panel (TEAP) – the technology and economics advisory body to the Montreal Protocol Parties – recently published their 2022 progress report.[104] The report considered whether there has been progress made since the RACHP Technical Options Committee (RTOC) last considered and published a report on standards (in relation to RACHP) in 2018.[105] TEAP confirmed that some progress has been made since the publication of the 2018 RTOC report. The Ozone Secretariat also provide tools and background information on relevant standards to support Parties.[106]

European (CEN/CENELEC) standards

European standards are based on international standards but can also deviate in certain aspects. There are three European Standardisation Organisations recognised by the UK, EU and EFTA as being responsible for developing and defining voluntary standards at the European level. Two of these organisations work on standards relating to F gases. The first is the European Committee for Standardization (CEN) and the second is the European Committee for Electrotechnical Standardization (CENELEC). The UK's national standards body – the British Standards Institution (BSI) – is a member (and founder member) of CEN and CENELEC.

CEN focuses on the development of standards and other technical documents in relation to various products, materials, services and processes. It was established to strengthen the internal economies and enable the production of goods and services capable of competing in international materials. CEN sets technical standards to foster trade, encourage environmental protection and ensure workers safety. CENELEC is responsible for setting voluntary standards in the area of electrical engineering and supports standardisation activities, for example in electric and electronic goods. CEN and CENELEC work together, along with other EU standardisation bodies to remove barriers in quality, safety and trade.

[104] Progress report of the Technology and Economic Assessment Panel (2022)

[105] Technical Options Committee assessment report on Refrigeration, Air Conditioning and Heat Pumps (2018)

[106] Ozone Secretariat safety standards resources

The use of harmonised standards is not mandatory, but BSI has adopted European standards, developed via CEN and CENELEC, through a consensus-based system involving national experts.

Table 3 provides an overview of the most relevant European standards for the RACHP sector.

Standards	Relevant sub-sectors and uses
EN 378	Refrigerating system and heat pumps – safety and environmental requirements. EN 378 provides guidance to define parameters such as the maximum refrigerant charge. It is harmonised with EU legislation to some extent. The flammability classification 2L was included in 2016 to harmonise with international standards such as ISO 817.
IEC EN 60335-2-24	Safety requirements for household and similar electrical appliances (including refrigerators and freezers)
IEC EN 60335-2-40	Safety requirements for electrical heat pumps, air conditioners and dehumidifiers
IEC EN 60335-2-89	Safety requirements for commercial refrigerating appliances
EN 1127-1	Explosive atmospheres – explosion prevention and protection
EN 60079	Requirements for electrical systems used in potentially explosive atmospheres
EN 13463	Non-electrical equipment for use in potentially explosive atmospheres
EN 13313	Refrigerating systems and heat pumps – competence of personnel

For the RACHP sector, the European Commission have a process in place to submit a request to one or several European standardisation organisations to draft European standards. This is referred to as a European standardisation deliverable. This process involves providing technical specifications for the installation and operation of RACHP equipment containing flammable refrigerants, complementing existing harmonised standards. There is an expectation that it should be developed on the basis of a comprehensive assessment of existing standards with regard to flammable refrigerants to avoid conflicts and overlaps with harmonised standards.

The European Commission's retrospective analysis[107] of the EU's F gas Regulation summarised a Commission report published in 2016[108] in which it was found 'that standards (at an international, European and national level) regarding the use of flammable refrigerants appear to be an important barrier to the uptake of climate-friendly alternatives to HFCs'. It was noted that European (CEN and CENELEC) standards setting restrictions for RACHP no longer appear justified on the grounds of safety. The report concluded these standards require further updating in line with technological developments and based on empirical appreciation of the actual risks showing that acceptable safety levels can be maintained while using flammable refrigerants.

Recent updates

At an international level, one new single component refrigerant and eighteen refrigerant blends have received a designation and safety classification under ASHRAE[109] Standard 34 and under ISO Standard 817. One of the refrigerants is a single-component refrigerant, trifluoroiodomethane – IFC-13I1 (mentioned in the RTOC 2018 Assessment Report referenced previously). IFC-13I1 is now classified as non-flammable and with low toxicity (safety classification A1) in ASHRAE 34, while it is not listed in ISO 817.

IEC standard 60335-2-40 has been updated.[110] This includes changes to allow higher charge limits for flammable refrigerants (including propane) in domestic air-conditioning systems and heat pumps. Hydrocarbons had previously been restricted under previous versions of IEC 60335-2-40 to small charge sizes in cooling equipment. The update to this standard goes some way to address this barrier. For propane, the revised standard allows for the use of up to 988 g in a standard air-conditioning system.

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[107] Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

[108] EU Commission report on barriers posed by codes, standards and legislation to using climate-friendly technologies in the RACHP and foam sectors

[109] The American Society of Heating, Refrigerating and Air-Conditioning Engineers

[110] IEC 60335-2-40 – household and similar electrical appliances

For most appliances and components used in manufacturing them, particular safety standards are available within the IEC 60335 framework. The regulatory schemes and standards on energy efficiency are instrumental to manufacturers' drive to innovate products for better energy efficiency at lower costs. As mentioned above, such standards will help equipment manufacturers to develop and introduce product solutions relying on flammable refrigerants for the UK/Great Britain and European market.

Domestic standards

National standards in the UK are mostly based on international and/or CEN/CENELEC standards but adjusted to account for any particular domestic requirements or circumstances. The possible codes, standards and legislation in different countries are very wide in scope. Appendix H sets out a non-exhaustive list of F gas relevant standards from different geographies and jurisdictions that are applicable in Great Britain.

As well as influencing the design of products, national requirements could affect:

- factories manufacturing RACHP equipment (such as those filling equipment with a flammable gas)
- waste disposal (for example disposal of equipment containing a flammable gas)
- energy efficiency (rules similar to eco-design, which define minimum efficiency standards)
- refrigerant choice, as many lower GWP alternative refrigerants are flammable. Other relevant issues are toxicity levels and pressure requirements. The technical issues that need to be addressed for various lower GWP alternative refrigerants currently under consideration are summarised below

Table 4 sets out some of the technical issues to be addressed for lower GWP alternatives.

Low GWP alternatives	Practical issues	Safety classification (ISO 817 and EN 378)
Hydrocarbons	High flammability	A3
HFOs, HFO/HFC blends, HFC-32	Low flammability	A2L
Ammonia	Higher toxicity, low flammability	B2L
CO2	High operating pressure	A1

The approach to market regulation and trade within the UK is set out in the UK Internal Market Act 2020.[111] Products placed on the market in Great Britain that are covered by relevant UK product regulatory requirements need to bear the UKCA (UK Conformity Assessed) marking.[112] The UKCA marking has replaced the CE marking (which was used when the UK was part of the EU) for these regulations.[113] In Northern Ireland, under the Northern Ireland Protocol, the EU CE conformity markings continue to be required.

Standards can pose a barrier to the safe use of low GWP and alternative refrigerants. Some stakeholders operate in a number of countries, and although UK standards/codes may not restrict them in those other countries, restrictions that apply in other European countries will influence the European market as a whole.

The flammability classification of a gas should require technicians to have an appropriate level of skill and to take the appropriate level of care in the installation, maintenance and servicing of a product throughout its life and at its end-of-life disposal. Relevant training is also important when dealing with gases with higher toxicity (ammonia) or where high pressure is required. RACHP stakeholders suggest that mandatory training should be introduced to ensure the appropriate minimum levels of skills are set to work with lower GWP refrigerants with flammability, toxicity and high-pressure properties.

8. State of technology

This section includes a review of the availability of technically feasible and cost-effective alternatives to F gas containing products and equipment (focused on those not listed in Annex 3 (placing on the market prohibitions) of the F gas Regulation), taking into account energy efficiency.

RACHP

RACHP may be further divided into refrigeration and comfort cooling and heating and then subdivided into residential, commercial, industrial, and transport. Regardless of function, these systems all belong to one of two general types: direct systems where the refrigerant gas is circulated to the area to be heated or cooled, and indirect systems where the

[111] United Kingdom Internal Market Act 2020

[112] Using the UKCA marking guidance

[113] CE marking

refrigerant gas is used to heat or cool a liquid medium (such as water or glycol) which is pumped to the area being heated or cooled.

Indirect systems have the advantage of requiring a smaller refrigerant charge because the gas is not circulated throughout the facility. In the case of factory built monobloc systems – where the refrigerant gas always remains within a single unit – they are also easier to seal, reducing leakage.

For small systems, direct expansion is typically more energy efficient than indirect systems. They may also be more compact and less complex. This reverses for the largest applications where indirect systems are more efficient and involve less complex pipework. Notably however, heat pumps, which are likely to form an increasing portion of the RACHP sector, often use indirect systems for very small applications. This may be because of the cost advantage of using indirect heat pumps as a drop-in replacement for the boiler in an existing hot water radiator system. For example, a hydronic system which uses water to distribute heating and cooling capabilities.

Refrigerant choice is partly determined by function. Refrigerants suitable for low temperature cooling will have a different boiling point to refrigerants used for heating. Generally, there are more low GWP gases available for refrigeration than for air-conditioning and heating. However, even where applications may have the same function, the size and location of the system can significantly affect the choice of gas available.

Flammability and toxicity can both impact where and when a refrigerant may be used. For flammable refrigerants such as hydrocarbons, there is a maximum safe charge size which varies depending on application. Hydrocarbons are most suitable for very small applications such as domestic refrigeration or large indirect systems where the refrigerant can be safely located away from people.

Safety standards now allow the use of flammable gases in a wider range of applications. For example, a change to safety standard IEC 60335-2-40 was recently approved, which allows higher charge limits for flammable refrigerant in domestic air-conditioning and heat pump systems. But some applications of RACHP equipment in specific environments, such as airports and railway stations, still require a completely non-flammable gas.

Toxic gases like ammonia may be suited to industrial applications where equipment can be located away from untrained personnel but cannot easily be used in a domestic setting. Again, indirect systems may offer a way to overcome some of these safety issues, but use is limited to larger indirect systems. In general, a greater selection of low GWP refrigerants are available for very small or very large applications than for mid-size applications.

As well as safety issues, size can also influence gas choice for other reasons. Low pressure gases require larger compressors. For example HFO-1233zd is efficient for large chillers which use centrifugal compressors, but not for the displacement compressors used in smaller applications. On the other hand, while CO_2 can be used in small applications, the very high pressures involved require components and pipework that can withstand such pressures, leading to heavier and bulkier units. This can potentially limit its use when compactness is required.

Refrigeration

Domestic refrigeration

In domestic applications HC-600a (isobutane) has replaced HFC-134a. Isobutane is cheaper than both HFC-134a and HFO alternatives, such as HFO-1234yf. As permitted charge sizes have increased, isobutane has become ubiquitous and is used even in larger units such as American style refrigerators.

Commercial refrigeration

For smaller standalone units, for chilled and frozen goods, industry has moved away from HFC-134a entirely. While R-513A is available as a drop-in replacement for HFC-134a this also has largely disappeared in favour of cheaper and lower GWP options. Predominantly industry favours propane where flammability issues can be addressed. Where propane is not suitable, there are lower flammability alternatives such as HFO blends R-454A/R-455C. Pure HFOs such HFO-1234yf and HFO-1234ze(E),[114] although not currently used, are also suitable for refrigeration but not freezing.

In larger applications, non-flammable medium GWP gases R-513A and R-448A/R-449A are suitable as drop-in replacements for HFC-134a and R-404A respectively. They are appropriate both for retrofill of existing units and as a ready replacement for high GWP gases in new units without retooling production lines. However, these gases still have a relatively high GWP, are more expensive than natural refrigerants and should only be treated as interim options.

Both R-454C and R-455A are suitable for large refrigeration and freezing units. R-1234yf is suitable for refrigeration but not freezing. Due to flammability hydrocarbons are only suitable for small direct systems but there has been widespread adoption of CO2 in retail applications. Switching to low GWP gases is one way to reduce emissions from refrigeration. Users may also reduce emissions by reducing leakage or by reducing cooling load.

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[114] HFO-1234ze(E) is an isomer of 1234ze which is more similar to R-134a in physical properties.

Propane remains viable for large chiller units (up to several hundred kW) when the unit can be safely located and access restricted to trained personnel. HC-1270 (propene) is also suitable for low and medium temperature refrigeration.

CO2 is an efficient natural alternative for refrigeration in cold and temperate climates. The efficiency of CO2 varies more with ambient temperature than most other refrigerants, as a result it is often more efficient than HFCs during the colder months and less efficient during the summer months.

CO2 is generally unsuited for air-conditioning, which is mainly used during the warmer summer months, but it is sometimes used in combined systems that provide both comfort cooling and refrigeration. This may either be as the sole refrigerant or as part of a cascade system (where multiple gases are used in sequence). Combined systems may also use waste heat from refrigeration to provide comfort heating during cold seasons.

CO2 is non-flammable, is safe at low concentrations, and can be used in both direct and indirect systems. This makes it suitable for the commercial refrigeration sector where there has been widespread adoption by supermarkets. However, CO2 is an asphyxiant and can become toxic at high concentrations. It is heavier than air meaning the gas can pool in poorly ventilated areas. Units using CO2 also require more steel to cope with the higher pressure needed for the gas and units therefore tend to be larger than existing HFC alternatives. This may limit the use of CO2 where space is a constraint.

Logbook data from Poland[115] suggests that leakage rates for refrigeration, containing 5 tonnes or more CO2e, exceeded 16% per year prior to the introduction of the F gas Regulation and have now fallen below 4% since its introduction. Leakage not only vents gas to atmosphere but equipment becomes less efficient when refrigerant level falls below recommended levels. Better leak detection therefore not only reduces gas losses but also improves energy efficiency. Some new technologies designed to monitor efficiency of equipment could also provide an early warning for possible leaks.

Reducing cooling load, such as fitting doors to retail display cabinets, both reduces energy usage and the amount of coolant charge required. Not all energy saving measures reduce cooling: variable speed compressors can increase energy efficiency during periods of low load, but total charge size will still be determined by peak load. An Australian study by Robertson found that installing doors on display cases reduced energy usage by 42% and would also reduce the size of the refrigeration equipment and hence reduce the refrigerant

[115] Confidential data provided by stakeholder.

charge required.[116,117] Switching off anti-sweat heaters on doors and using high efficiency fans and LED lighting can reduce energy usage a further 10-20%.[118]

Industrial refrigeration

Industrial units are required in all sizes, up to several megawatts (MW) in some instances. While industry may use the same refrigerants as residential or commercial users, the choice of gas is less limited by safety concerns because access can be limited to trained personnel.

This is most notable by the wider use of ammonia, which is limited in residential and retail applications due to its high toxicity. Although used in a range of sizes, and in both direct and indirect cooling, it is most suitable for large (typically >100kW) cooling applications. Flooded systems, a type of refrigeration system suitable for large applications such as cold storage warehouses, already use ammonia almost exclusively for refrigeration. In recent years, CO2 has also started to be used in large industrial applications.

Ammonia is also used in absorption chillers, which use heat rather than electricity as an energy source. These units are not widely used due to both high capital cost and low energy efficiency but may sometimes be suited to industrial applications if a suitable source of waste heat is available.

Mobile applications

MAC and heating

CO2 is available as an option in a few vehicles but high pressures required for CO2 requires more steel making the systems costlier, heavier and bulkier. This can be a barrier to adoption in mobile applications, where added weight reduces fuel economy.

CO2 is also less efficient at higher ambient temperature, making it less suitable for air-conditioning. Energy efficiency is of particular importance in mobile applications as the unit must be powered by the vehicle's engine. As CO2 is less suitable for use in warmer climates, manufacturers would be unable to use a single refrigerant in all markets. Although there are regional differences in the automotive cooling market, manufacturers generally prefer to use the same refrigerant across all vehicles sold globally.

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[116] Robertson, G., (Apr. 2015) "Trial Retrofit of Doors on Open Refrigerated Display Cabinets" *AIRAH*

[117] Technical Options Committee (2022) "Refrigeration, Air Conditioning and Heat Pumps"

[118] Ibid.

With the switch to electric vehicles, it will no longer be possible to utilise the engine's waste heat for heating. The vehicle must either use an electric heater, which is inefficient and reduces vehicle range, or use a reversible air-conditioning system as a heat pump. Heat pumps using HFO-1234yf can lose efficiency in very cold temperatures leading manufacturers to explore alternative refrigerants.[119]

While HFO-1234yf is used in some larger vehicles (buses and trains) (approximately 30% of the Great Britain market in 2022),[120] the majority use either HFC-134a or R-410A, but R-513A (a drop-in alternative for HFC-134a; GWP 631) holds a growing market share.

HFO-1234yf is suitable for most larger MAC applications. HFC-32 is also viable and has a similar GWP to R-513A but is preferred by industry (possibly for economic reasons). CO2 and hydrocarbons may also be viable in larger applications. Although CO2 suffers the same obstacles described above, bulk may be less of an issue in larger vehicles. While hydrocarbons are potentially an efficient option, there are safety concerns about the use of flammable refrigerants as well as regulatory obstacles.

Transport refrigeration

With the exception of marine refrigeration, which has largely transitioned to natural refrigerants (CO2 and ammonia), transport refrigeration currently relies heavily on R-452A (GWP 2140), having previously used R-404A (GWP 3922). However, low GWP HFO blends such R-454C and R-455A (GWP 148) are possible alternatives. Regulations are an extra constraint in the transport sector, with approval required under the UN ATP treaty on the transport of perishable foods.

Both CO2 and hydrocarbons may be viable alternatives for some transport refrigeration applications. However, both suffer from the constraints on size and safety described above.

Comfort cooling and heating

Residential cooling and heating

Comfort heating and cooling comprise 53% of HFC usage in the Great Britain market with the bulk of use in commercial applications. The residential sub-sector only comprises 20%

[119] Very cold temperatures may not present a major issue in Great Britain but may affect cars that are sold in Great Britain which are built for a global market.

