OzonAction Kigali Fact Sheet 1

Introduction to the Kigali Amendment

Background:

In October 2016 the Kigali Amendment was adopted by all Parties to the Montreal Protocol. The Kigali Amendment brings the future production and consumption of hydrofluorocarbons (HFCs[1]) under the control of the Protocol and will make a major contribution towards the fight against climate change. Control of HFC production and consumption will add to the climate benefits already achieved by the Montreal Protocol through the phase-out of ozone depleting substances (ODS) including CFCs and HCFCs.

Fluorocarbon chemicals, including HFCs, include many of the most powerful greenhouse gases. The release of 1 kg of certain fluorocarbons is typically between 1 000 and 10 000 times worse than the release of 1 kg of CO_2, in terms of impact on global warming. It has been shown that using alternatives to HFCs in key end-user markets, such as refrigeration and air-conditioning, is one of the most cost-effective ways of reducing greenhouse gas emissions. Under the Kigali Amendment, the global use of HFCs will be cut by around 85% before 2050. This phase-down in the global consumption of HFCs could save as much as 0.5 degrees centigrade of warming.

GWPs and ODPs of some common refrigerants

Most of the commonly used fluorocarbons are very powerful greenhouse gases

Type	Gas	GWP[2]	ODP[3]
ODS	CFC-12	10 900	1.0
	HCFC-22	1 810	0.055
HFC	HFC-404A	3 922	0
	HFC-410A	2 088	0
	HFC-134a	1 430	0
	HFC-32	675	0
HFO	HFO-1234yf	4	0
Natural	Propane	3	0
	CO_2	1	0

HFCs are non-ozone depleting chemicals that were first introduced in the 1990s as alternatives to CFCs and HCFCs. The growing use of HFCs was stimulated by the urgent need for cost effective alternatives to ODS. The use of HFCs has facilitated the rapid phase-out of ODS and has helped protect the Earth's fragile ozone layer. However, the high global warming potential (GWP) of HFCs is a major disadvantage and every effort now needs to be made to use non-ozone depleting alternatives with a low climate impact.

It is worth noting that CFCs had even higher GWPs than HFCs. The phase-out of CFCs was carried out to protect the ozone layer, but it had a very positive secondary benefit in terms of reducing impact on climate change. To further build on this good progress, the Montreal Protocol Parties have agreed that reducing the consumption of HFCs is an important next step.

Which markets are affected?

The biggest market for HFCs is refrigeration, air-conditioning and heat pumps (RACHP). Most applications of RACHP could be affected by the Kigali Amendment; for example, supermarket refrigeration, building air-conditioning and car air-conditioning. Other markets that will be affected include the manufacture of insulation foam, aerosols and fire protection equipment. See Kigali Fact Sheet 2 for further details about current HFC applications.

How is the HFC phase-down process structured?

The aim of the phase-down is to encourage use of low GWP alternatives and to reduce consumption and emissions of high GWP HFCs. To allow a flexible and customised response by individual Parties, the phase-down process is structured with a "basket approach". Progress is measured in terms of reducing the total "tonnes CO_2 equivalent" of all the different HFCs consumed. This favours the use of low GWP gases and low leakage technologies. However,

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[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

[2] GWP = global warming potential. GWPs used in the Kigali Fact Sheets are from the amended Montreal Protocol text, Annexes A, C and F, which are based on the 2007 UNFCCC 4th Assessment Report and are 100-year values

[3] ODP = ozone depletion potential

it does not require any specific technical solutions and it does not prevent use of some higher GWP gases where there is no cost-effective alternative.

See Kigali Fact Sheet 3 for further details about GWP, tonnes CO_2 equivalent and the basket approach.

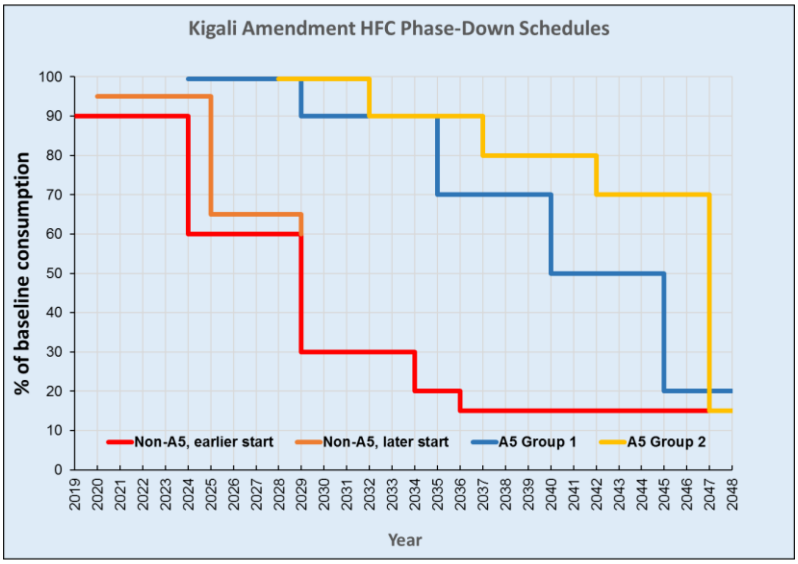
Are low GWP alternatives commercially available?

In some market sectors low GWP alternatives are already in widespread use. For example, there are hundreds of millions of domestic refrigerators using a hydrocarbon refrigerant. The car air-conditioning market recently began a major transition away from HFCs – by the end of 2017 more than 10 million cars will be using a low GWP alternative. Several markets are more challenging and some residual use of high GWP HFCs may be required – which is why the Kigali Amendment is for a phase-down not a phase-out and enables a flexible approach to be adopted by different groups of countries.

See Kigali Fact Sheet 4 for further details about low GWP alternatives.

What is the timetable for HFC phase-down?