[120] In terms of physical tonnes of refrigerant used in new vehicles.

of overall demand and has historically not been a market for cooling.[121] However, it is expected that government heat pump targets, combined with increased need for cooling due to climate change, will both grow and alter the composition of this market. These factors are discussed in more detail in sections 9 and 10.

Direct systems are the most energy efficient solution for small and medium sized systems and are generally more cost-effective. Most new systems are primarily intended for cooling, but nearly all are reversible and can be used as heat pumps. In some cases, these systems provide both hot water and space heating and may use waste heat from air-conditioning to heat water during summer months.

For heating-only systems, an increased number of indirect systems (hydronic heat pumps) is expected. While direct air heating remains a more efficient option, most homes are already fitted with radiators whereas ducted air systems are not common in the UK. Replacing a boiler with a hydronic heat pump may be cheaper than installing a multi-split direct expansion system, although this will depend on whether a home’s central heating is adequately plumbed to use low temperature water.

Indirect systems can be further broken down into monobloc and split systems. A typical air-to-water monobloc heat pump is a factory built single unit located outdoors, with a connection made to the home’s central heating water. Split air-to-water units have an outdoor unit extracting heat from ambient air, connected by site installed pipework to an indoor unit that heats the central heating water. Monoblocs can be installed by an appropriately trained plumber. Split units require a trained refrigeration engineer to carry out parts of the installation, with an F gas certification if the heat pump uses an HFC refrigerant.

It is likely many monobloc systems could use propane as the refrigerant: both because of smaller charge size and because external systems (located outdoors) may be able to safely accommodate a larger charge of flammable refrigerant. Currently split heat pumps are not available using propane, as the refrigerant charge is too high for safe use in the indoor unit.

Maximum safe charge size varies with the size of the area being heated/cooled (to allow leaks to safely disperse), with larger charge sizes permitted for larger rooms. The heating and cooling load also increases with room size. Hence for air-to-air split systems larger systems tend to only be used in larger rooms, enabling safe use of a larger flammable refrigerant charge. However, rooms must be adequately insulated to permit a split system of the maximum charge size to provide sufficient heating.

[121] 20% of demand in 2020 calculated in terms of CO2e of gas. Number derived from Great Britain model.

For split hydronic heating systems, the indoor unit that heats the central heating water is often located in a small room – the room size is independent of the size of heat pump required to heat the whole house. This makes the use of flammable refrigerants more problematic in split hydronic systems.

Despite lower efficiency at high temperatures, CO2 may be suitable for domestic hot water heating as CO2 is more efficient when heating water over a large range of temperature. It is not generally used for space heating/cooling, although some UK manufacturers are developing CO2 heat pumps for multi-occupancy residences and small heat networks.[122]

Larger residential systems, and most air-to-air systems, will likely still require an HFC refrigerant. Until recently R-410A (GWP 2088) was used for most systems. Most new systems now use the lower flammability (A2L) refrigerant HFC-32 (GWP 675). HFO-1234yf and HFO-1234ze might be suitable for cooling but not for heating. HFO blends such as R-454C/R-455A are feasible but require up to 60% more space than a comparable HFC-32 system. At present, there are no systems on the market using an HFO blend with a GWP under 150.

The UK government aims to replace 600,000 boilers a year with heat pumps by 2028.[123] The majority of these will be a one-for-one replacement but in some cases a single heat pump may supply heat to multiple residences via a heat network. At present, there is little information about the number of residences that may be served in this way. Heat networks could be used where a home cannot accommodate the external unit required for a heat pump or air-conditioning equipment. Placing the heat pump further from the residence may potentially increase the choice of gases that may be safely used.

Commercial cooling and heating

Hydrocarbons, in particular propane, can be used for both heating and cooling with maximum charge size dictated by safety standards. With chiller systems, propane can be used in large applications.

Chillers are cheaper than direct expansion units at a large scale, for example multi-storey office buildings. Variable Refrigerant Flow (VRF) units are a form of direct expansion system that are becoming increasing viable at larger sizes although applications over 100 kW still generally require a chiller. Very large units, heating multiple buildings, benefit from a diversity factor. The peak load across several buildings could be as little as 60-70% of

[122] Information provided through discussion with the supporting consultant and industry.

[123] UK net zero strategy: build back greener and UK heat and buildings strategy (2021)

the combined individual peaks, meaning the system can be smaller and can deliver a more consistent load, increasing efficiency.

CO_2 is suitable for chillers over 70 kW and can provide both cooling and refrigeration. However, the efficiency of CO_2 is lower at higher ambient temperature which can make it inefficient for cooling applications which are only used during warmer seasons. CO_2 systems are less efficient for space heating and tend to be larger than HFC alternatives.

Evaporative cooling uses water to reduce the cooling load and improve energy efficiency. It is increasingly popular with trans-critical CO_2 systems whose efficiency is more affected by ambient temperature.[124]

Adiabatic cooling takes this principle further, relying on water to cool the air. A general downside of these systems is that they increase the humidity of the air, which can make them unsuitable for providing cooling for offices and retail space.

The humidity problem may be alleviated by use of a two-stage system which pre-cools the air (still using evaporative cooling through a piped water system), thus lowering the final temperature and also reducing the amount of water absorbed by the air in the second stage. While adiabatic cooling cannot entirely replace systems relying on a refrigerant, they may help meet the cooling demand due to climate change.

MDIs

HFCs (known as hydrofluoroalkanes, or HFAs, when used in inhalers) are used as propellants in MDIs treating asthma and chronic obstructive pulmonary disease (COPD). There are currently two approved gases, HFA-134a (GWP 1430, approximately 96% of the UK MDI market) and HFA-227ea (GWP 3220, around 4% of the market).[125] The use of HFCs as MDI propellant is exempt from the HFC phasedown in the F gas Regulation.

MDI manufacturers recognise the need to move away from high GWP propellants where possible. This transition has also been driven by international action (such as the Kigali Amendment HFC phasedown) and domestic climate targets. Some manufacturers have

[124] Trans-critical (or "booster") systems operate with the gas sometimes or always above the critical point (a pressure at which the CO_2 is transformed into an "undefined gas," where it has properties of both a liquid and a gas). They use a gas cooler in place of a condenser to disperse heat and a high-pressure expansion valve to control introduction to the evaporator. Trans-critical CO_2 systems are popular with the retail industry due to cost and the ease of reclaiming waste heat.

[125] Gluckman, R., Brown, P., Webb, N., Watterson, J., (2019) "Assessment of the potential to reduce UK F gas emissions beyond the ambition of the F gas Regulation and Kigali Amendment" Ricardo Energy and Environment ED11335/ No. 6

set independent net zero targets and the majority of device manufacturers have begun development of inhalers that use lower GWP alternative propellants.

At present, two lower GWP propellants for use in MDIs have been developed and are awaiting regulatory approval for commercial use. These are HFA-152a, which has a GWP of 124, and HFO-1234ze with a GWP of 7.[126] Both the gases and any inhaler using them must be separately approved by the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK. This is a lengthy and expensive process taking multiple years and manufacturers cannot be certain that a replacement product will be successful until testing is complete. MDIs are typically sold in multiple international markets with different regulatory approval authorities and the length of the approval processes may vary between markets.

Development of replacement gases for medical use began as early as 2019 and some manufacturers have already begun testing alternatives. However, stakeholders indicate that MDIs using these lower GWP propellants will not start to become commercially available until the end of 2025 at the earliest, subject to regulatory approval processes. Manufacturers have indicated a willingness to begin switching to new inhalers once they are approved but have expressed concerns about the cost implications of providing different products for different markets.

Due to the flammability characteristics of the replacement gases, manufacturers will need to install new production facilities. Operating multiple facilities, even for different inhaler lines, may increase manufacturer cost. This creates an incentive to transition the entire product line as rapidly as possible once the first low GWP inhalers come to market. Larger manufacturers who have already begun the development process express a belief they will be able to transition their entire MDI product line to low GWP propellants by 2030.

MDIs are not the only inhaler options for delivering necessary medicines. There are two other main types of inhalers currently available, dry power inhalers (DPIs) and soft mist inhalers (SMIs). Neither require propellant. This eliminates propellant emissions, although DPIs and SMIs require more plastic than MDIs which may increase upstream pollutants including CO2. Despite this, DPIs and SMIs significantly reduce overall CO2e emissions relative to current MDIs given the ongoing reliance on HFA-134a and HFA-227ea propellants. They will still have a smaller carbon footprint than proposed low GWP MDIs, although the difference may be trivial compared to those using HFO-1234ze.[127]

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[126] HFOs are hydrofluoro-*alkenes* and should not be confused with HFAs which are hydrofluoro-*alkanes.*

[127] Jeswani, H. K., & Azapagic, A. (2019). Life cycle environmental impacts of inhalers. *Journal of Cleaner Production,* 237

Although DPIs and SMIs have these advantages, they generally remain a more expensive option and may be unsuitable for some patients with severe breathing disabilities due to reliance on the patient taking a sharp breath. DPIs and SMIs may be more suitable for non-Salbutamol inhalers (preventative inhalers such as Inhaled Corticosteroids) rather than SABA (Short-Acting Beta-Agonist, or reliever) inhalers which currently comprise the majority of inhaler use in the UK.

Both industry and NHS representatives agree that inhaler choice remains a clinical decision, which will be specific to an individual patient's circumstances. Some MDI manufacturers expressed a concern that patients need proper training on DPIs and SMIs to use the inhaler effectively, and that inadequate training could lead to worse disease management and higher use of SABA inhalers.[128] Studies suggest poor disease management may be a significant contributor to excessive use of reliever inhalers.[129]

NHS England, Scotland and Wales all have targets to reduce emissions from MDIs.[130] Targets and policies vary across the nations on the method of the reduction – but include the transition to lower GWP propellants in MDIs and the switch away from MDIs to DPIs and SMIs where appropriate.

Power

SF_6 (GWP 22,800) is widely used in electrical equipment and applications, such as GIS and gas insulated lines (GIL), in the power sector. There are no prohibitions or legislative mechanisms in the F gas Regulation to reduce the use of SF_6 in new equipment in this sector, although leakage prevention, gas recovery and technician training requirements are applicable.

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[128] Capanoglu, M., Dibek Misirlioglu, E., Toyran, M., Civelek, E., & Kocabas, C. N. (2015). "Evaluation of inhaler technique, adherence to therapy and their effect on disease control among children with asthma using metered dose or dry powder inhalers." *Journal of Asthma, 52*(8), 838-845 provides an academic perspective

[129] As shown by Brennan, V., Mulvey, C., & Costello, R. W. (2021). The clinical impact of adherence to therapy in airways disease. *Breathe*, *17*(2) and Romão, M., Godinho, A. R., Teixeira, P. M., Mendes, Z., Bernardo, F., Rodrigues, A. T., & de Sousa, J. C. (2021). "Characteristics of Reliever Inhaler Users and Asthma Control: A Cross-Sectional Multicenter Study in Portuguese Community Pharmacies." *Journal of Asthma and Allergy*, 14, 943

[130] For example see report on delivering a 'net zero' National Health Service and NHS England "Net Zero Supplier Roadmap"

High voltage transmission switchgear and medium voltage distribution switchgear still primarily relies on the use of SF_6. The absence of reduction controls or prohibitions in the F gas Regulation may in part be responsible for this as industry are neither incentivised or motivated to develop, consider or deploy alternatives at pace.

Manufacturers and research institutes have worked to develop alternatives to the use of SF_6 in this sector and as a result there are now a number of alternatives available. One of the challenges with finding suitable alternatives to SF_6 is its effectiveness as an insulating gas enabling a smaller footprint than many of the alternatives. The applicability of different technical solutions varies depending on whether the equipment is medium or high voltage. The alternatives available are broadly broken down between in-kind and not-in-kind technologies.

In-kind options are lower GWP insulating gases, which function in a similar fashion to SF_6. This includes fluorinated ketones and fluoronitriles blends, which are low GWP F gases not covered by the current F gas Regulation. In-kind options are available on the market for certain high voltage applications (at 132kV and 400kV). Options for high voltage switchgear include Novec 4710 and g^3 (that uses Novec 4710). In-kind alternatives have also been developed for medium voltage switchgear using Novec 5110 with a GWP of less than 1.[131] Some applications are still being developed but should be available within the next five years. One of the concerns with in-kind alternatives is that they still require the use of F gases.

Not-in-kind technologies are another available option to move away from SF_6 and can be used at medium and high voltage.[132] One such F gas free alternative is the use of vacuum technology, which is available for switchgear and other applications. Air insulated solutions are another option, but require more space than current switchgear technology, which can be a limitation in some locations.

It has been shown that the cost-effectiveness of replacing SF_6 assets with non-SF_6 alternatives decreases with decreasing voltage level on a life-cycle cost-analysis basis.[133] Within the Great Britain market, 132kV replacements are the most cost-effective options, with 33kV replacements being significantly less cost-effective and 11kV the least cost-effective. This difference in cost-effectiveness, as well as availability of the alternative options across different voltages, are important considerations for operators of equipment when considering the possible transition away from SF_6.

[131] Examples of in-kind options are provided by GE Grid Solutions, Hitachi Energy and 3M.

[132] Not-in-kind technology options are provided by Siemens Energy and Schneider Electric.

[133] As shown in Sustainability First's DNO SF6 Strategies

Other sectors

There are a number of smaller sectors that use F gases, some of which have been targeted by prohibitions under the F gas Regulation. Such prohibitions have influenced the choice of gases in these applications.

Semiconductor manufacturing uses PFCs, SF_6 and HFCs for plasma etching and chamber cleaning. The use of HFCs for etching of semiconductor material or the cleaning of chemicals vapour deposition chambers within the semiconductor manufacturing sector is exempt from quota and the phasedown.

Smaller uses of SF_6 include the magnesium industry, where it is used as a cover gas during the casting of liquid magnesium. Some of these uses have transitioned to HFCs such as HFC-134a, which, while still an F gas, has a hugely reduced GWP compared to SF_6. SF_6 is also used as insulating gas in radar systems on Airborne Warning and Control System (AWACS) military aircraft.

9. HFC demand forecast

The demand forecast set out in this section used the Great Britain model. This is a bottom-up model of HFC use across all sectors, together with use of lower GWP alternatives including HFOs, CO2 and hydrocarbons. The model provides estimates of historic use and emissions of HFCs, as well as four alternative forecasts through to 2050. These forecasts demonstrate different levels of ambition for HFC mitigation, reflecting alternative assumptions about the introduction of lower GWP alternatives and other mitigation measures such as leakage reduction and end-of-life recovery.

The model develops a detailed picture of demand built up from each technology application individually. For each sector the model creates market demand assumptions based on historical data and future forecasts. Future growth forecasts are done individually for each application, taking into account the maturity of the current market. For some sectors, such as hydronic heat pumps, the model assumes much faster growth than indicated by past trends to account for government targets and other factors that may increase demand.

The Great Britain model can provide demand estimates under both the definitions provided in the Kigali Amendment and the F gas Regulation. In both cases estimates are calculated using AR4 GWPs (as shown in Appendix A). The model also estimates end-of-life recovery from equipment and use of recovered gas to provide gross and net estimates of demand. Except where stated otherwise, all data in this section is derived from the Great Britain model.

Forecast scenarios

The latest version of the model includes three alternative scenarios, and a fourth scenario developed from the European Commission's April 2022 proposal.[134]

Low ambition

This assumes relatively little change in the current mix of technologies used in the Great Britain market.

Commercially available

This assumes industry relies on existing technologies but increases deployment of lower GWP alternatives that are already commercially available.

Challenging

This assumes industry adopts technologies that have either not been developed or have not yet reached the market, but that are likely to be technically feasible in the near future. The scenario is based on assumptions around the ability to address matters such as safety, capital cost, energy efficiency and timeframes for deployment.

The model also uses a fourth scenario to assess the impact of the European Commission's April 2022 proposal:

This scenario repeats many of the assumptions in the 'Challenging' scenario but incorporates compliance with the new equipment bans in the European Commission's proposed revised EU F gas Regulation. The scenario does not incorporate any other assumptions from the Commission's modelling or attempt to match proposed phasedown targets.

Gas choice

Gas choices in the model are based on expert opinion regarding feasibility within each market sector and technology type. The appropriate gas choice takes into account factors such as safety and energy efficiency. Where possible an ultra-low GWP gas choice is made (GWP < 10, such as hydrocarbons, CO2 and HFOs). However, in some markets it

[134] EU Commission proposal to replace Regulation (EU) No 517/2014

is currently impossible to combine safety, high efficiency and reasonable capital cost without using gases with a higher GWP.

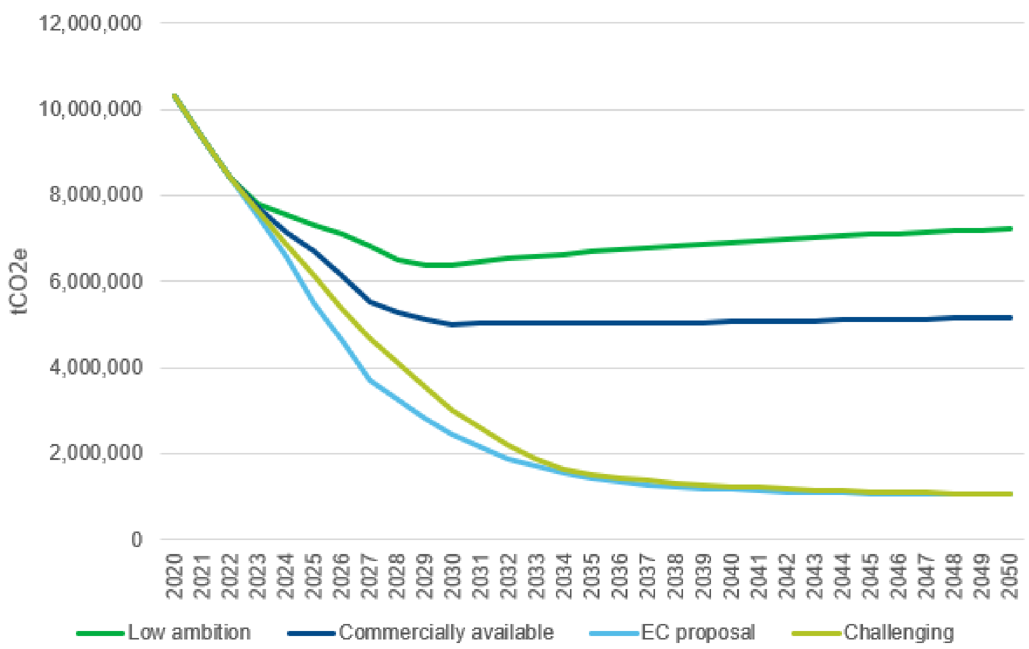
Consumption

The term consumption is sometimes used more narrowly than in the economic sense, to mean the definition given under the Kigali Amendment. Throughout the course of this section consumption means the total amount of HFCs used/consumed (in terms tCO2e) under either the definition given by the Kigali Amendment or by the broader placing on the market definition set out in the F gas Regulation. The below text describes these differences in more detail.

Summary of findings

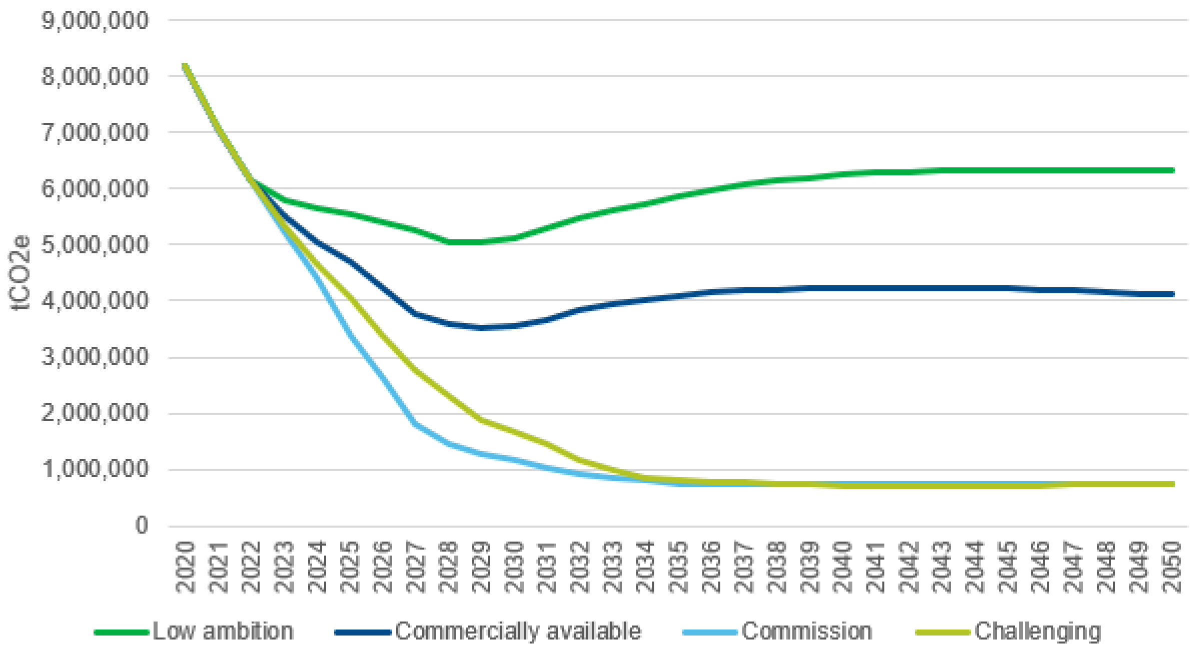
Figure 3 shows the gross consumption of HFCs between 2020-2050, for each of the modelling scenarios. Under the 'Low Ambition' scenario consumption for HFCs will continue to decline to 6.4 MtCO2e in 2030 before beginning to climb again as the heat pump rollout accelerates, reaching 7.2 MtCO2e in 2050. In the 'Commercially Available' scenario, demand increases slightly from 2030 onwards, rising less than 4% between 2030 and 2050.

Figure 3: Gross consumption (tCO2e) of HFCs, 2020 – 2050 (not including recovery)



In the 'Challenging' scenario, HFC consumption continues to decline despite the added demand from heat pumps, before levelling out towards the middle of the 2030s. In this scenario, demand falls well below the current phasedown targets. HFC usage falls more quickly in the ‘European Commission’ scenario than in the ‘Challenging’ scenario. This is as a result of the ‘Challenging’ scenario reflecting the assumptions built into the model that it would be difficult to roll out new technologies in the timescale permitted by the EU proposal. However, the model does predict that HFC usage in the ‘Challenging’ and ‘European Commission’ scenarios will converge after the middle of the 2030s.

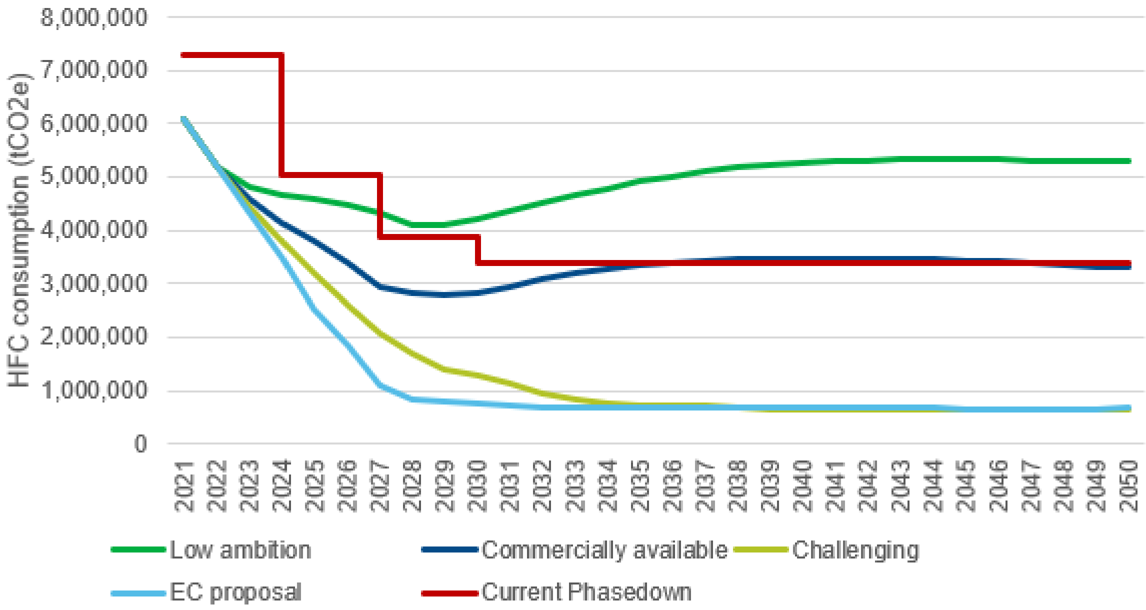
Figure 4: Net consumption (tCO2e) of HFCs, 2020 – 2050 (after recovery)



Introducing gas recovery and reuse into the model provides an estimate of net consumption. There are substantial quantities of gas currently in equipment of which a large portion was installed prior to the start of phasedown. Consequently, a supply of higher GWP gases becomes available for recovery and reclamation through to the end of this decade. This causes demand for virgin gases to dip before rising again as the supply of recovered gases declines. However, the more ambitious scenarios assume a more rapid transition to lower GWP gases and are less able to utilise these higher GWP gases.

Removing MDI usage (to enable comparison with the current HFC phasedown which exempts such use), as highlighted by Figure 5, shows that all scenarios except ‘Low Ambition’ are possible within existing targets. Although the ‘Commercially Available’ scenario slightly exceeds existing limits, this suggests the heat pump rollout is compatible with existing targets with only moderate improvements over existing technology. Comparing current targets with the high abatement scenarios (‘Challenging’ and ‘European Commission’) suggests considerable room for further abatement.

Figure 5: HFC consumption against the current HFC phasedown (set out in the F gas Regulation)



The current HFC phasedown does not account for commitments under the Kigali Amendment, which sets a lower "headline" final phasedown step (an 85% cut in HFC consumption by 2036) compared to the Regulation's 79% cut in HFCs placed on the market by 2030. But these percentage cuts can be misleading as they are based on different ways of measuring phasedown.

The Kigali Amendment includes in its consumption calculation gas placed in equipment for export and contains no exemption for MDIs. However, it does not include gas contained in imported pre-charged equipment, which the F gas Regulation does. The UK is a net importer of pre-charged equipment containing HFCs. Using the definition of consumption under the Kigali Amendment and applying the final phasedown step of 85% by 2036, all scenarios, including 'Low Ambition', would be compliant with the obligations under the Kigali Amendment. However, there remains some uncertainty about the portion of gas contained in pre-charged equipment particularly in the later modelled years.

Figure 6 shows HFC consumption, as defined by the Kigali Amendment, under each scenario. This figure indicates that Great Britain would be compliant with Kigali, even under the 'Low Ambition' scenario which is not compliant with current F gas Regulation phasedown targets. Some HFCs are still required in the 'Challenging' scenario, reflecting the high portion of imports in the comfort and cooling market. However this market is currently small and growth in heat pump usage might lead to increased domestic demand and production. Figure 6 does not show the 'European Commission' scenario but does include an additional scenario for 'Commercially Available' with an increase in domestic production. This line closely follows the 'Low Ambition' scenario and remains compliant with the Kigali Amendment.

Figure 6: HFC consumption (as defined under the Montreal Protocol, tCO2e) against the phasedown set out in the Kigali Amendment

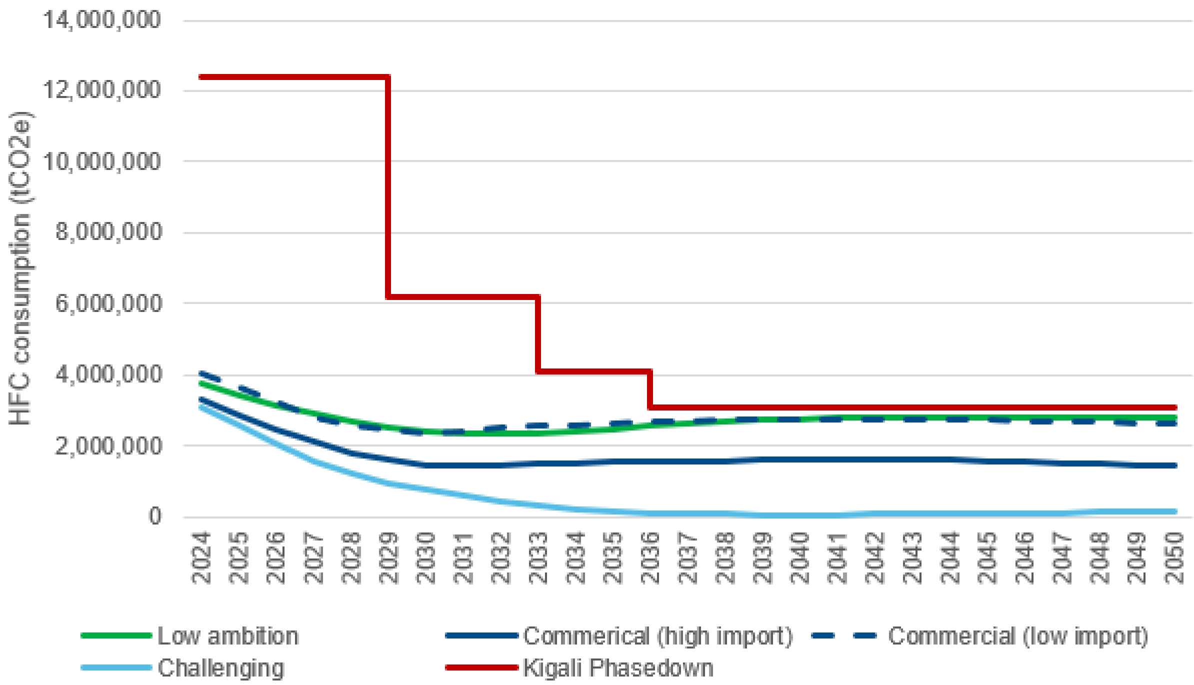
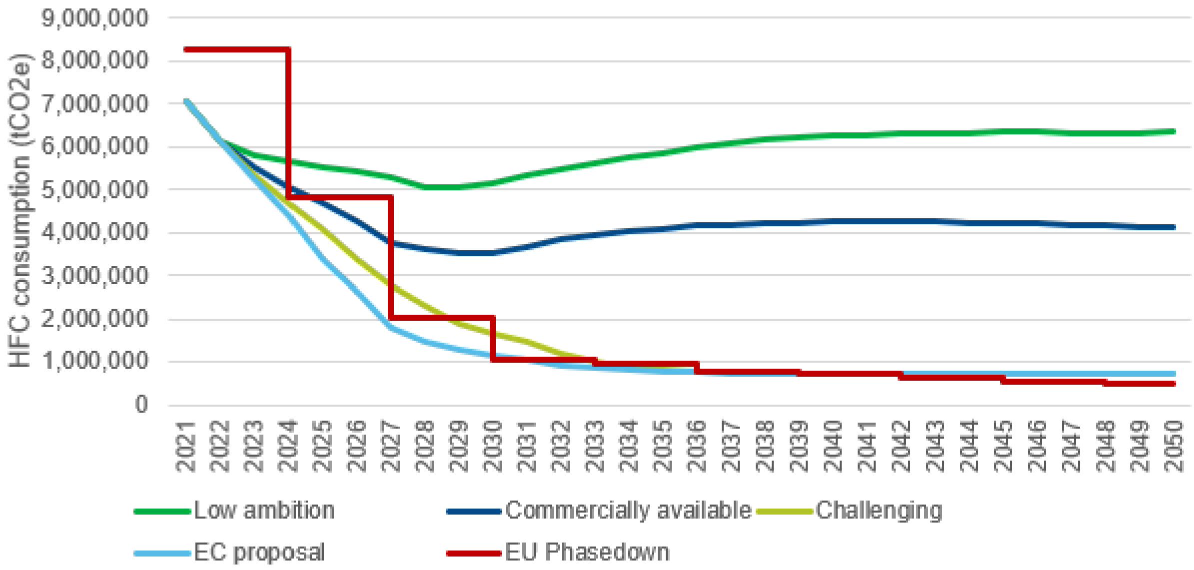


Table 5 shows modelled consumption in 2050 under scenario and in comparison, to the Kigali phasedown.

Scenario	2050 HFC consumption (tCO2e)
Kigali phasedown	3,094,500
Low ambition	2,779,579
Commercial (high import)	1,445,593
Commercial (low import)	2,622,138
Challenging	147,429

Comparing the four scenarios to the phasedown schedule put forward by the European Commission in its 2022 proposal for a revised EU F gas Regulation, as highlighted by Figure 7, suggests that industry in Great Britain would struggle to meet the required reductions and timeframes. Even in the most ambitious scenario ('European Commission' Scenario), which assumes industry is able to comply with all the proposed bans and timeframes, the phasedown is still more ambitious than initial modelling suggests may be feasible for the Great Britain market.

Figure 7: Net HFC consumption (tCO2e) (as shown in Figure 4) against the European Commission proposed phasedown



There are likely two reasons for this. The first is differences between initial usage and sectoral composition between the Great Britain and EU markets: different industries are able to reduce HFC usage at different rates. The F gas Regulation sets a baseline for usage based on prior demand. Relative to the EU, the UK used less air-conditioning at the beginning of the phasedown. The EU has already observed considerable cost-effective abatement in air-conditioning (resulting in lower average costs for Southern Europe) and continues to anticipate further cost-effective abatement. At the same time the UK has proposed a slightly more ambitious heat pump rollout which will likely increase the use of HFCs in some residences. This and other factors may limit the ability of Great Britain to match the EU Commission's phasedown targets.

The second reason is that the Commission's proposed bans establish a maximum GWP varying by application, but this is based on the highest GWP gas that might be needed. EU modelling assumes that much of industry will be able to go further than these bans by widespread use of HFOs and natural refrigerants. Under the 'European Commission' scenario, the Great Britain model does not use any HFCs with a GWP above the maximum permitted by the proposed bans, but it assumes greater reliance on HFC blends at or near that maximum than the European Commission's model. Consequently, modelled demand is likely higher than under the Commission's assumptions used to develop their proposed new phasedown schedule.

Sector-by-sector analysis

Stationary refrigeration

In stationary refrigeration, there is a substantial decline in tCO_2e in all scenarios. Use declines by 90%, from over 3 $MtCO_2e$ in 2020 to just over 300 $ktCO_2e$ by 2050, in the 'Low Ambition' scenario, and to under 100 $ktCO_2e$ in the three other scenarios. Notably the 'Commercially Available' scenario closely tracks the 'Challenging' scenario, indicating a high confidence in reductions.

Transport refrigeration (excluding marine)

Transport refrigeration is considerably smaller than the stationary refrigeration sector but potentially presents greater challenges. The sector used just 200 $ktCO_2e$ of HFCs in 2020 versus 3 $MtCO_2e$ in stationary refrigeration. But safety concerns and regulations around the use of flammable refrigerants make reductions more challenging.

In transport refrigeration, the 'Commercially Available' scenario sees R-404A (GWP 3,922) replaced with R-452A (GWP 2,140), and HFC-134a (GWP 1,430) replaced with non-flammable HFO-HFC blends with a GWP around 600, such as R-513A and R-450A. In the 'Challenging' Scenario, lower flammability alternatives with a GWP just below 150 are proposed, such as R-454A or R-455C.