Under the Kigali Amendment, the phase-down timetable varies between 4 different country groups. Most non-Article 5 (developed) countries begin their phase-down by 2019 and must achieve an 85% cut from their baseline, by 2036. Article 5 countries are split into 2 groups and will follow a slower timetable starting with a freeze in either 2024 or 2028. The final phase-down steps in A5 countries are in 2045 or 2047. See Kigali Fact Sheet 5 for details about the phase-down timetable and baseline consumption.



What should Parties do next?

All Parties need to be taking active steps to implement the Kigali Amendment and to start planning the reduction of their consumption of HFCs. The actions required by individual countries fall into a number of different areas. These include:

- Development of a national strategy to achieve the phase-down targets in the most practical and cost-effective way (e.g. which market sectors should take early action and which may need to wait for further technology developments). See Kigali Fact Sheet 6.
- Preparation and implementation of relevant legislation (e.g. to ratify the Kigali Amendment and to set up legislation to control HFC use). See Kigali Fact Sheet 7.
- Set up of appropriate national-level administration systems (e.g. to monitor and report HFC consumption and to licence the production or import of HFCs). See Kigali Fact Sheet 7.
- Engagement with relevant stakeholders to help develop and implement the national HFC phase-down strategy. See Kigali Fact Sheet 8.

Some technical issues: The switch to low GWP alternatives presents technical challenges in some HFC applications. It is important to be aware of these challenges and the work that is taking place at an international level to overcome them. Two critical issues are:

- **Operation of RACHP equipment at high ambient temperature** (HAT). Some countries have extreme ambient temperature levels that create technical difficulties related to the design and operation of RACHP systems. These are discussed in Kigali Fact Sheet 9.
- **Use of flammable alternatives**. Some of the low GWP alternatives are flammable (and are replacing high GWP HFCs that are non-flammable). This creates several technical and regulatory issues which are explained in Kigali Fact Sheet 10.

Barriers to HFC phase-down: There are various barriers that make the phase-down of HFCs more difficult. It is important to be aware of the key barriers during the development of a Kigali Amendment implementation plan. Barriers are discussed in Kigali Fact Sheet 11; they include:

- Lack of availability of low GWP fluids and technologies
- Lack of technician skills / training
- Inadequate safety codes and standards

Interaction with other policy measures: The Kigali Amendment should not be treated in isolation. It creates important interactions with other policy measures. These interactions are described in Kigali Fact Sheet 12 and include:

- Links between existing plans to phase-out HCFCs and the new plans to avoid high GWP HFCs. These objectives could be in conflict and should be considered as a package of measures. There could be significant financial and environmental advantage to “leap-frog” from HCFCs to low GWP alternatives, avoiding the use of high GWP fluids altogether.
- Links between the HFC phase-down plan and the wider national climate change policy. There are good opportunities to network with other climate change policy makers and to maximise the HFC emission reductions included in the Intended Nationally Determined Contribution.
- Recognising the energy related emissions from equipment affected by the Kigali Amendment. In particular, it is important that any switch to a low GWP alternative refrigerant does not prejudice efforts to improve energy efficiency of refrigeration and air-conditioning equipment.

Benefits of Rapid Action: The phase-down of HFCs will provide significant environmental benefits and it will stimulate a lot of innovation and design improvements. Kigali Fact Sheet 13 summarises the key benefits of the Kigali Amendment and shows why it is of advantage to avoid the high GWP HFCs currently used in non-A5 countries by starting the phase-down early.

Photo by IISD/ENB | Kiara Worth

Index of OzonAction Kigali Fact Sheets

OzonAction has prepared a set of Fact Sheets about the Kigali Amendment to the Montreal Protocol. They are aimed at policy makers and industry stakeholders and are intended to help support the successful implementation of a global phase-down of HFC production and consumption.

The Fact Sheets will be regularly updated and are available for viewing and download on the OzonAction website:

www.unep.org/ozonaction

In addition to the Fact Sheets listed below, this website also provides links to other useful resource materials related to the implementation of the Kigali Amendment.

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OzonAction Kigali Fact Sheet 2

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Current Use of HCFCs and HFCs

Background:

Fluorocarbon chemicals have properties that make them well suited to a range of applications. Unfortunately, they also have unfavourable environmental properties, especially those related to ozone depletion and to climate change. This has led to the phase-out process for ozone depleting substances (ODS[1]) and the more recent phase-down process for hydrofluorocarbons (HFCs) that have high GWP. There are five main markets for the various fluorocarbon molecules and blends:

1. Refrigerants in RACHP (refrigeration, air-conditioning and heat pumps)
2. Propellants in aerosols
3. Blowing agents to manufacture insulating foam
4. Fire protection fluids
5. Solvents

The relative size of these main markets has changed significantly over the last 25 years. Prior to the recognition of the ozone problem, the largest use of CFCs was for aerosols. The solvent market was also significant at that time. During the phase-out of CFCs, the market structure altered and large parts of the aerosol and solvent markets switched to not-in-kind (NIK) alternatives. The RACHP market has grown in relative importance with most CFC and HCFC applications switching to HFC alternatives. Before developing a strategy for reducing use of HFCs, it is important to understand the key market sectors and sub-sectors that use both HCFCs and HFCs.

The Journey to Fluids with Zero ODP and Low GWP:

As the global community understood and began to respond to the ozone and climate issues, the users of fluorocarbons have progressed through four different generations of products.