The Great Britain model assumes no use of natural gases, in contrast with the AnaFgas model used by the European Commission, which assumes CO_2 will be suitable for the bulk of applications, with propane comprising the balance.[135] As noted in section 8, CO_2 systems are bulky which may limit their rollout. Propane may be suitable for some mobile applications, but its use may be restricted by safety concerns and regulatory restrictions.

It remains possible that high and medium GWP HFCs could be phased out in this sector, but a switch to HFO-HFC blends would be adequate to eliminate most usage. The Great Britain model shows overall demand declines (in terms of tCO_2e) in all scenarios from just over 200 $ktCO_2e$ in 2020 to 120 $ktCO_2e$ in 2050 in the 'Low Ambition' scenario, and to 7 $ktCO_2e$ in the 'Challenging' scenario.

[135] See AnaFgas sector sheets in the Öko-Recherche support contract for an evaluation and impact assessment for the F gas Regulation.

Marine refrigeration

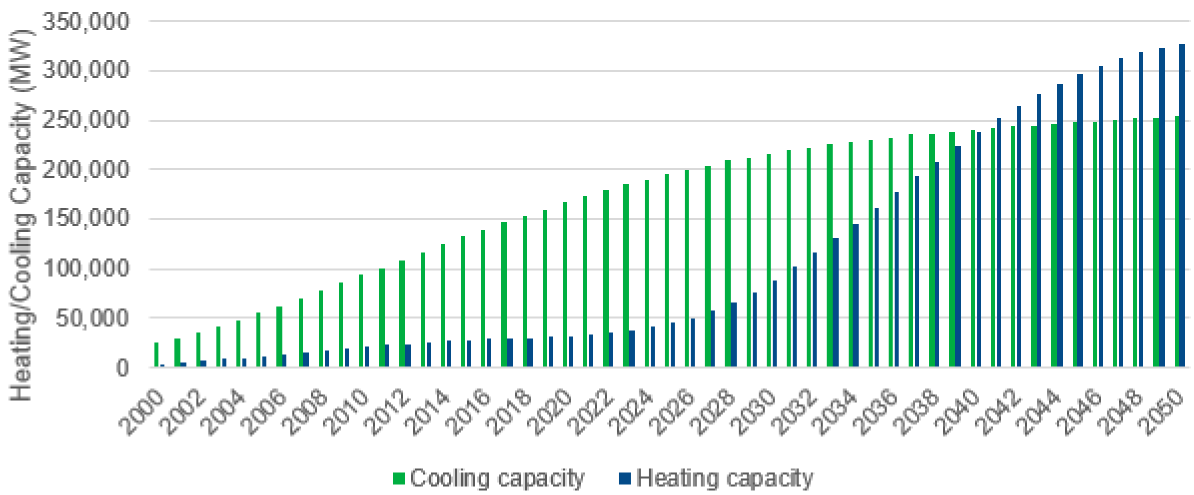
Marine refrigeration used less than 38 ktCO2e of HFC refrigerant in 2020 but offers a substantial opportunity to transition away from HFCs toward ammonia and CO2, both of which are already in use. At present, R-404A and HFC-134a are still widely used in marine refrigeration.

In all scenarios, the Great Britain model predicts that non-flammable alternatives such as R-448A and R-449A will help industry transition away from R-404A. For small marine systems a transition to A2L HFO-HFC blends with a GWP below 150 is likely, with larger systems making greater use of R-717 and R-744.

Comfort heating and cooling

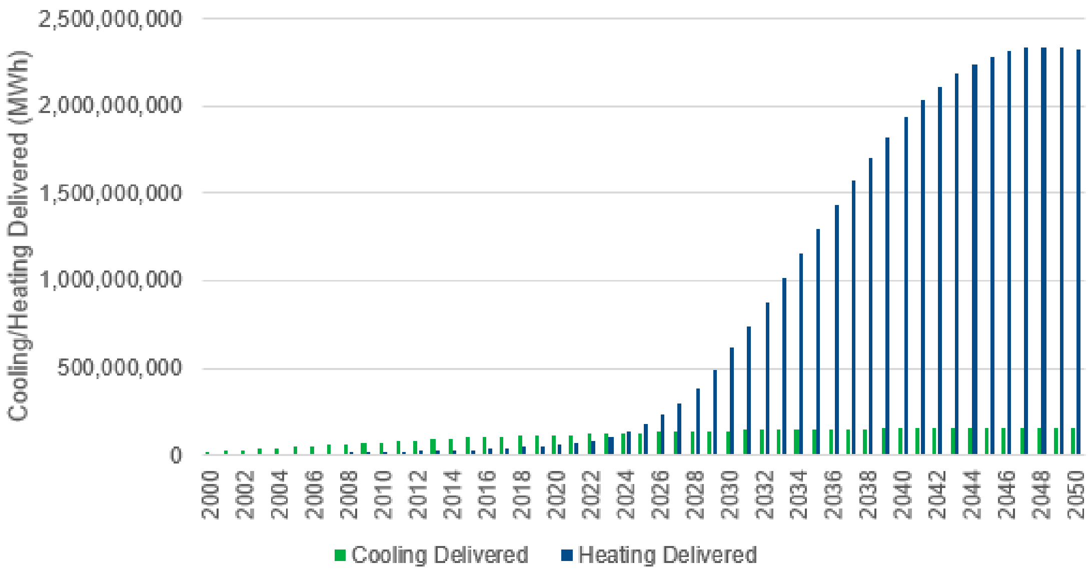
Although the Great Britain market for air-conditioning is small compared with the United States and Southern Europe, the comfort heating and cooling market within RACHP has predominantly been a cooling market. However, with the need to shift away from fossil fuels for heating this is likely to reverse well before 2050. Figure 8 shows that although cooling capacity has greatly exceeded heating capacity in the past and will continue to grow, total heating capacity will overtake around 2040.

Figure 8: Total heating/cooling capacity (MW) in the Great Britain market



The shift in energy delivered is even more substantial. This measure takes into account how much heating or cooling is delivered, as shown in Figure 9, and reflects that heat pumps will be in use for significantly more hours per year than cooling equipment. By 2030, heating delivered will dwarf cooling and will continue to grow rapidly.

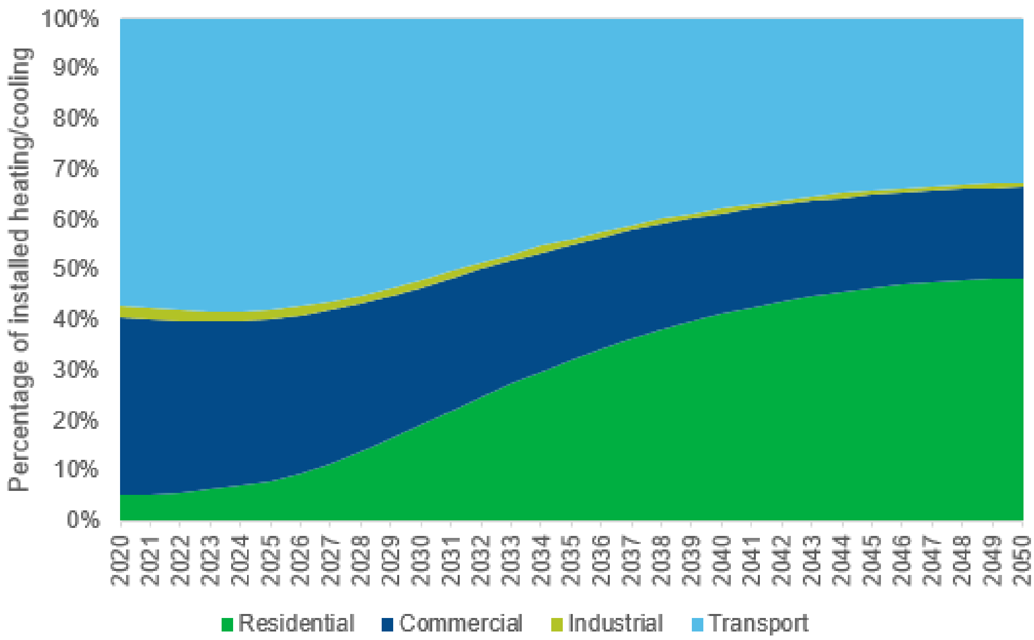
Figure 9: Total heating/cooling delivered (in megawatt hours (MWh)) in the Great Britain market



Residential air-conditioning and heat pumps

Figure 10 shows the percentage of the installed heating and cooling capacity across the residential, commercial, industrial and transport sectors. This shows that residential air-conditioning and heat pumps have historically been a small market. However, a combination of climate change and government heat pumps targets are likely to substantially expand the requirement for residential cooling and, in particular, for heating.

Figure 10: Percentage installed comfort cooling/heating capacity (MW)



The UK government aims to replace 600,000 boilers with heat pumps every year by 2028, as set out in the UK heat and building strategy.[136] This target is for small hydronic heat pumps which can replace domestic boilers, this will be a mixture of both monobloc and split heat pump systems.[137] In contrast to most sectors, residential heat pumps show substantial growth in HFC demand, even in the 'Challenging' and 'European Commission' scenarios.

Under the 'Low Ambition' and 'Commercially Available' scenarios, this target is met largely with a combination of propane and HFC-32 (both are forecast to occupy 40% of the market by 2030). This is a substantial increase in market share for both gases (from 8% and 7% respectively in 2020), replacing higher GWP gases (predominantly R-410A, although this remains in small quantities under both low abatement scenarios).

The UK market has already seen significant growth in the use of HFC-32 which is suitable for both heating and cooling. HFC-32 has doubled its market share in new equipment in the past two years,[138] albeit from 8% to 16%, largely at the expense of R-410A although the latter still comprises 67% of the market.[139] In addition to having a lower GWP (675), HFC-32 is cheaper than R-410A and requires a smaller refrigerant charge.

Although propane currently only holds a small share in the Great Britain market for hydronic heat pumps, it is a suitable alternative for monobloc systems. For split hydronic heat pumps propane is unlikely to be a safe alternative to R-410A. With a medium GWP of 675 the lower flammability HFC-32 is already gaining a significant market share. However, despite a lower GWP than R-410A, the scale of the government's heat pump rollout means if industry were to rely on HFC-32 alone the heat pump rollout could consume most of the available quota even under the existing HFC phasedown.

Use of propane increases only slightly in the 'Challenging' and 'European Commission' scenarios, reaching 50% penetration of the market. This reflects the safety limits on using propane in split systems and also the high use of propane in the 'Low Ambition' and 'Commercially Available'. The 'Challenging' and 'European Commission' scenarios assume technology developments that will enable a switch away from HFC-32 to A2L HFO-HFC blends with a GWP under 150, such as R-454C or R-455A.The most notable difference between the 'Challenging' and 'European Commission' scenarios is the more

[136] UK heat and buildings strategy (2021)

[137] See section 8 – residential heating and cooling for a more detailed description of the types of systems.

[138] From 2020 to 2022.

[139] In 2022.

rapid phaseout of high GWP gases under the proposed EU bans in the latter scenario. The ’European Commission’ scenario assumes compliance with the proposed ban in 2027 is possible. This is not an assessment of the feasibility of that assumption and the model does not evaluate the impact on demand for heat pumps if lower GWP technologies are not available in time.

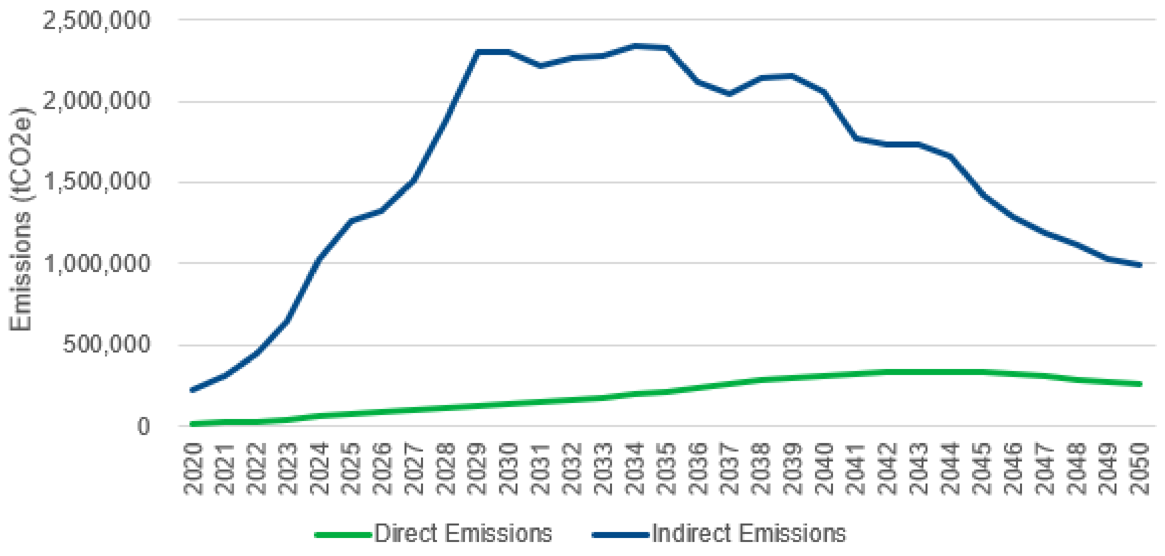
Although modelling assumes reliance on hydronic heat pumps, it is also possible that more heat could be supplied by air-to-air units.[140] Expanding the UK government’s heat pump rollout targets to include air-to-air heat pumps could increase the quantity of HFC required per unit to heat the whole dwelling,[141] and also reduce the ability to use propane. When compared to hydronic heat pumps (under 12kW), of which 50% are monobloc systems using propane, only 40% of small split systems (under 3.5 kW) use propane under the ‘European Commission’ scenario and only 30% under the ‘Challenging’ scenario.

Despite increased use of HFCs, air-to-air units may be more efficient. At present, indirect emissions (from energy generation) account for approximately 93% of total emissions from heat pumps. Consequently, gains from greater efficiency may outweigh any benefits from smaller charge size or lower GWP refrigerants. Over time, however, the switch to green energy generation will shift this ratio. Figure 11 shows how refrigerant emissions become a larger portion of total emissions from heat pump usage. The Great Britain model is conservative in estimating total grid decarbonisation meaning indirect emissions are likely to be smaller than shown here.

[140] Other direct systems are also viable here, such as ground-to-air or water-to-air although these are only likely to comprise a small portion of the market. For simplicity only ‘air-to-air’ is referred to in this section.

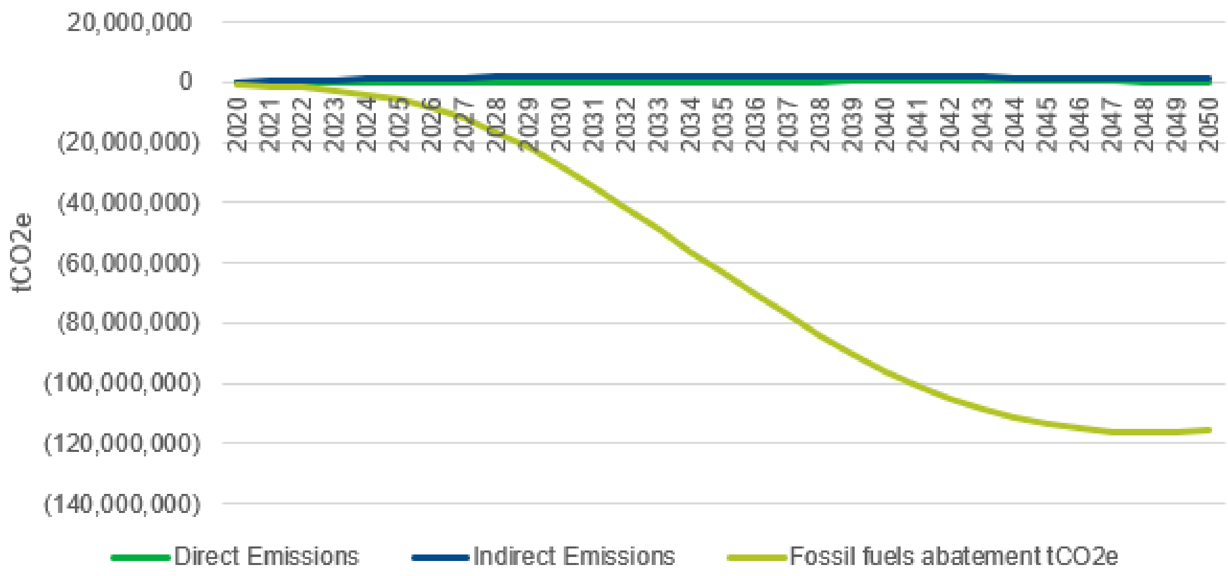
[141] Noting that in existing homes these would be multi-split systems.

Figure 11: Total annual emissions from hydronic heat pump usage



It is important to find a balance between the efficiency of heat pumps and reducing the use of HFCs, and the optimal balance may change over time as the grid switches to renewable energy. However, as Figure 12 shows, the impacts of both direct and indirect emissions from the heat pumps are much smaller than the potential savings from replacing gas boilers. Net savings from heat pump deployment are in the order of 115 MtCO2e/year by 2050. Any measures implemented to reduce direct or indirect heat pump emissions will therefore need to be designed to avoid impeding the deployment of heat pumps, as the decarbonisation of heating must be treated as a much higher priority.

Figure 12: Direct and indirect emissions from heat pumps against total abatement (per year) from replacing fossil fuels



In some cases, homes may not be adequately plumbed for hydronic heat pumps to operate efficiently without modifications, such as larger radiators or underfloor heating. In these cases, air-to-air split units may be a cheaper solution. These units can also provide air-conditioning in the summer, which could offset improvements in energy efficiency. On the other hand, the added functionality may increase value to consumers and increase the uptake of heat pumps. As Figure 12 indicates, the potential for emissions abatement from replacing gas boilers is orders of magnitude greater than the direct and indirect emissions from heat pumps.

Climate change may also increase the need for air-conditioning, especially for vulnerable people. National Grid project uptake of air-conditioning equipment to reach 18 million units by 2050, with between 5.1-12.8 million UK households fitted with cooling.[142] This demand is likely to be concentrated in the South East of England. In London, Day et al. project cooling demand for all buildings will increase from 1.6 TWh per year in 2004 to 2.5 TWh per year by 2030.[143] Nationally, cooling demand for households alone will reach between 5-13 TWh by 2050.[144]

Using the same system for heating and cooling would both reduce cost and use of refrigerants. It may also allow the hot water system to use waste heat from the air-conditioning during the summer, reducing overall energy use. Hydronic heat pumps can be used to provide cooling, but this is more likely to require modifications such as underfloor heating/cooling.

Commercial heating and cooling

In the commercial sector, air-conditioning is already more widespread than domestic residences. While it remains likely that the need for cooling will grow due to climate change there is less need to install new systems, although higher peak temperatures may require larger cooling units. In many cases, a single system provides both heating and cooling but not all of these systems are designed to use the air conditioner as a heat pump. Converting commercial spaces to decarbonised heat will generate less new demand for HFCs than converting residences, although heating may require a larger unit than is currently installed.

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[142] National Grid – Future Energy Scenarios and Paul Watkiss Associates "Monetary Valuation of Risks and Opportunities in CCRA3;" *Report to the Climate Change Committee as part of the UK Climate Change Risk Assessment 3* (2021).

[143] Day, A. R., Jones, P. G., Maidment, G.G., (2009) "Forecasting future cooling demand in London." *Energy and Buildings,* 41, 942–948

[144] Sansom, R., (2017) "Domestic heating demand study" Birmingham, UK.

In contrast to the residential sector, which will see large growth in demand for HFCs, the commercial sector will see a significant decrease (in terms of tCO2e) in all scenarios. In the ‘Low Ambition’ scenario, demand falls from over 3 MtCO2e in 2020 to under 1.5 MtCO2e by 2050. The ‘Challenging’ and ‘European Commission’ scenarios both see this decline even further to under 0.4 MtCO2e by 2050.

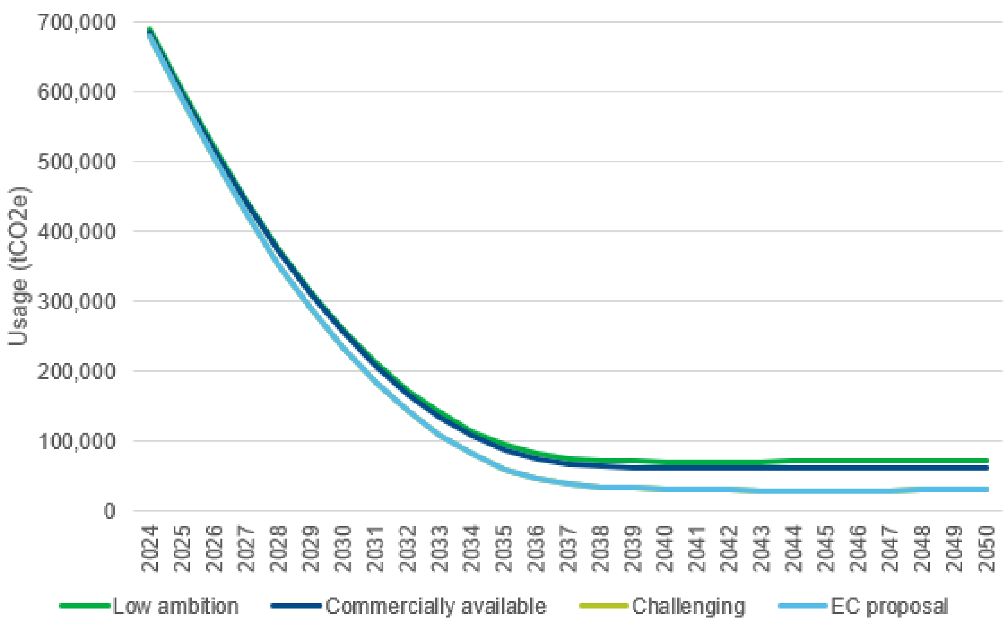
In the ‘Low Ambition’ and ‘Commercially Available’ scenarios, the decline in HFC demand is driven by a switch from R-410A to HFC-32 in stand-alone and air-to-air split systems, and from R-410A and HFC-134a to HFC-32, HFO-1234ze and other HFOs in chiller units. The ‘Challenging’ and ‘European Commission’ scenarios assumes that HFC-32 use in both air-to-air splits and in small chillers transitions to HFO-HFC blends with GWP under 150, such as R-454C and R-455A.

Transport heating and cooling

In MAC, HFO-1234yf has dominated total refrigerant usage in new small vehicles (including vans and trucks where only the cab is cooled) since 2017, when the MAC Directive prevented further use of HFC-134a. There is still use of HFC-134a to service older vehicles, but use will steadily fall over the next 10 years.

In larger vehicles such as buses and trains, the flammability of HFO-1234yf poses an obstacle to adoption (although it still comprises an estimated 20% of physical gas used in new vehicles). HFC-134a still holds the largest market share and comprises the majority of emissions. Figure 13 shows the HFC use in transport heating and cooling, the timeline starts from 2024 to make the later differentiation between the scenarios more visible.

Figure 13: Total HFC use (tCO2e) in transport heating and cooling



In both the 'Challenging' and 'European Commission' scenarios, HFC-134a is replaced entirely with a combination of HFO-1234yf and HFC-32. The 'Low Ambition' and 'Commercially Available' scenarios still see HFC-134a replaced, but with an increased amount of non-flammable HFC-134a alternatives such as R-513A. The 'Low Ambition' and 'Commercially Available' scenarios also retain a small amount of R-410A. Despite these differences, all scenarios result in most HFC usage (in tCO2e) being abated.

Non-RACHP

HFCs are used outside of RACHP in aerosols (including general aerosols and MDIs) and insulation foams. Use for general aerosols and foams has fallen dramatically since the introduction of the F gas Regulation, with bans on HFCs with a GWP > 150 between 2018 and 2023. Use for MDIs is not controlled under the F gas Regulation.[145] Consumption of HFCs in these non-RACHP applications has dropped from 4 MtCO2e in 2017 to 1.6 MtCO2e in 2022.

Under the 'Challenging' scenario, HFC use for non-RACHP will continue to fall to ~100 ktCO2e from 2035. However, the industry will continue to use small quantities of HFC-134a and HFC-152a as an aerosol propellant, and the model predicts a sustained demand of ~100 ktCO2e through to 2050 in the 'Challenging' scenario.

For insulating foams, the model predicts a rapid phasedown in HFC use, driven largely by a switch to hydrocarbons and HFOs. In both the 'Commercially Available' and the 'Challenging' scenario, industry is able to shift completely away from the use of HFCs by 2023.

Since the 2009 ban on HFCs in novelty devices, the aerosol sector may be divided into technical aerosols and medical devices. Prior to the introduction of the current F gas Regulation, there was a decline in the use of HFCs in technical aerosols, and a gradual switch from HFC-134a to HFC-152a. After 2017, these trends accelerated dramatically. The CO2e of HFC usage fell from 684 ktCO2e in 2017 to 41 ktCO2e in 2020. At the same time, the market shifted entirely from HFC-134a to HFC-152a, to HFO-1234ze and to non-fluorocarbon propellants. The model predicts HFC use will remain stable through to 2050.

This leaves MDIs as the dominant source of HFC demand outside of RACHP, as shown by Figure 14. While representing only a quarter of total non-RACHP demand in 2017, the Great Britain model predicts that MDIs will represent over 90% of all non-RACHP consumption of HFCs by 2023. Beyond this point the model predicts HFC demand from MDIs will decline significantly in the 'Challenging' scenario.

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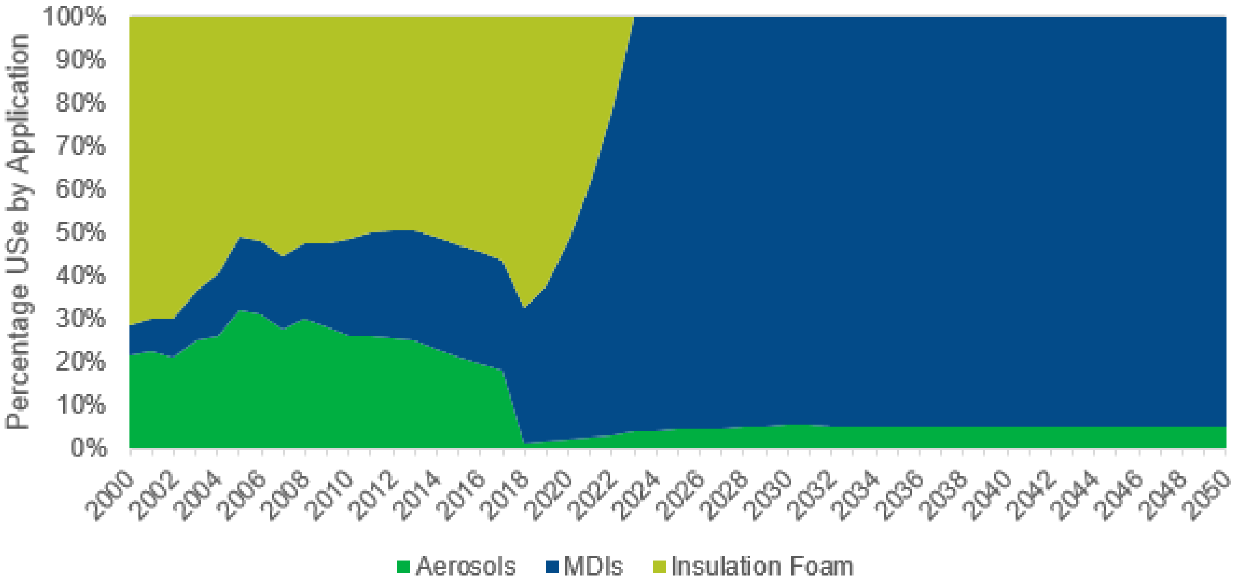
[145] Although MDIs were briefly included in the phasedown.

Figure 14: GWP-weighted HFC/HCFC use by application



Commercially available MDIs have yet to shift toward alternatives or lower GWP propellants. As described in the state of technology section, both low GWP propellants and DPIs and SMIs may replace current inhalers but a rapid shift to either carries associated health risks. The coronavirus pandemic may have further reduced the ability of GPs to provide the necessary support to enable patients to transition to DPIs or SMIs, slowing the transition.

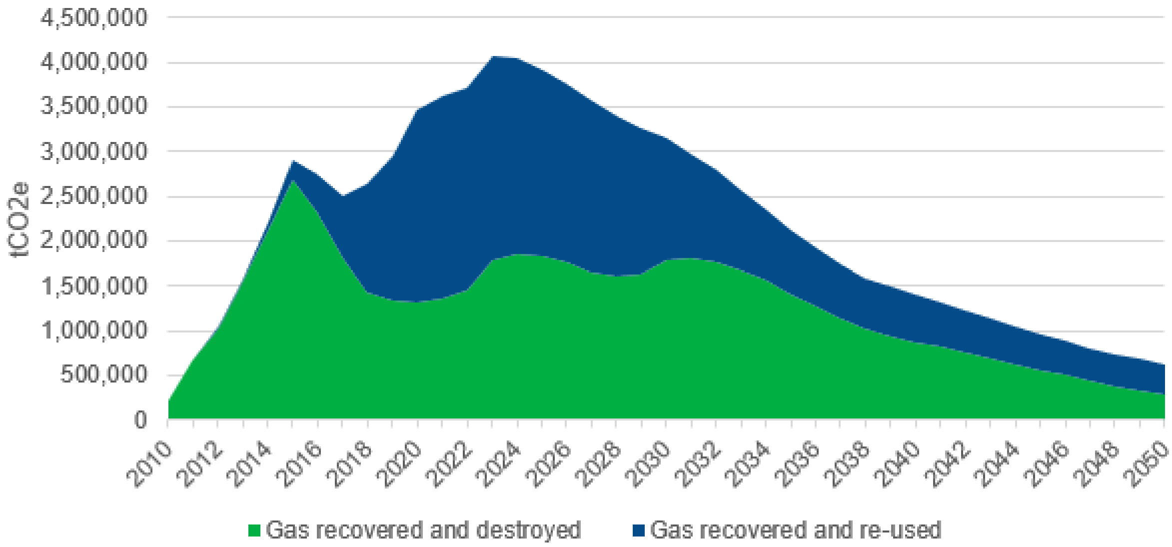
DPIs and SMIs are not suitable for all patients and the Great Britain model predicts continued use of MDIs with an eventual switch to low GWP propellants – either HFA-152a or HFO-1234ze. Although industry expects to use both propellants in the future, currently there is insufficient information to predict the ratio. The model assumes 100% use of HFA-152a as a replacement gas, which is likely a conservative assumption regarding overall abatement.

While modelling does account for increased use of MDIs, there are additional NHS policies and targets not currently included in the Great Britain model, including those to reduce the use of MDIs and the use of high GWP propellant in MDIs. While the effects of these policies are too uncertain to model, it is possible that current modelling is conservative in the future use of MDIs.

Gas recovery and reuse

In addition to gross demand, the Great Britain model also estimates gas recovery and reuse. This includes estimates of (a) the quantity of gas available for recovery in equipment reaching end-of-life or being retrofitted, (b) the quantity of gas actually recovered, (c) the quantity of gas reused (either reclaimed or recycled) and (d) the quantity of gas destroyed. Figure 15 shows the quantity of HFCs recovered and reused or destroyed. Understanding recovery is necessary to estimating the demand for virgin gases. However, a lack of information about gas that is recovered and recycled onsite leads to a degree of uncertainty regarding estimates of recovery levels.

Figure 15: Destruction and reuse of HFCs



Modelling suggests a significant increase in recovery from 2014. This is mainly because HFCs only started to be used in significant quantities around 2000 and begin to reach end-of-life around 2010. Also there is a need to retrofill equipment affected by the 2020 service ban relating to equipment using F gases with a GWP of 2,500 or more with a charge size of 40 tCO2e or more (Article 13(3)). This creates an extra source of HFCs available for recovery. The model projects recovery will dip slightly in 2025 before resuming an upward trajectory. Initially most of the recovered gas is destroyed, but after 2017, when quota prices rise substantially, industry began to reuse the recovered gas.

The increase in reuse helps to offset some of the reduced availability of HFCs due to the phasedown. However, there is insufficient data to determine whether reclamation is more cost-effective than the combined cost of creating virgin gas and destroying old gas. The switch to recovered gas may also offset some of the benefits of the phasedown if the gas would otherwise have been destroyed.

Recovery begins to decline (in terms of tCO2e) after the middle of the 2030s as the amount of high GWP gas in equipment also declines. However, both forward modelling and the retrospective analysis described earlier, indicate that only a relatively small portion of the available gas is recovered. There is limited good data available on the amounts of gas actually recovered. Figure 16 shows best estimates of the significant quantities of gas that are illegally vented to atmosphere (Article 8 of the Regulation requires all gas to be recovered from RACHP equipment at end-of-life).

Figure 16: HFC recovery and venting

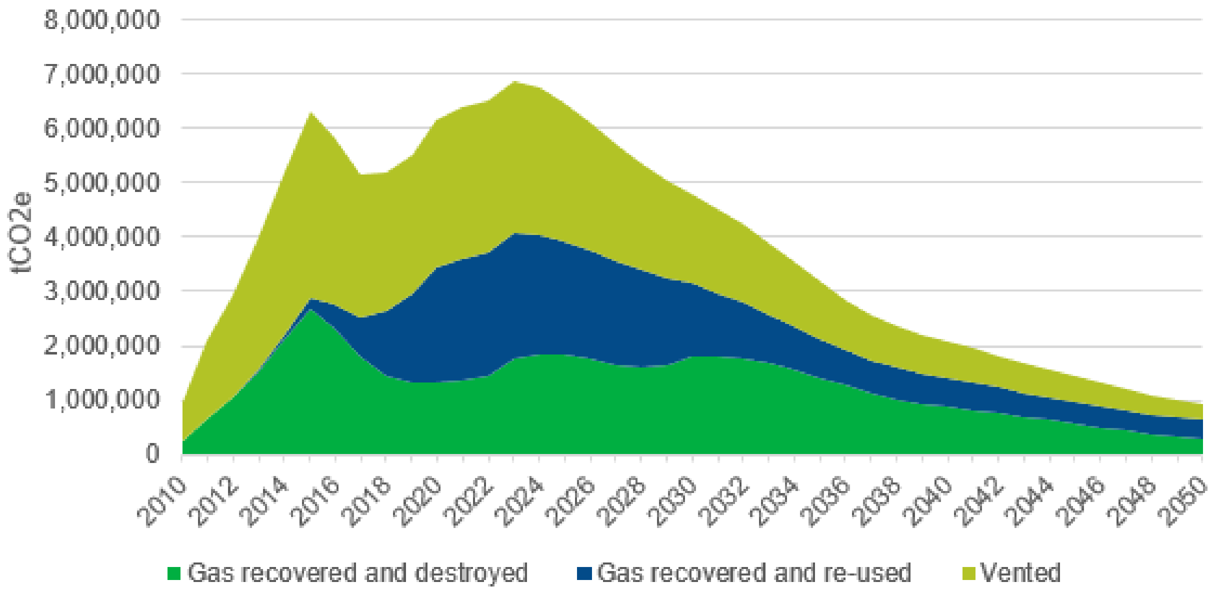
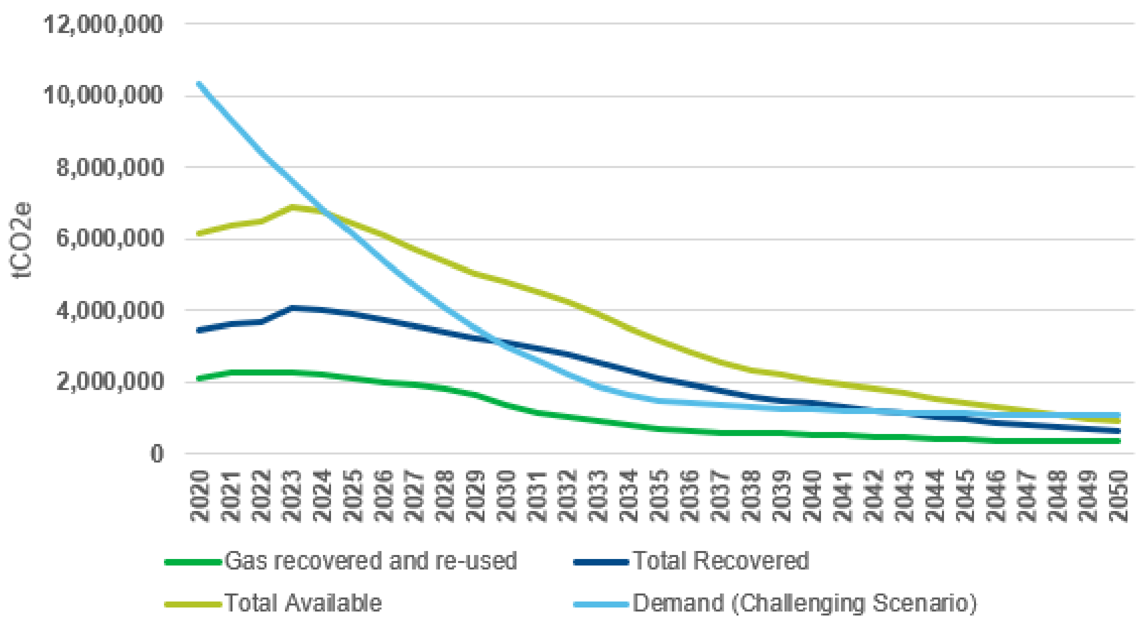