	ODP	GWP
1st generation	Very high	Very high
2nd generation	High	High
3rd generation	Zero	High
4th generation	Zero	Low / Very low

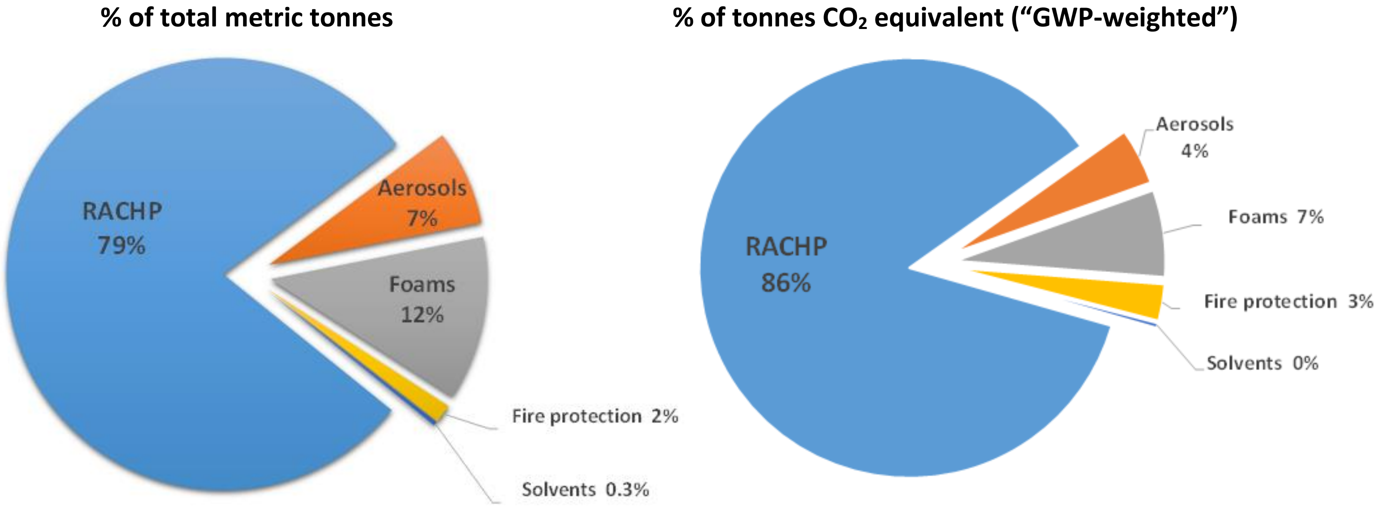
- **1st Generation: 1940 to 1990; CFCs dominant**. CFCs were developed by chemists in the 1930s and quickly recognised as well suited to various applications, especially in refrigeration and air-conditioning. Being non-toxic and non-flammable they became a very popular choice and by the 1960s were the dominant refrigerant in many applications. Use grew rapidly in other markets such as aerosols, solvents and foam blowing.
- **2nd Generation: 1990 to 2010; HCFC use grows**. A solution to the ozone problem adopted for some applications was to switch from CFCs to certain HCFCs. HCFCs also damage the ozone layer but they are much weaker ODS than CFCs. HCFCs are only being used as "interim" solutions, with a complete phase-out by 2030 in Article 5 countries.
- **3rd Generation: 1995 to 2020;** HFCs become dominant. HFCs were not used prior to 1990 as they were more expensive to produce than CFCs and had no perceived benefits, prior to control of ODS under the Montreal Protocol. For many CFC applications, a switch to HFCs was the lowest cost solution, so various HFCs became very popular in non-Article 5 countries.
- **4th Generation: 2010 onwards; Lower GWP fluids**. Users of HFCs begin to search for lower GWP alternatives. Various NIK refrigerants such as hydrocarbons, CO_2 and ammonia are adopted in some markets, although some of their properties are not ideal for all applications (e.g. the high flammability of hydrocarbons). Fluorocarbon producers introduce various alternatives including new hydro-fluoro-olefin (HFO) molecules.

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

Split of Use in Main Markets: Figure 1 provides an approximate split of the global HCFCs and HFCs sold in 2012, split by main market. Data for 2012 has been used as it represents a year in which there was little influence from the use of 4th Generation fluids.

The dominance of the RACHP market is clear. The left-hand chart is the split of consumption of HCFCs plus HFCs expressed in metric tonnes. The right-hand chart is “GWP-weighted”, with the consumption expressed in tonnes CO_2 equivalent[2]. The RACHP market is even more dominant in the right-hand chart because it uses particularly high GWP HFCs such as R-404A and R-410A, whilst the aerosol and foam markets use lower GWP HFCs.

Figure 1: Markets using HCFCs and HFCs, 2012



The Importance of Market Sub-Sectors: To understand how particular fluorocarbon molecules or blends are selected for specific applications it is important to recognise that the main markets illustrated in Figure 1 include a wide variety of different market sub-sectors that influence the choice of fluids used. For example, in the RACHP market, the type of equipment used is mainly based on a very similar technical process – the vapour compression cycle. However, the temperature of operation can vary considerably in different subsectors of this market. The refrigerant evaporating temperature might vary as follows:

- -40°C for freezing ice cream
- 0°C for storing chilled foods
- +10°C for air-conditioning
- +30°C for a heat pump

The optimum thermodynamic properties for each of these applications are quite different, resulting in different refrigerants being selected at these different temperature levels. The size and location of equipment can have an impact on fluid selection. A large industrial refrigeration system can use a refrigerant such as ammonia (which is toxic and slightly flammable) whereas as small air-conditioning unit in a residential location ideally requires a fluid that is non-toxic and non-flammable.

The figures overleaf provide a breakdown of the combined use of HCFCs and HFCs in different sub-sectors of the largest main markets. These are global average figures – the actual split can vary from country to country. For example, the size of the air-conditioning market will be much larger than shown in Figure 2 in very hot countries. Understanding the split of usage in a specific country is a very important step in the development of an HFC phase-down strategy (see Kigali Fact Sheet 6 for more details).

[2] See Kigali Fact Sheet 3 for an explanation of CO_2 equivalent

Figure 2: RACHP Markets, HCFC and HFC Use, 2012, GWP-weighted

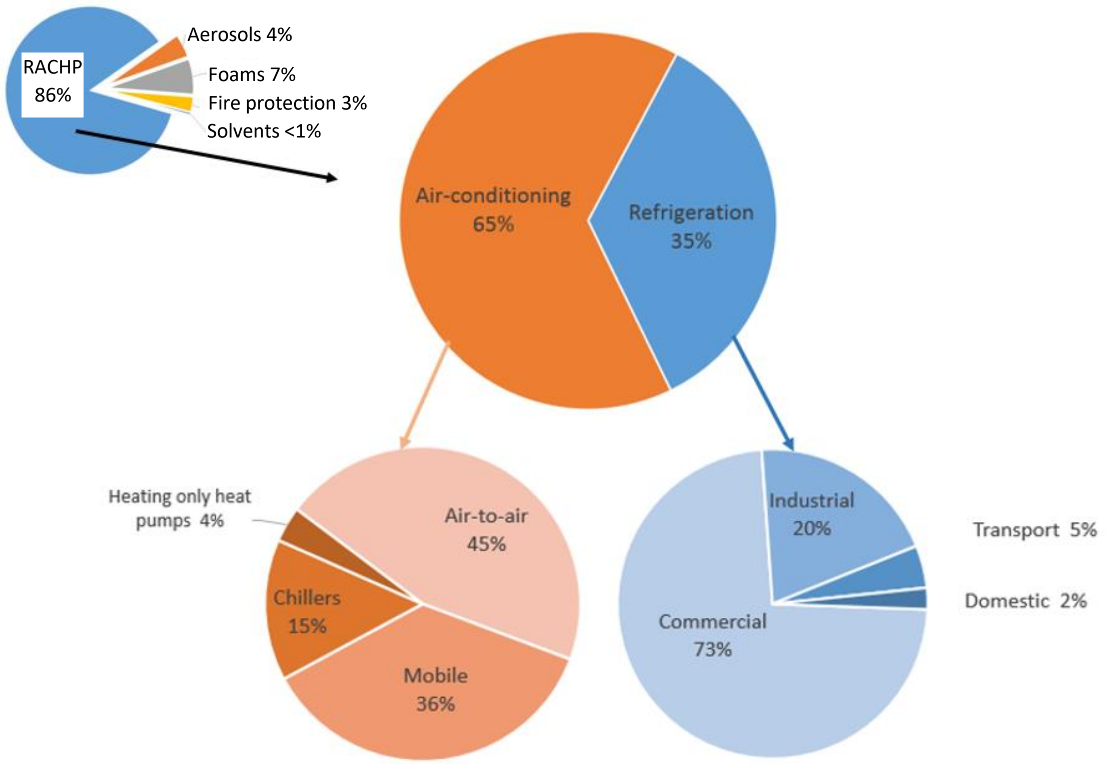


Figure 2 shows how the RACHP market can be split between air-conditioning and refrigeration and further split into sub-sectors (such as commercial refrigeration). To understand the factors that influence the choice of a specific refrigerant it is often necessary to further sub-divide RACHP markets, considering the type and size of equipment. This is illustrated in Figures 3 and 4 and illustrated for the commercial refrigeration sub-sector in Box 1 and for building air-conditioning in Box 2.

Box 1: Commercial Refrigeration

Commercial refrigeration is mainly used for food retail and catering activities. As shown in Figure 3, this sector can be split into 3 sub-sectors, based on size and design. The amount of refrigerant required is illustrated in the table below. Stand-alone systems are factory sealed, have virtually no leakage and a very small refrigerant charge. This allows a wide range of refrigerant choice, including flammable options. Central systems can be the most energy efficient option, but the large refrigerant charge and a high level of leakage, restricts the choice of refrigerant to non-flammable options.

Sub-sector	Typical refrigerant charge, kg
Stand-alone	0.1 to 0.5
Condensing unit	5 to 10
Central systems	50 to 200

Figure 3: Subsectors of refrigeration markets

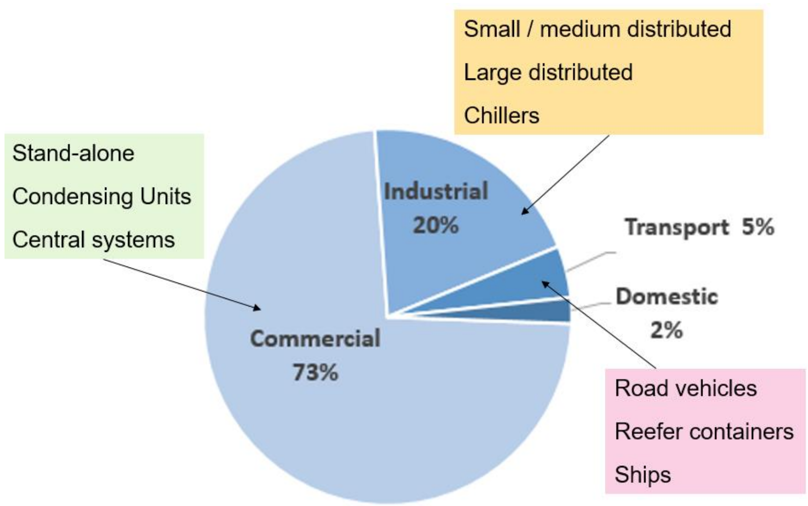
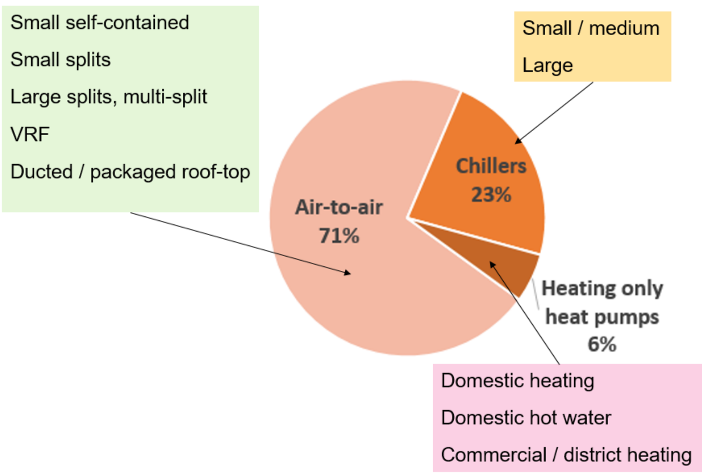


Figure 4: Subsectors of air-conditioning and heat pump markets



Box 2: Building Air-conditioning

There are many design options for building air-conditioning, varying from small systems cooling one small room to water chillers that can cool a large multi-storey building or a whole district.