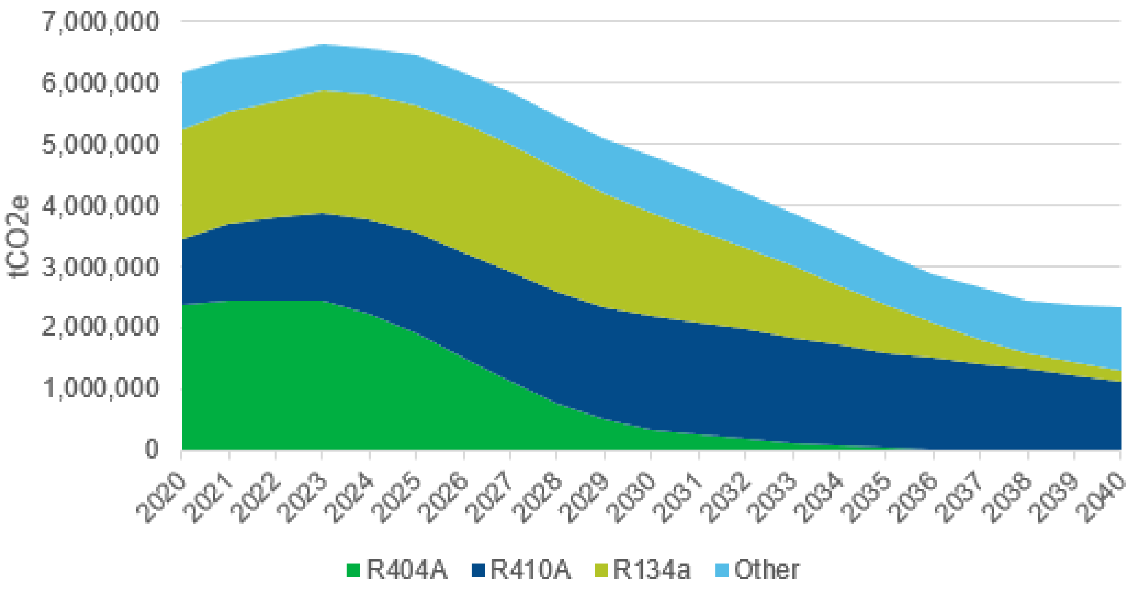
Figure 17 highlights how the challenge in reducing emissions during the next 20 years switches from one of usage to one of containment. Notably, the quantity of gas available, when measured in tCO2e, is greater than the expected demand under the 'Challenging' scenario. Comparing available and recovered gas with gross demand demonstrates that from the middle of this decade until 2050, there is more gas available for recovery than total demand for virgin gas. While the previous figures show that the HFC phasedown has created incentives to recover and reuse gas, they also show that incentives for destruction are weaker.

Figure 17: Gas recovery and gas available for recovery against total demand (tCO2e)



Recovery for the purpose of reuse is limited by the type of gas available. Gas in equipment reflects the composition of the market that existed 10-25 years previously. The rapid phasedown of HFCs, and reduction of permitted GWPs as a result of bans being implemented, means the gases available for recovery are not the low GWP gases needed for new equipment. Figure 18 shows that over the next two decades the majority of HFCs available for recovery is comprised of just three widely used gases, all with relatively high GWPs.

Figure 18: Gas available for recovery by type



While new equipment could reuse the high GWP gases (provided it is not prohibited under Annex 3 of the F gas Regulation), this would significantly increase demand which is expressed in tCO2e. Although the above figures demonstrate both a challenge and an opportunity to reduce emissions through more effective recovery, they also highlight a risk. If the phasedown severely restricts the availability of virgin gases, it is possible that industry will rely on the available supply of high GWP gases – either by placing the recovered gas in new equipment or by keeping older equipment (which is more likely to be leaky and inefficient) in service longer.

10. Further UK action

International commitments

The F gas Regulation was implemented in 2014, before the Kigali Amendment to the Montreal Protocol was adopted in 2016. As a result, there are some areas where further action is needed to ensure full alignment and compliance with Montreal Protocol, specifically in relation to HFCs.

There are three core compliance obligations under the Montreal Protocol. These are for Parties to control production and consumption (Article 2), to license imports and exports (Article 4B) and to report annually on production, imports and exports (Article 7).[146]

The Montreal Protocol requires Parties to phase down production and consumption of HFCs. The F gas Regulation controls and reduces consumption through the HFC phasedown and the requirement for quota to place on the market. The HFC phasedown set out in the F gas Regulation will need to be extended to meet the Kigali Amendment, which requires a phasedown in consumption by 85% by 2036. The same phasedown is set for HFC production under the Kigali Amendment. While there is currently no HFC production within the UK, legislation is needed to safeguard continued compliance with the production phasedown. The EU F gas Regulation did not set out a phasedown for production, as regulating production was considered to be a Member State competency.

The F gas Regulation sets out uses that are exempt from the requirement for quota and thereby the phasedown. The Kigali Amendment does not include any exemption from the phasedown, so it may therefore be necessary to review the exempted uses under the F gas Regulation to ensure compliance with the obligation to phasedown consumption by 85% by 2036.

The Montreal Protocol requires licensing of imports and exports. Under the F gas Regulation, registration to the F gas system is mandatory and constitutes an import or export licence. Registration is required in order for companies to receive quota and for those importing or using HFCs for exempted uses. There has been some feedback from industry that this licensing system could be strengthened. For example, the ODS Regulation requires per consignment licences.[147] Changes to the current F gas system could be considered to enable real time reductions in available quota.

The F gas Regulation includes thresholds for placing on the market and reporting thresholds (below which reporting is not required). The Kigali Amendment does not include any thresholds for consumption or reporting, therefore providing an area where strengthening will be required.

In addition, the Montreal Protocol imposes restrictions on trade of HFCs with non-Parties to the Kigali Amendment, which will need to be implemented in future legislation. As well as the changes needed to ensure compliance with the Montreal Protocol, there is also scope for improvements in reporting, for instance on new substances and

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[146] Article 2 of the Montreal Protocol, Article 4B of the Montreal Protocol and Article 7 of the Montreal Protocol

[147] Regulation (EC) No 1005/2009

recovery/reclamation. This could improve data gathering on gases and uses. Emissions reporting could also be reviewed and considerations for how to strengthen this to help provide improved data reported to UNFCCC on F gases.

Future policy

Following this report, further policy work and analysis will be undertaken to assess potential future policy proposals. These will include consideration of greater ambition on F gases in support of the UK's net zero commitment, taking account of technological developments, and will ensure continued compliance with international obligations under the Montreal Protocol. Subject to agreements, policy proposals will be published in a joint consultation in due course.

Two of the key sectors where particular attention will be needed are heat pumps and MDIs.

Heat pumps

While the current HFC phasedown is already driving industry to move towards alternative gases, thereby decreasing use and emissions in most RACHP sub-sectors, the heat pump sub-sector is predicted to increase its demand for HFCs.[148] This is as a result of steps being taken to decarbonise the heating market through deploying more low-carbon technologies, such as heat pumps, in support of meeting the UK's net zero target. This is set out in the UK heat and building strategy, published in October 2021.[149]

The Scottish government published its heat in buildings strategy on 7 October 2021, setting out its approach to deliver a 68% emissions reduction (from the heating sector) over the 2020s.[150] Achieving this will require over a million homes and the equivalent of 50,000 non-domestic buildings to switch to zero emissions heating, with a strategic focus on heat pumps and heat networks.

Heat pumps and heat networks will make a key contribution to meeting net zero, but there are important interactions between heat pumps and the F gas Regulation, as many heat pumps contain HFCs as the refrigerant. While many commercially available heat pumps currently rely on HFCs, such as R-410A, there is industry action to develop heat pump

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[148] Many commercially available heat pumps currently rely on HFCs, such as R32.

[149] UK heat and buildings strategy (2021)

[150] Heat in buildings strategy - achieving net zero emissions in Scotland's buildings (2021)

systems using alternatives to high GWP F gases. The heat and building strategy sets out deployment targets for the UK market and aims to deploy 600,000 hydronic heat pump systems per year by 2028, as part of the transition to net zero. Decarbonising heat and buildings are devolved policy and will require join-up across the UK, similar to F gases.

The Climate Change Committee's (CCC) Sixth Carbon Budget[151] acknowledges the expected rise in F gas emissions associated with an increased deployment of heat pumps up to 2050. The CCC go on to state that the greenhouse gas benefits of switching from fossil fuel heating to heat pumps far outweigh the potential increase in HFC emissions from refrigerant leakage.[152] This finding is supported by the analysis in this report (see Figure 12). If heat pumps use lower GWP F gases or non-F gas alternatives (taking account of energy efficiency), the expected rise in emissions can potentially be minimised and the net benefit to meeting the net zero target of switching to heat pumps will be even greater.

MDIs

The use of HFCs as a propellant in MDIs is an area of joint policy between Defra, Scottish government and Welsh government. Prescription of inhalers (MDIs), including policies in support of meeting net zero targets is led by the NHS (England, Scotland and Wales) and the Department of Health and Social Care and devolved administrations. The NHS have several related targets across England,[153] Scotland[154] and Wales. Many of these targets are tied specifically to supporting NHS net zero objectives or indirectly support them. Examples of relevant policies include:

- helping patients to better manage their condition to avoid overuse of 'reliever' inhalers
- a reduction in MDI usage by encouraging a switch to DPIs and SMIs for non-Salbutamol inhalers (inhalers used for disease management rather than emergency relief). This must be done by working with patients and GPs such that patients feel comfortable and are properly trained to use their inhaler

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[151] The Climate Change Committee Sixth Carbon Budget – The UK's Path to Net Zero

[152] The Climate Change Committee Sixth Carbon Budget – F gases. Analysis for the government in 2014 showed that for every additional 1 tCO_2e of additional HFC emissions from refrigerant leakage in heat pumps, there are 161 tCO_2e of CO_2 savings due to avoided emissions from gas boilers and efficiency improvements.

[153] NHS England Delivering a 'Net Zero' National Health Service and NHS England Investment and Impact Fund 2022/23 (ES-01 and ES-02)

[154] NHS Scotland climate emergency and sustainability strategy: 2022-2026

- shifting patients away from MDIs with a large charge size. Although all MDIs use HFCs, some (including some older designs) use more gas per dose than others
- encouraging recovery of remaining gas in used inhalers to prevent release to atmosphere

In Wales, the use of inhalers, including policies in support of meeting net zero targets, is a collaborative effort between patients and the public of Wales, the pharmaceutical industry, healthcare professionals in NHS Wales and the Welsh government. There are a range of activities underway to drive progress towards Wales's initiatives to support net zero ambitions. The following, for example, have been ratified and endorsed by the All Wales Medicines Strategy Group (AWMSG):

- All Wales adult asthma management and prescribing guideline[155] – which aims to reduce variation in inhaler prescribing in the management of adult asthma
- All Wales COPD management and prescribing guideline[156] – which aims to reduce variation in inhaler prescribing in the management of COPD

This includes recommending the preferential prescribing of DPIs rather than MDIs and is aligned to the NHS Wales target of reducing the use of MDIs from more than 70%, down to less than 20% by 2025.[157]

The Scottish government and NHS Scotland Assure developed the NHS Scotland climate emergency and sustainability strategy, which was published in August 2022 and sets out Scotland's actions to reduce emissions from inhaler propellants by 70% by 2028.[158]

Additionally, in Scotland, the price of inhalers which have a lower volume of HFC per dose has been lowered as part of the Scottish Drug Tariff to encourage their use and prescribing while reducing greenhouse gas emissions.

Further consideration will be needed on the role of future F gas policy in controlling and reducing consumption and emissions of HFCs in MDIs.

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155 All Wales Adult Asthma Management and Prescribing Guidelines

156 All Wales COPD Management and Prescribing Guidelines

157 NHS Wales Decarbonisation Strategic Delivery Plan

158 NHS Scotland climate emergency and sustainability strategy: 2022-2026

Appendix A: F gases and GWPs

Annex 1 of the F gas Regulation – fluorinated greenhouse gases (as defined in the F gas Regulation) and GWP values (based on AR4 values).[159]

Section 1: HFCs

Industrial designation	Chemical name (Common name)	Chemical formula	GWP
HFC-23	trifluoromethane (fluoroform)	CHF_3	14,800
HFC-32	difluoromethane	CH_2F_2	675
HFC-41	fluoromethane (methyl fluoride)	CH_3F	92
HFC-125	pentafluoroethane	CHF_2CF_3	3,500
HFC-134	1,1,2,2-tetrafluoroethane	CHF_2CHF_2	1,100
HFC-134a	1,1,1,2-tetrafluoroethane	CH_2FCF_3	1,430
HFC-143	1,1,2-trifluoroethane	CH_2FCHF_2	353
HFC-143a	1,1,1-trifluoroethane	CH_3CF_3	4,470
HFC-152	1,2-difluoroethane	CH_2FCH_2F	53
HFC-152a	1,1-difluoroethane	CH_3CHF_2	124
HFC-161	fluoroethane (ethyl fluoride)	CH_3CH_2F	12

[159] AR4 means based on the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change.

Industrial designation	Chemical name (Common name)	Chemical formula	GWP
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	CF_3CHFCF_3	3,220
HFC-236cb	1,1,1,2,2,3-hexafluoropropane	$CH_2FCF_2CF_3$	1,340
HFC-236ea	1,1,1,2,3,3-hexafluoropropane	CHF_2CHFCF_3	1,370
HFC-236fa	1,1,1,3,3,3-hexafluoropropane	$CF_3CH_2CF_3$	9,810
HFC-245ca	1,1,2,2,3-pentafluoropropane	$CH_2FCF_2CHF_2$	693
HFC-245fa	1,1,1,3,3-pentafluoropropane	$CHF_2CH_2CF_3$	1,030
HFC-365mfc	1,1,1,3,3-pentafluorobutane	$CF_3CH_2CF_2CH_3$	794
HFC-43-10mee	1,1,1,2,2,3,4,5,5,5-decafluoropentane	$CF_3CHFCHFCF_2CF_3$	1,640

Section 2: PFCs

Industrial designation	Chemical name (Common name)	Chemical formula	GWP
PFC-14	tetrafluoromethane (perfluoromethane, carbon tetrafluoride)	CF_4	7,390
PFC-116	hexafluoroethane (perfluoroethane)	C_2F_6	12,200
PFC-218	octafluoropropane (perfluoropropane)	C_3F_8	8,830
PFC-3-1-10 (R-31-10)	decafluorobutane (perfluorobutane)	C_4F_{10}	8,860

PFC-4-1-12 (R-41-12)	Dodecafluoropentane (perfluoropentane)	C_5F_{12}	9,160
PFC-5-1-14 (R-51-14)	tetradecafluorohexane (perfluorohexane)	C_6F_{14}	9,300
PFC-c-318	octafluorocyclobutane (perfluorocyclobutane)	$c\text{-}C_4F_8$	10,300

Section 3: Other perfluorinated compounds

Industrial designation	Chemical name (Common name)	Chemical formula	GWP
	sulphur hexafluoride	SF_6	22,800

Appendix B: HFC phasedown

HFC phasedown schedule as set out in Article 15 and Annex 5 of the F gas Regulation.

Years	Percentage of baseline[160]	Annual quota for Great Britain market (approx. MtCO2e)[161]
2015	100%	
2016 to 2017	93%	
2018 to 2020	63%	
2021 to 2023	45%	7.3
2024 to 2026	31%	5.0
2027 to 2029	24%	3.9
2030	21%	3.4

[160] Under the EU F gas Regulation, the baseline is calculated as the annual average placed on the EU market in the period 2009-2012. Under the Great Britain F gas Regulation, the baseline period is 2015-2019.

[161] Annual quota for each reference value period estimated when calculating annual quota for the 2021-2023 reference value period. Numbers provided rounded up to one decimal place.

Appendix C: Sector groups

Listed below are the three sector groups and the stakeholders who attended these meetings.