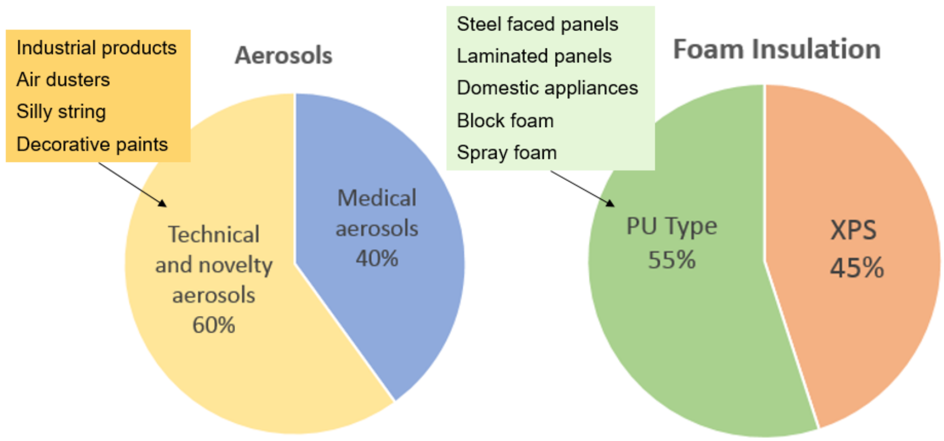
For water chillers, the refrigerant charge is high, but the equipment is usually in a limited access location e.g. a machinery room or a roof-top. This allows a wide choice of refrigerants, including flammable fluids, despite the large size.

For split systems and VRF* systems the refrigerant flows into the room being cooled, which makes the selection of a flammable refrigerant more difficult, especially for VRF systems because of their high refrigerant charge.

Sub-sector	Typical refrigerant charge, kg
Small splits	0.5 to 3
VRF	20 to 60
Water chillers	50 to 500

* VRF = variable refrigerant flow. VRF systems are sophisticated multi-split air-conditioning systems used to cool and heat medium sized buildings.

Figure 5: Subsectors of aerosol and foam markets



Box 3: Aerosols

Since the phase-out of CFCs, most aerosols are now manufactured with flammable hydrocarbon (HC) propellants. HFCs are used as propellants in situations where the cheaper HCs cannot be used. MDIs (metered dose inhalers) use HFCs to administer drugs for lung diseases such as asthma. Various technical and novelty aerosols (e.g. lubricant sprays and air-dusters) require a non-flammable propellant and currently use HFCs.

Box 4: Foam Insulation

Many Article 5 countries still use HCFCs to manufacture insulation foam. For large foam production plants making PU type foam it is often cost-effective to convert to HCs. Where flammable blowing agents cannot be used, various HFCs have been introduced, such as HFC-245fa. For example, a significant part of the PU foam market is for spray foam, that is applied to buildings in-situ – a non-flammable blowing agent is required for spray foam.

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GWP, CO_2(e) and the Basket of HFCs

Background: Progress towards the HFC phase-down targets under the Kigali Amendment will be measured in **tonnes CO_2 equivalent**. It is very important that policy makers and industry stakeholders understand how this parameter is calculated and the way that it enables a flexible approach to HFC phase-down to be adopted by each country. To calculate tonnes CO_2 equivalent it is necessary to know the **GWP**[1] (global warming potential) of each relevant gas.

What is GWP? Global warming potential (GWP) is a measure of the relative global warming effects of different gases. The GWP indicates the amount of heat trapped by 1 tonne of a gas relative to the amount of heat trapped by 1 tonne of CO_2 over a specific period. CO_2 was chosen by the Intergovernmental Panel on Climate Change (IPCC) as the reference gas and its GWP is defined as 1. Most HCFCs and HFCs have GWPs that are thousands of times higher than the GWP of CO_2. For example, HFC-134a has a GWP of 1 430. This means that the emission of 1 tonne of HFC-134a will create the same contribution to global warming as the emission of 1 430 tonnes of CO_2.

Why are there different GWP values for the same gas? Different publications do not always quote the same GWP values for a particular gas. There are two main reasons for this:

a) GWPs can be defined to measure impact over different timescales, e.g. 20 years, 100 years or 500 years. This results in different GWP values for each of these timescales.

b) There is some uncertainty about the best GWP value to assign to each gas. A key source of GWP data are the IPCC Assessment Reports. GWP values published by the IPCC have been updated several times over the last 20 years.

GWPs used under the Kigali Amendment: Under the Kigali Amendment a standard set of GWP values has been agreed for reporting consumption and production of HFCs. The GWPs of HCFCs and HFCs are listed in Annex C and Annex F of the Montreal Protocol and are based on the 100-year GWPs in the IPCC 4th Assessment Report.

Some HCFCs and HFCs are used as pure fluids e.g. HFC-134a in various RAC applications. However, many of the most commonly used HFCs are blends of two or more separate HFC molecules. The GWP of a blend is the weighted average of the GWPs of the blend components. See Box 1 for an example calculation of a blend GWP.

Box 1: Calculating the GWP of a Blend

A widely-used blend is R-404A. It consists of:

52% HFC-143a + 44% HFC-125 + 4% HFC-134a

GWPs: HFC-143a: 4470 HFC-125: 3500 HFC-134a: 1430

Blend GWP = 52% * 4470 + 44% * 3500 + 4% * 1430

= 3922

Group	Fluid	Montreal Protocol Standard GWP Value
HFCs	HFC-134a	1 430
	HFC-227ea	3 220
HFC blends	R-404A	3 922
	R-410A	2 088
HCFCs	HCFC-22	1 810
	HCFC-141b	725

The GWPs of HCFCs are of importance because they form part of a country's baseline consumption (see Kigali Fact Sheet 5 for details on baselines).

The table shows the GWP values that should be used for some of the most common HFCs and HCFCs. A table at the end of this Fact Sheet includes a comprehensive list of GWP values for all relevant molecules and blends.

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

What is tonnes CO_2 equivalent?

Tonnes CO_2 equivalent is the GWP-weighted quantity of a gas.

It is often referred to as tonnes CO_2e or simply as tonnes CO_2.

Tonnes CO_2 equivalent is calculated by multiplying the mass of gas (in tonnes) by the GWP (global warming potential) of that gas.

Box 2: Calculating tonnes CO_2 equivalent

For example, the tonnes CO_2 equivalent of 100 kg of HFC 404A is calculated as follows:

CO_2 equivalent = mass (in tonnes) x GWP

Mass = 100/1 000 = 0.1 tonnes

GWP of R-404A = 3 922

Hence 100 kg R-404A is 0.1 x 3 922 tonnes CO_2e

= 392.2 tonnes CO_2e

Measuring HFC phase-down for a "basket" of gases:

Using the parameter **tonnes CO_2e** to measure progress towards HFC phase-down makes it possible to use a single set of phase-down targets that apply to the whole basket of HFCs. The basket of controlled HFCs are listed in Annex F of the Montreal Protocol, together with standard GWP values. Production and consumption targets are set in tonnes CO_2e and are applied to the total use of the whole basket of HFCs.

This approach allows each country to plan their phase-down in a way that best suits their local conditions. There are no prescriptive requirements to stop using specific HFC molecules – it is the aggregate target for all HFCs measured in tonnes CO_2e that must be met. This encourages the use of low GWP alternatives but allows continuing use of small quantities of high GWP gases in markets where there is no cost-effective alternative.

The baseline for the HFC phase-down calculations is based on a combination of both HFC and HCFC consumption (see Kigali Fact Sheet 5 for details). The baseline amount is also treated as a basket of gases, with the GWP values for HCFCs used to calculate their tonnes CO_2e.

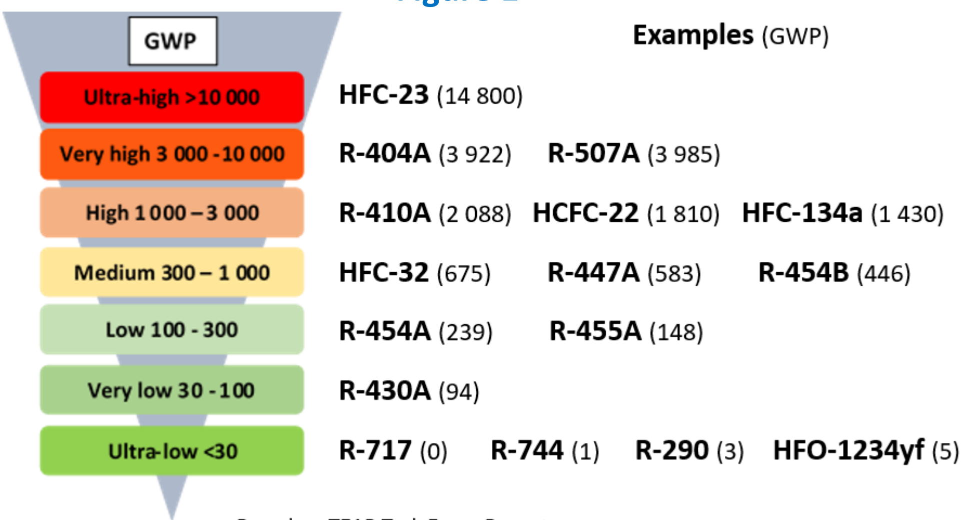
The spectrum of GWP:

Figure 1 illustrates the spectrum of GWP for HFCs, HCFCs and not-in-kind (NIK) fluids, using GWP-bands specified by the Montreal Protocol Technology and Economic Assessment Panel. The bands are somewhat arbitrary and not universally accepted, but they help illustrate the mix of fluids that may be used in the future.

The most commonly used HCFCs and HFCs[2] have GWPs in the range 1 400 to 4 000. The weighted average GWP of these HCFCs and HFCs is around 2 000.

To achieve an 80% to 85% cut in HFC use via the Kigali Amendment it will be necessary to be using HFCs with an average GWP around 200 to 300. As shown in the figure, there are various "ultra-low" GWP options with GWPs well below 30. It is likely that in the future there will be significant use of ultra-low GWP gases, together with some use of medium GWP gases and limited use of high GWP gases where no other technical alternatives can be used. See Kigali Fact Sheet 4 for details about low GWP options.

Figure 1



Based on TEAP Task Force Report

[2] HFC-134a, R-410A, R-404A and HCFC-22 represent about 90% of global HFC and HCFC consumption

Table of GWP Values: The tables below provides a detailed list of the GWPs of various fluids that are impacted by the Kigali Amendment. Colour coding based on Figure 1.