RACHP

- Air Conditioning and Refrigeration Industry Board (ACRIB)
- Acumen Public Affairs
- A-Gas
- Airedale
- Association of Manufacturers of Domestic Appliances (AMDEA)
- Home Appliance Europe (APPLiA)
- AREA (European association of RACHP contractors)
- Arkema
- ATMOsphere
- BEAMA
- Beijer Ref
- Department for Business, Energy and Industrial Strategy (BEIS)
- Building Engineering Services Association (BESA)
- BOC Ltd
- Bureau Veritas
- Business GE Ltd
- Carrier
- Chemours
- City & Guilds
- Climalife
- Daikin Airconditioning UK Ltd.
- Daikin Chemicals
- Daikin Europe N.V.
- Department for Environment, Food & Rural Affairs (Defra)
- Environment Agency
- European Partnership for Energy and the Environment (EPEE)
- Food Service Equipment Association (FEA)
- Federation of Environmental Trade Associations (FETA)
- Gluckman Consulting
- Harp
- Honeywell
- Institute of Refrigeration (IOR)
- Kensa
- Klima-Therm

- Koura
- Mitsubishi Electric UK
- Mitsubishi Electric Air Conditioning Systems Europe Ltd
- National Refrigerants
- PA Consulting
- Panasonic
- Quidos
- Refcom
- Scottish government
- SEPA
- TEV Ltd
- Welsh government
- Wolseley

MDI

- Association of the British Pharmaceutical Industry (ABPI)
- Acumen Public Affairs
- Aptar Group
- Asthma UK / British Lung Foundation (BLF)
- Aspire Pharma
- Astra Zeneca
- Boehringer Ingelheim
- Chiesi
- Daikin Chemicals
- Defra
- Department of Health
- Environment Agency
- Ethical Medicines Industry Group
- FTI Consulting
- GlaxoSmithKline (GSK)
- Gluckman Consulting
- Honeywell
- International Pharmaceutical Aerosol Consortium (IPAC)
- Kindeva
- Koura
- MHRA
- NHS England and Improvement
- NHS Scotland
- NHS Wales
- Novartis / Sandoz

- Recipharm
- SEPA
- Scottish government
- Sustainable Healthcare Coalition
- Vectura
- Welsh government

Power

- 3m
- ABB
- Balfour Beatty
- BEAMA
- Brush
- Department of Agriculture, Environment and Rural Affairs (DAERA)
- Defra
- Eaton
- EDF Energy
- Electricity North West (ENWL)
- Energy Networks Association (ENA)
- Environment Agency
- Equitix
- GE Grid Solutions
- GE Renewable Energy
- Gluckman Consulting
- GTC UK
- Hitachi
- Hitachi ABB Power Grids
- Independent Networks Association (INA)
- National Grid
- Office of Gas and Electricity Markets (Ofgem)
- Ormazabal
- S&C Electric Company
- Schneider Electric
- Scottish government
- SEPA
- Siemens energy
- Siemens plc
- Scottish and Southern Electricity Networks (SSEN)
- Welsh government
- Western Power

Appendix D: HFOs and GWPs

The table below shows Annex 2, Section 1 of the F gas Regulation, which shows unsaturated hydro(chloro)fluorocarbons commonly referred as HFOs.

Common name / industrial designation	Chemical formula	GWP
HFC-1234yf	$CF_3CF = CH_2$	4**
HFC-1234ze(E)	trans — $CHF = CHCF_3$	7**
HFC-1336mzz(E)	$CF_3CH = CHCF_3$	9*
HCFC-1233zd	$C_3H_2ClF_3$	4.5*
HCFC-1233xf	$C_3H_2ClF_3$	1***

* Based on the Fourth Assessment Report adopted by the Intergovernmental Panel on Climate Change, unless otherwise indicated.
** GWP according to the Report of the 2010 Assessment of the Scientific Assessment Panel (SAP) of the Montreal Protocol, Tables 1-11, citing two peer-reviewed scientific references.[162]
*** Default value, GWP not yet available.

[162] Report of the 2010 Assessment of the Scientific Assessment Panel (SAP) of the Montreal Protocol

Appendix E: GWP of common F gas blends

Many refrigeration applications use blends of two or more F gases. The table below provides the GWP and CO2e thresholds for common F gas blends, not listed in Annex 1 (Appendix A) or Annex 2 of the F gas Regulation.[163]

F gas blends	GWP
R-507A	3,985
R-404A	3,922
R-452A	2,140
R-410A	2,088
R-407C	1,774
R-449A	1,397
R-448A	1,387
R-513A	631
R-450A	605
R-454A	239
R-454C/R-455A	148

[163] Adapted from "Calculate the carbon dioxide equivalent quantity of an F gas" UK government" and Öko-Recherche support contract for an evaluation and impact assessment for amending Regulation (EU) No 517/2014 on F gases

Appendix F: Discounted costs and benefits

Summary of discounted costs predicted in Defra's 2014 prospective analysis (cost in millions pound sterling at 2014 prices). In addition to the central estimate, reflecting the most likely outcome for costs, analysts calculated low and high end estimates reflecting inherent uncertainty.

Year	low	central	high
2015	22	54	86
2016	13	23	33
2017	73	125	178
2018	89	152	216
2019	88	150	212
2020	87	148	209
2021	69	113	158
2022	66	109	151
2023	63	102	142
2024	65	106	148
2025	59	96	133
2026	56	91	126
2027	55	90	124
2028	52	84	117
2029	49	80	110
2030	47	76	105

Year	low	central	high
2031	45	73	102
2032	44	71	98
2033	42	68	94
2034	40	65	91
2035	39	63	87
Total	**1,162**	**1,941**	**2,720**

Summary of discounted benefits predicted in Defra's 2014 prospective analysis (cost in millions pound sterling at 2014 prices). In addition to the central estimate, reflecting the most likely outcome for benefits, analysts calculated low and high end estimates reflecting inherent uncertainty.

Year	low	central	high
2015	11	24	38
2016	20	43	67
2017	62	131	209
2018	99	202	316
2019	135	268	412
2020	165	318	493
2021	174	337	516
2022	185	356	549
2023	191	370	560

Year	low	central	high
2024	203	386	587
2025	210	397	600
2026	216	407	612
2027	220	415	626
2028	219	417	634
2029	222	422	628
2030	222	419	631
2031	236	449	675
2032	246	474	710
2033	260	498	749
2034	274	253	787
2035	276	531	797
Total	**3,847**	**7,388**	**11,198**

Appendix G: Calculation of costs and benefits

Methodology

In this analysis, the F gas Regulation is considered in full, rather than as a group of separate measures. While there were small impacts associated with non-HFC gases, the bulk of projected benefits come from the reductions in HFC usage. All reductions in HFC usage and emissions are attributed to the phasedown. Because the phasedown fixes HFC usage, any impacts from other measures would result in gas being reallocated rather than an overall reduction in usage.

This analysis assumes that most of the associated benefits, such as energy savings, cannot be separated from the effects of phasedown. For example, in the case of control of use, Defra's initial analysis noted that it would be difficult for industry to meet the phasedown targets without the limits on new equipment. Conversely this also implies that industry would have been forced to adopt lower GWP gases (and where necessary to replace existing equipment) in response to the phasedown alone.

The quota system, as well as most of the other measures contained within the F gas Regulation, addresses placing on the market rather than emissions directly. It is possible that some proscribed uses are more highly emissive. In these instances, reducing a highly emissive use under a supply constraint would free up quota for other uses but these would be less emissive on average. Thus, there would still be benefits not attributable to quota. However, the European Commission did not indicate that this was a reason for adopting particular bans and there is no evidence to suggest that proscribed uses are on average, more emissive.

The F gas Regulation contained specific provisions to deal with leakage, which is entirely emissive. However, available evidence suggests that the price of gas was the driving factor in reducing emissions. It was therefore considered reasonable to focus on the quota system as the primary driver of costs and benefits.

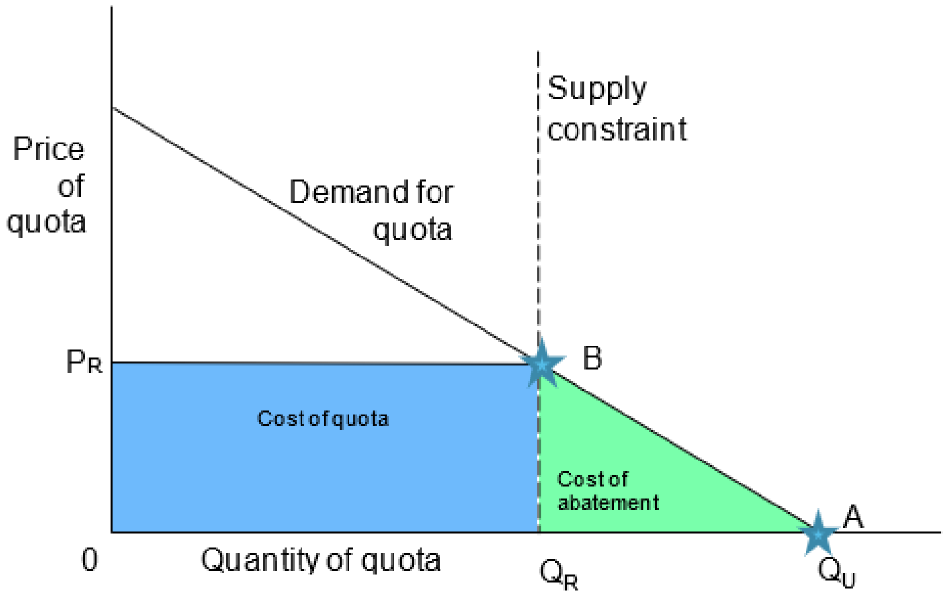
In contrast to previous studies, the implied price of quota was used to estimate the marginal cost of abatement.[164] Economic principles argue that the HFC quota creates a supply constraint which will increase the price of HFCs placed on the market. Users will try

[164] See discussion below for more detail on how the price of quota was calculated.

to reduce their costs by undertaking abatement, or forgoing low value uses, thereby reducing the quantity demanded until it matches the quantity supplied.

As users are motivated to reduce their costs, they will be willing to spend up to the price of quota on abatement measures. If quota costs €50/tCO2e then users should spend up to €50 for a technology that reduces their consumption by 1 tCO2e.

Figure 19: Calculation for total abatement cost



Point A represents how much quota would be consumed (Q_U) if there was no supply constraint (equivalent to an unregulated scenario). Point B shows the price of quota (P_R) and quantity of quota consumed (Q_R) where a regime imposes a supply constraint. The green area shows the cost of abatement, with a marginal cost of P_R and total abatement of Q_U - Q_R.

The blue area represents the transfer between quota holders and end-users (for example the additional price paid for gas). This is not part of the abatement cost because this results in higher revenues for quota holders. Total abatement is calculated by assuming that in the absence of quota that total usage would remain at 2012 levels. A linear demand curve (such as costs rise at a constant rate in proportion to the amount of abatement) is then assumed to calculate average and total cost.[165] This may overstate cost. The

[165] Assuming a linear demand curve gives an average cost equal to ½ marginal cost. Total cost is equal to average cost multiplied by the assumed quantity of abatement (the difference between quota and 2012 levels).

European Commission’s initial analysis suggests that the bulk of abatement could be carried out for under €20. It is recognised that actual costs may be lower than calculated.

It is also noted that this methodology does not measure the cost of quota (or increased cost of gas) to HFC end-users. Rather the cost that businesses incurred to avoid using quota is calculated, not the additional cost paid to buy quota (including quota cost embedded in the price of gas). While rising HFC prices are an additional cost to end-users this is passed on as additional revenue to quota holders. Hence there is no net cost to businesses.

Advantages and limitations

This top-down approach has both advantages and disadvantages. It provides a less granular analysis than the bottom-up approach taken by the European Commission, which looked at each individual technology. There are some advantages to the latter approach, particularly in calculating average cost where the approach used depends on assuming the shape of the demand curve. However, whilst it does provide accurate results the bottom-up approach requires access to significant amounts of commercial data, which are not available to Defra.[166]

Moreover, the bottom-up approach only looks at expenditures. But if a user reduces their consumption of a gas by ceasing an activity, there is still an economic cost because that activity previously generated economic benefits which must now be foregone. The top-down approach does not distinguish between expenditures and forgone benefits. In this sense it may be more comprehensive.

There is a potential risk that the cost of an individual ban, for example the cost of a particular gas or type of equipment, exceeds the marginal cost imposed by the supply constraint. In this case the top-down approach would not capture the additional costs associated with the ban. Instead, the ban would reduce the measured marginal cost by artificially reducing demand for quota.

This is of particular concern in recent years where the price of quota has dropped significantly. While quota itself expires at the end of the year it is possible to convert quota into quota authorisations, which do not expire. In recent years the EU has observed stockpiling of quota authorisations. There is not yet the same data for Great Britain to

[166] This was the only viable approach in Defra’s prospective analysis, however Jacobs’ reported considerable uncertainty.

confirm whether this effect has been seen on the Great Britain market, but it is assumed there may be a similar trend.

There are several possible reasons for this decline. Industry representatives point to an increase in smuggling of HFCs, estimated at up to 20-30% of total supply within the EU.[167] It is not possible to predict with any certainty whether the UK market is equally vulnerable to illegal imports, but note that studies suggest the majority of smuggling is through porous land borders which may serve to mitigate any risk to the market in Great Britain.

The recent pandemic may have impacted both demand and supply of HFCs and may continue to do so. Some markets, such as air-conditioning installations, saw a decline in demand during the pandemic. Of 100 countries studied globally, the UK and Turkey saw the biggest declines in air-conditioning demand.[168] Global supply chain issues may also have had an impact. Industry sources reported a shortage in iso-containers used for the shipping and storage of HFCs. Other sources also mentioned that wholesale HFC prices from China, which should be unaffected by quota, increased in recent years.[169]

While it is possible that new equipment bans contribute to declining demand, they are not the only possible cause. As previously noted, a significant portion of compliance costs are heavily front-loaded due to the high cost of investment with smaller costs coming from more expensive low GWP gases. Thus even with a declining quota price there may be little incentive to switch back to older technologies, especially if industry views a demand slump as short term and anticipates further supply constraints from forthcoming phasedown steps.

Moreover, despite the failure to use all quota in the current year, quota and quota authorisations continue to trade at a non-trivial positive price.[170] This implies that quota continues to constrain HFC consumption. Market participants may choose to hold quota authorisations as a store of value in anticipation of higher future prices. Similar behaviour was observed in advance of the phasedown, with industry importing additional gas beyond their need in 2014 and storing that gas in expectation of future supply constraints. Quota

[167] EEA report on indications of illegal HFC trade based on an analysis of data reported under the F gas Regulation, Eurostat dataset and Chinese export data and the EIA's report on illegal trade ("Europe's Most Chilling Crime: The illegal trade in HFC refrigerant gases")

[168] Ibid.

[169] Via confidential conversations with industry. Sources were not able to identify the exact reasons for the price increase.

[170] Based on listed prices retrieved from a quota broker.

authorisations can be stored much more cheaply than gas, so it is rational for market participants to prefer to hold assets in this manner.

It is therefore highly likely that quota under the current phasedown still imposes a market supply constraint even though not all quota is used in the present year. This does not mean that none of the equipment bans impose costs above the cost of quota. A more detailed discussion of this possibility is provided further on. Nonetheless, despite significant methodological differences between this approach and that of the EU, the two approaches yield similar results. This provides confidence that this approach is a reasonable estimate of cost.

Calculating quota price

While quota is traded there is no open exchange and accurate time series data is not held. Quota price was therefore inferred from the traded price of gases of different GWPs.[171] Confidential price information provided to Defra shows that the most common HFCs traded at around €6/kg prior to the implementation of quota, and thereafter converged to stable price per tCO2e.[172] That these prices remain relatively consistent across commonly used gases and suppliers indicate that this is a fair indicator of quota price.[173]

Companies providing price data to Defra were unable to separate UK price data from EU prices. Prior to the UK's exit from the EU, quota could be traded freely between countries in the EU-28. It was assumed that prices were constant across the EU market.[174] Post-exit, Great Britain quota can only be used in the Great Britain market. This creates the possibility for price divergence in the Great Britain market compared to the EU. This is true even though Great Britain and the EU have the same phasedown schedules because the two economies have a different market composition. Individual sectors will have different

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[171] These prices were taken from EU-wide market surveys from before EU exit and by data provided by commercial operators in subsequent years.

[172] Specifically, the most common gases measured were R404A, R410A, and HFC-134a. Less common gases, and especially more expensive HFO blends, do not necessarily follow this trend. This is discussed in more detail in the next section.

[173] Although Great Britain does not have access to price data captured by the European Commission, there is access to summary charts which suggest the numbers gathered through this assessment remain representative. See "Excerpt for participants: monitoring of refrigerant prices against a background of regulation (EU) 517/2014" prepared for the European Commission by Öko-Recherche.

[174] Although the price remains variable at different points in the supply chain.

abilities to phase down usage meaning that identical rules can still produce divergent outcomes.

Confidential conversations with suppliers indicate that they have not seen any divergence. Snapshot data of the price of traded quota similarly indicates that Great Britain prices are currently consistent with EU prices.[175] It is possible that there has been insufficient time to observe any significant divergence. The UK used 'placing on the market' data since the implementation of the F gas Regulation to establish Great Britain quota, thus any impact of divergence will be observed in addition to subsequent phasedown steps. At present, EU price data is considered to be reflective of the Great Britain market, but it is accepted that divergence is possible in the future. Gathering accurate data for the domestic market will therefore be important in continuing to effectively monitor the performance of this and future regulations.