Group	Fluid	GWP
HFCs	HFC-23	14 800
	HFC-32	675
	HFC-41	92
	HFC-125	3 500
	HFC-134	1 100
	HFC-134a	1 430
	HFC-143	353
	HFC-143a	4 470
	HFC-152a	124
	HFC-227ea	3 220
	HFC-236cb	1 340
	HFC-236ea	1 370
	HFC-236fa	9 810
	HFC-245fa	1 030
	HFC-365mfc	794
	HFC-4310mee	1 640
HCFCs	HCFC-22	1 810
	HCFC-123	77
	HCFC-124	609
	HCFC-141b	725
	HCFC-142b	2 310
CFCs	CFC-11	4 750
	CFC-12	10 900
	CFC-113	6 130
	CFC-114	10 000
	CFC-115	7 370
HFOs	HFO-1234yf	4
	HFO-1234ze	7
	HFO-1233zd	4
	HFO1336mzz	9
Other	Ammonia	0
	CO_2	1
	Propane	3
	Iso-butane	3
	Pentane	3
	Propylene	2

Blend	GWP
R-401A	1 182
R-401B	1 288
R-402B	2 416
R-403A	3 124
R-403B	4 457
R-404A	3 922
R-407A	2 107
R-407C	1 774
R-407F	1 825
R-408A	3 152
R-409A	1 585
R-409B	1 560
R-410A	2 088
R-411A	1 597
R-412A	2 826
R-413A	2 053
R-415A	1 507
R-415B	546
R-416A	1 084
R-417A	2 346
R-418A	1 741
R-419A	2 967
R-420A	1 536
R-421A	2 631
R-421B	3 190
R-422A	3 143
R-422B	2 526
R-422C	3 085
R-422D	2 729
R-423A	2 280
R-424A	2 440
R-425A	1 505
R-426A	1 508
R-427A	2 138
R-428A	3 607
R-429A	13
R-430A	94
R-431A	37
R-432A	2
R-434A	3
R-433B	3
R-433C	3
R-434A	3 245
R-435A	26

Blend	GWP
R-436A	3
R-436B	3
R-437A	1 805
R-438A	2 265
R-439A	1 983
R-440A	144
R-441A	3
R-442A	1 888
R-444A	93
R-444B	296
R-445A	135
R-446A	461
R-447A	583
R-448A	1 387
R-449A	1 397
R-449B	1 412
R-450A	605
R-451A	149
R-451B	164
R-452A	2 140
R-452B	698
R-453A	1 765
R-454A	239
R-454B	466
R-454C	148
R-455A	148
R-456A	687
R-457A	139
R-458A	1650
R-459A	460
R-459B	145
R-460A	1352
R-461A	2103
R-502	4 657
R-507A	3 985
R-508A	13 214
R-508B	13 396
R-510A	1
R-511A	9
R-512A	189
R-513A	631
R-513B	596
R-514A	7
R-515A	939

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OzonAction Kigali Fact Sheet 4

Low GWP Fluids and Technologies

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Background:

Kigali Fact Sheet 2 described the main markets for HCFCs and HFCs. Key uses for these gases are RACHP (refrigeration, air-conditioning and heat pumps), foam blowing agents and aerosol propellants. Most HCFCs and HFCs used in these applications have GWP[1]s in the range 1 000 to 4 000. To achieve the objectives of the Kigali Amendment it will be necessary to use fluids with much lower GWPs.

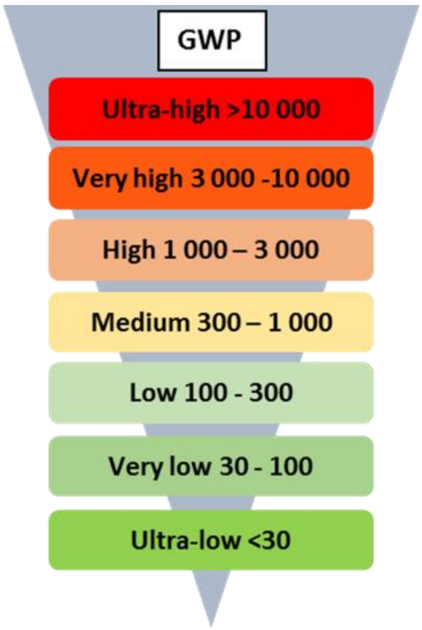
To maximise the long-term benefits of an HFC phase-down, end users need access to technologies that use fluids with the lowest practical GWP. It can be expected that the final product mix will include many products that use an "ultra-low" GWP fluid together with some products that have a higher GWP. See Kigali Fact Sheet 3 for further details about the range of GWPs for existing and future technology options.

Selection of Lower GWP Alternatives:

The most widely used HCFCs and HFCs all have "high" or "very high" GWP. Ideally, all applications would switch to the "ultra-low" category. This category includes the three most common not-in-kind (NIK) fluids – ammonia, CO_2 and hydrocarbons (HCs) together with several recently introduced fluorocarbons called HFOs[2].

However, not all applications are suited to the currently available ultra-low GWP fluids. For example:

- HCs are well suited to small sealed refrigeration products (such as domestic refrigerators) but cannot be used for many types of larger equipment because of the safety issues related to flammability.
- HFOs are well suited to medium and large sized air-conditioning water chillers, but cannot achieve the same level of energy efficiency as higher GWP fluids for small and medium sized split air-conditioning.



Based on TEAP Task Force Report

The designers of products and equipment that currently use HFCs need to seek lower GWP alternatives that provide the best compromise in terms of a range of different performance criteria, including:

1) High energy efficiency
2) Safe operation
3) Competitive capital and operating costs
4) Good environmental performance

It is important to remember that good environmental performance in most HCFC and HFC markets is a combination of high energy efficiency (to minimise emissions of energy related CO_2) and low GWP. The best overall environmental performance could be based on the use of a medium GWP fluid if that provides the highest energy efficiency and if leakage emissions can be minimised.

Safe operation with flammable alternatives:

Most HCFCs and HFCs are non-flammable – it is a property that makes them very popular fluids in a wide range of markets. Many of the ultra-low and low GWP alternatives have some degree of flammability – this can restrict their use in some market sectors.

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

[2] HFOs = hydro-fluoro-olefins, also called "unsaturated HFCs". Molecules of carbon, fluorine and hydrogen that include a double-bond between 2 carbon atoms. All recently introduced HFOs have a GWP below 10.

During the phase-out of ODS we have seen various highly flammable fluids successfully and safely introduced into a range of different markets. For example:

a) Consumer aerosols (e.g. personal care products) use hydrocarbon (HC) propellants

b) Parts of the polyurethane foam panel sector have switched to HC blowing agents.

c) Domestic refrigerators use HCs in the refrigeration circuit and for foam insulation.