HFC phasedown

As discussed above, it was assumed that the large majority of costs and benefits can be attributed to the phasedown, which imposes a cap on the quantity of gas, measured in tCO2e, that can be placed on the market. The cap only applies to virgin gases. Maintenance engineers can reuse recovered HFCs (from the Great Britain market) for leak replacement without the need for quota and equipment manufacturers may do the same subject to new equipment bans described above.[176]

To establish quota levels the European Commission examined the likely state of the HFC market by 2030. Based on the best information available at the time it was determined where lower GWP alternatives would be available provided such alternatives were cost-effective and not less energy efficient. The latter means that abatement cost would be no more than €50/tCO2e; corresponding to the marginal cost of CO2 emissions as calculated at the time. The European Commission then set steps in intermediate years based on that endpoint.

Quota is fully tradeable and can only be used within the calendar year of allocation. However, quota may be used to import gas and either sell it or store it for future years without losing any allowance. Thus, although quota is awarded at no cost, the artificial scarcity imposed by the system means that once awarded, quota automatically assumes a

[175] Based on listed prices retrieved from a quota broker.

[176] Article 13 of the F gas regulation; see also discussion below on "Control of Use."

positive price. By extension, HFCs placed on the market (accounted for with quota) would trade at a premium over wholesale gas.

Measuring benefits

To calculate benefits, it was assumed that total consumption (as defined under the Regulation) would have remained at 2012 levels in the absence of the F gas Regulation. An adjusted estimate of quota (to take account of exemptions and the exclusion of pre-charged equipment in the first two years) was subtracted to find the total use abated in each year.

Conversations with industry indicate that prior to the introduction of the F gas Regulation, importers stockpiled substantial quantities of HFCs. In the initial stages of implementation suppliers drew down these stockpiles meaning that actual supply of gas was greater in the first years of the F gas Regulation than formally permitted by quota. Price data confirms that there was no observable supply constraint until 2017. To compensate for this, no abatement in the first two years after the F gas Regulation came into effect was assumed.

As gas will frequently sit in equipment for long periods of time (10-25 years) most of the benefits associated with reductions in usage since 2014 will occur in the future. While this is a retrospective analysis, only looking at emissions reductions since 2015 would significantly underestimate actual benefits. While Great Britain has modelled future emissions, it was decided not to include any emissions reductions due to future reductions in usage. Therefore emissions reductions are calculated based on an average ratio between emissions and use.

Earlier analysis found that emissions decline linearly with reductions in use but with an average lag of five years.[177] To calculate an average ratio the modelled relationship between emissions and use over time was considered.[178] This suggests that 50-60% of gas placed in equipment is released to the atmosphere. While this was based on the best information currently available, it was recognised that the majority of benefits come from future reductions in emissions and could be influenced by future regulatory actions.[179]

It was estimated the F gas Regulation has reduced usage of HFCs in Great Britain by 40.4 MtCO2e between 2015 and 2021. This equates to 20.2 to 24.3 MtCO2e of emissions

[177] Based on modelled outcomes.

[178] Using the Great Britain model.

[179] For example, if a future regulatory action improved recovery this could reduce the emissions/use ratio and therefore reduce overall benefits.

abated in Great Britain. The detailed modelling of use suggests that although industry has switched to lower GWP gases, the majority of this effect is driven by a shift away from HFCs whose use in metric tonnes halved from 2012 to 2021.[180] This mirrors the findings of the European Commission.[181]

This was converted to a monetary benefit using BEIS and HM Treasury's latest methodology which is based on the minimal marginal cost needed to reach net zero by 2050.[182] This differs from the method used in the prospective analysis and assigns a higher monetary value to each tCO2e abated. As the updated methodology is considered best practice, it was considered to be the most appropriate standard by which to evaluate the F gas Regulation. This gives an overall monetary benefit of £2.8- 8.5 billion.[183]

A number of industry representatives have raised a concern about illegal smuggling which could substantially reduce benefits. Some representatives suggested this could be the primary factor in the decline in the price of gas. At present data is not held to estimate the extent of illegal activity in the Great Britain market, but the EIA estimates suggest smuggling could account for up to 20-30% of gas sold.[184] To account for this possibility it was assumed following the decline in price from 2019 onwards that 30% of all HFCs sold in Great Britain entered illegally without quota. Given the greater geographical barriers to smuggling into the Great Britain market this estimate was used as an upper bound for smuggling. This number was used as a sensitivity test to determine if smuggling could potentially alter the result of the analysis. This would result in total abatement of 13.6-16.3 MtCO2e and total benefits of £1.9-5.7 billion.[185]

Measuring costs

As discussed in the above methodology section, cost is calculated by using the estimated price of quota to determine the marginal cost of abatement. A linear demand curve was

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[180] Noting that the Great Britain baseline was calculated differently to the European Commission, following EU Exit.

[181] The European commission found a 47% decline in CO2e of HFCs and a 37% decline in metric tonnes of HFCs from 2015.

[182] Valuation of greenhouse gas emissions: for policy appraisal and evaluation, which also contains a detailed explanation of the current methodology and rationale.

[183] £2.7-8.1 billion using a 3.5% discount rate.

[184] EIA's report on illegal trade ("Europe's Most Chilling Crime: The illegal trade in HFC refrigerant gases")

[185] £1.8-5.5 billion using a 3.5% discount rate.

assumed to calculate average abatement cost in each year, and multiply by total abatement in that year. Consumer Price Index data is used to convert all costs to 2021 prices; the most recent year for which complete data was held.[186] Summing cost in each year provides total overall cost and the weighted average cost over the life of the F gas Regulation until the end of 2021. Net present cost in the current year (2022) was calculated using a discount rate of 1.5% and at an alternative discount rate of 3.5% (see footnotes).

A constant ratio of emissions to use was assumed. Price data was received in Euros, which provided an average cost per tonne for abated use of €2.90 and a maximum marginal cost of €14.70.[187] This translates to an average cost per tonne for abated emissions of €4.80-5.80, a maximum marginal cost of €27.40-32.90, and a total cost of €117 million. Converting to Great Britain currency at current prices gives an average cost per tonne of £4.10-5.00 for abated emissions, a marginal cost of £23.60-28.30 and a total cost of £101 million.[188]

As with benefits, a sensitivity analysis was performed to account for the possibility of illegal smuggling. As the purpose of this analysis is to identify the lower bound for net benefits, it was assumed that industry and consumers still carry out the same abatement activity but that this is offset by illegal smuggling. Hence total costs remain the same but average cost per tonne for abated emissions increases to £6.20-7.40 (€7.20-8.60).[189]

Despite methodological differences, the Great Britain average cost estimates are similar to those calculated by the European Commission. Average per tonne cost per tonne for abated emissions of €4.80-8.60 were found, versus €6 from the EU. The Great Britain estimate of marginal cost is somewhat higher but only in one year. Although there is some uncertainty around the estimates this would support the assumption that the large majority of costs and benefits can be attributed to the phasedown.

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[186] Consumer price inflation tables; *Office of National Statistics*, retrieved on 17th June 2022

[187] Recorded in 2017. Marginal cost was lower in other years.

[188] Assuming an exchange rate of £1 = €1.16; exchange rate retrieved on 17th June 2022. Using a 3.5% discount rate this equates to an average of £4.40 to £5.30 per tonne abated, and a total cost of £106 million.

[189] £6.50-7.80 using a 3.5% discount rate.

Appendix H: Standards relating to F gas

The list was compiled using BSI Knowledge.[190]

Issuing body	Document identifier	Sector	Publication date	Committee reference
ISO	ISO 817 AMD 2	Refrigerant	2021-03-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	ISO/DIS 17584	Refrigerant	2021-03-00	ISO/TC 86 Refrigeration and air-conditioning
CEN	EN 378-2	RACHP	2016-11-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 378-4+A1	RACHP	2019-09-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 378-1+A1	RACHP	2020-10-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 378-3+A1	RACHP	2020-10-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
IEC	IEC 60335-2-24	RACHP	2022-05-00	IEC/SC 61C Household appliances for refrigeration
IEC	IEC 60335-2-40	RACHP	2022-05-00	IEC/SC 61D Appliances for air-conditioning for household and similar purposes

[190] BSI Knowledge

Issuing body	Document identifier	Sector	Publication date	Committee reference
IEC	IEC 60335-2-89	RACHP	2022-05-00	IEC/SC 61C Household appliances for refrigeration
IEC	IEC 60335-2-118	RACHP	2020-03-00	IEC/SC 61C Household appliances for refrigeration
IEC	IEC 60335-2-104	RACHP	2021-05-00	IEC/SC 61D Appliances for air-conditioning for household and similar purposes
CEN	CEN/TS 17606	RACHP	2021-03-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	CEN/TS 17607	RACHP	2021-03-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	CEN/TR 17608	RACHP	2022-04-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
ISO	ISO 11650	Refrigerant	1999-12-00	ISO/TC 86 Refrigeration and air-conditioning
CEN	EN 1736	RACHP	2008-11-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 12693	RACHP	2008-05-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 13313	RACHP	2010-11-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 13136+A1	RACHP	2018-11-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements

Issuing body	Document identifier	Sector	Publication date	Committee reference
ISO	ISO 5149-4	RACHP	2014-04-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	ISO 5149-1 AMD 2	RACHP	2021-01-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	ISO 5149-3 AMD 1	RACHP	2021-03-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	ISO/DIS 24664	RACHP	2021-03-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	ISO 5149-2 AMD 1	RACHP	2020-06-00	ISO/TC 86 Refrigeration and air-conditioning
CENELEC	CLC/TS 50574-2	RACHP	2014-11-00	CLC/TC 111X Environment
CEN	EN 12309-2/AC	Gas-fired sorption appliances	2015-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CENELEC	EN 50569/A1	RACHP	2018-01-00	CLC/TC 61 Safety of household and similar electrical appliances
CENELEC	EN 50570/A1	RACHP	2018-01-00	CLC/TC 61 Safety of household and similar electrical appliances
ISO	ISO 8066-2	MAC	2001-09-00	ISO/TC 45 Rubber and rubber products
ISO	ISO 7183	Compressed-air dryers	2007-12-00	ISO/TC 118 Compressors and pneumatic tools, machines and equipment
CEN	EN 732	Absorption refrigerators	1998-11-00	CEN/TC 181 Dedicated liquefied petroleum gas appliances
ISO	ISO 20843	Petroleum and related products	2011-01-00	ISO/TC 28 Petroleum products and lubricants
ISO	ISO 13043	MAC	2011-04-00	ISO/TC 22 Road vehicles

Issuing body	Document identifier	Sector	Publication date	Committee reference
ISO	ISO 14520-11	Fire	2016-10-00	ISO/TC 21 Equipment for fire protection and fire fighting
ISO	ISO 18566-1	Building environment design	2017-06-00	ISO/TC 205 Building environment design
ISO	ISO 18566-2	Building environment design	2017-06-00	ISO/TC 205 Building environment design
ISO	ISO 18566-3	Building environment design	2017-06-00	ISO/TC 205 Building environment design
ISO	ISO 18566-4	Building environment design	2017-06-00	ISO/TC 205 Building environment design
ISO	ISO/DIS 22712	RACHP	2018-09-00	ISO/TC 86 Refrigeration and air-conditioning
ISO	IEC 61010-2-011	Laboratory	2019-03-00	IEC/TC 66 Safety of measuring, control and laboratory equipment
ISO	ISO 14520-10	Fire	2019-07-00	ISO/TC 21 Equipment for fire protection and fire fighting
ISO	ISO 14520-8	Fire	2019-07-00	ISO/TC 21 Equipment for fire protection and fire fighting
ISO	ISO 14520-9	Fire	2019-07-00	ISO/TC 21 Equipment for fire protection and fire fighting
ISO	ISO 18566-6	Building environment design	2019-08-00	ISO/TC 205 Building environment design
ISO	ISO 20854	Transport refrigeration	2019-10-00	ISO/TC 104 Freight containers
ISO	ISO 6521-3	Refrigerating compressors	2019-10-00	ISO/TC 28 Petroleum products and lubricants

Issuing body	Document identifier	Sector	Publication date	Committee reference
ISO	ISO 12922	Hydraulic systems	2020-02-00	ISO/TC 28 Petroleum products and lubricants
CEN	EN 1117/A1	Heat exchangers	2002-10-00	CEN/TC 110 Heat exchangers
CEN	EN 1118/A1	Heat exchangers	2002-10-00	CEN/TC 110 Heat exchangers
CEN	EN 1216/A1	Heat exchangers	2002-10-00	CEN/TC 110 Heat exchangers
CEN	EN 12380	Drainage systems	2002-12-00	CEN/TC 165 Wastewater engineering
CEN	CEN/TR 14739	RACHP	2004-09-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
BSI	BS ISO 10294-5:2005	Fire	2005-04-11	FSH/22/-/4 Fire resistance tests for dampers, seals and smoke extraction
BSI	BS EN 1366-10:2011+A1:2017	Fire	2011-05-31	FSH/22/-/4 Fire resistance tests for dampers, seals and smoke extraction
BSI	BS EN 12101-7:2011	Fire	2011-06-30	FSH/25 Smoke, heat control systems and components
BSI	BS 6266:2011	Fire	2011-08-31	FSH/14 Fire precautions in buildings
BSI	BS EN 1366-12:2014+A1:2019	Fire	2014-10-31	FSH/22/-/4 Fire resistance tests for dampers, seals and smoke extraction
BSI	BS EN 1366-2:2015	Fire	2015-06-30	FSH/22/-/4 Fire resistance tests for dampers, seals and smoke extraction

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BSI	BS EN ISO 23953-2:2015	RACHP	2015-11-30	RHE/19 Commercial refrigerated food cabinets (cold room and display cases)
BSI	BS ISO 15042:2017+A1:2020	RACHP	2017-07-26	RHE/17 Testing of air conditioning units
BSI	BS EN ISO 22041:2019+A1:2019	RACHP	2019-07-03	RHE/19 Commercial refrigerated food cabinets (cold room and display cases)
BSI	BS EN 16838:2019	RACHP	2019-07-16	RHE/19 Commercial refrigerated food cabinets (cold room and display cases)
CEN	EN 12309-1	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 12309-3	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 12309-4	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 12309-7	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances

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CEN	EN 12309-5	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 12309-6	Gas-fired sorption appliances	2014-12-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 16905-1	Gas-fired sorption appliances	2017-03-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 16905-3	Gas-fired sorption appliances	2017-03-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 13487	Heat exchanger	2019-08-00	CEN/TC 110 Heat exchangers
CEN	EN 14624	Refrigerants	2020-03-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
BSI	BS 2626:1992	Compressors	1992-06-15	PTI/7 Lubricants and process fluids
CEN	EN 16905-2	Gas-fired sorption appliances	2020-01-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
BSI	BS 6880-2:1988	Heating systems	1988-02-29	RHE/2 Ventilation for buildings, heating and hot water services
CEN	EN 15004-5	Fire	2020-10-00	CEN/TC 191 Fixed firefighting systems
CEN	EN 15004-6	Fire	2020-10-00	CEN/TC 191 Fixed firefighting systems
CEN	EN 15423	Building ventilation	2008-05-00	CEN/TC 156 Ventilation for buildings

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CEN	EN 13142	Building ventilation	2021-04-00	CEN/TC 156 Ventilation for buildings
CEN	EN 50676	Gas detection	2019-12-00	CLC/TC 216 Gas detectors
CEN	EN 15378-1	Heating systems	2017-05-00	CEN/TC 228 Heating systems in buildings
CEN	EN 12102-2	RACHP	2019-05-00	CEN/TC 113 Heat pumps and air conditioning units
CEN	EN 15004-4	Fire	2020-10-00	CEN/TC 191 Fixed firefighting systems
CEN	EN 14276-2	RACHP	2020-02-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 14276-1	RACHP	2020-02-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 13771-2	RACHP	2017-09-00	CEN/TC 113 Heat pumps and air conditioning units
CEN	EN 15650	Building ventilation	2010-04-00	CEN/TC 156 Ventilation for buildings
ISO	ISO 8066-3	MAC	2020-08-00	ISO/TC 45 Rubber and rubber products
ISO	ISO/DIS 8066-4	MAC	2022-02-00	ISO/TC 45 Rubber and rubber products
CEN	EN 327	Heat exchangers	2014-08-00	CEN/TC 110 Heat exchangers
CEN	EN 328	Heat exchangers	2014-08-00	CEN/TC 110 Heat exchangers
CEN	EN 12599	Building ventilation	2012-10-00	CEN/TC 156 Ventilation for buildings
CEN	EN 12828+A1	Heating systems	2014-04-00	CEN/TC 228 Heating systems in buildings
CEN	EN 16147	RACHP	2017-01-00	CEN/TC 113 Heat pumps and air conditioning units
CEN	EN 13771-1	RACHP	2016-11-00	CEN/TC 113 Heat pumps and air conditioning units

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CEN	EN 12178	RACHP	2016-11-00	CEN/TC 182 Refrigerating systems, safety and environmental requirements
CEN	EN 12900	RACHP	2013-07-00	CEN/TC 113 Heat pumps and air conditioning units
CEN	EN 16905-4	Gas-fired sorption appliances	2017-03-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 16905-5	Gas-fired sorption appliances	2017-03-00	CEN/TC 299 Gas-fired sorption appliances and domestic gas-fired washing and drying appliances
CEN	EN 15450	Heating systems	2007-10-00	CEN/TC 228 Heating systems in buildings
CEN	EN 14620-1	Refrigerated storage	2006-09-00	CEN/TC 265 Site built metallic tanks for the storage of liquids
CEN	EN 14620-2	Refrigerated storage	2006-09-00	CEN/TC 265 Site built metallic tanks for the storage of liquids
CEN	EN 14620-3	Refrigerated storage	2006-09-00	CEN/TC 265 Site built metallic tanks for the storage of liquids
CEN	EN 14620-4	Refrigerated storage	2006-09-00	CEN/TC 265 Site built metallic tanks for the storage of liquids
CEN	EN 14620-5	Refrigerated storage	2006-09-00	CEN/TC 265 Site built metallic tanks for the storage of liquids