When ODS phase-out was first agreed in 1987 it was not known whether flammable fluids could be used in these applications, but product designers addressed the safety issues and found long-term financial benefits because the HCs were a cheaper raw material than the CFCs they replaced.

During HFC phase-down, similar developments are required to support the introduction of flammable alternatives. Barriers created by safety standards, building codes and national legislation may need to be addressed before the full market potential for flammable fluids can be reached. See Kigali Fact Sheet 10 for details about flammability and Kigali Fact Sheet 11 for comments on safety standards.

Use of Interim Medium and High GWP Fluids: The HFC phase-down journey takes place over a 15 to 20 year period. It is likely that some new products will be introduced on an interim basis and replaced later with other lower GWP products.

An example relates to new refrigerant blends introduced as alternatives to R-404A, which has a very high GWP of 3 922. Two new blends with GWPs of around 1 400 have recently been introduced as alternatives to R-404A. They are in the "high" GWP category and well above the long-term target required to achieve an 85% HFC phase-down. However, they both have a considerably lower GWP than R-404A and can make a useful contribution to the early phase-down steps. Both these new blends are non-flammable – this will be a significant advantage in the short term as it allows them to be used without any major design changes.

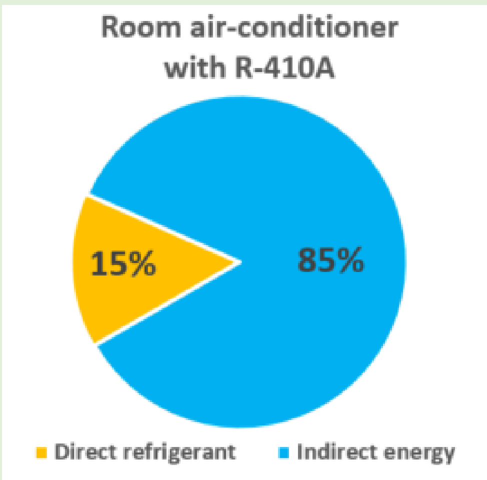
The market will need products using fluids in the high and medium GWP categories during the next 10 years. However, it may be impossible to achieve the longer-term phase-down cuts if significant quantities of such fluids are still used in the 2030s.

The Importance of Energy Efficiency

It is crucial to consider the total global warming impact of products and equipment. This includes two separate elements:

- the **direct** impact of the fluid used (e.g. leakage of a refrigerant with a high GWP)
- the **indirect** impact of energy used to operate equipment (e.g. refrigeration or air-conditioning)

In most RAC applications it is the indirect energy related emissions that are the dominant proportion of the total global warming impact, even if a high GWP fluid is used. It is crucial that new technologies using lower GWP fluids also have high energy efficiency. The pie chart shows a typical split of total global warming impact for a room air-conditioner. The refrigerant has a high GWP (2 088) but it is the CO_2 from electricity use that represents most of the GHG emissions. High energy efficiency and low refrigerant leakage levels for this type of equipment is crucial.



Market Developments with Lower GWP Fluids:

The tables below summarise the way in which low GWP fluids are being introduced into the various market sectors and sub-sectors.

Domestic refrigerators and freezers	
Small factory built refrigeration systems containing 0.05 to 0.25 kg refrigerant	
Typical ODS (GWP)	CFC-12 (10 900)
Typical HFC	HFC-134a (1 430)
Lower GWP fluorocarbon	HFO-1234yf (4)
Not-in-kind	HC-600a (iso-butane, 3)
From 2000, there is wide usage of hydrocarbons in Europe and some other regions. Hundreds of millions of HC refrigerators already in use. HFC-134a still used in USA, but HCs likely to enter that market. Good potential for HCs in most A5 countries. HFO-1234yf a possible option if a higher flammability fluid is unacceptable in a specific application.	

Car air-conditioning	
Small mobile air-conditioning systems containing 0.4 to 0.8 kg refrigerant	
Typical ODS (GWP)	CFC-12 (10 900)
Typical HFC	HFC-134a (1 430)
Lower GWP fluorocarbon	HFO-1234yf (4)
Not-in-kind	R-744 (CO_2, 1)
Global car industry began a move from HFC-134a to HFO-1234yf in 2013, initially driven by legislation in the EU that banned new mobile air-conditioning in cars if GWP > 150. Tens of millions of cars will use HFO-1234yf by the end 2017. A few car manufacturers have been concerned about flammability issues and are still considering a switch to CO_2.	

Food and drink retail refrigeration: large central systems	
Multi-compressor central systems for refrigerated displays in supermarkets. Low temperature (-20°C) for frozen food, medium temperature (+4°C) for chilled food. Large distributed systems connecting numerous retail displays and storage rooms, containing 50 to 200 kg of refrigerant	
Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-404A (3 922) HFC-134a (1 430)
Lower GWP fluorocarbon	Non-flammable blends R-448A, R-449A (1 400) Lower flammability blends e.g. R-454A (239)
Not-in-kind	R-744 (CO_2, 1) HC-290 (propane, 3)
Historically a very large consumer of HCFCs and HFCs; supermarket central systems have large system charge and high average leak rates – often more than 20% per year. Supermarket companies are at forefront of developing new lower GWP options. There is significant momentum behind transcritical CO_2 systems, especially in cooler climates. Cascade CO_2 systems can be used in hot climates. Some central systems are being replaced by small sealed propane systems cooled via a chilled water loop. Non-flammable blends are a good interim option with a GWP 65% lower than R-404A. Where possible R-404A should be avoided as a zero ODP alternative to HCFC-22; it has a very high GWP and it does not deliver the best energy efficiency compared to various lower GWP options.	

Food and drink retail refrigeration: condensing units

Condensing unit (one compressor / condenser) connected to one or two retail displays, either for chilled or frozen food. Usually quite small systems in small shops or convenience stores containing 5 to 10 kg of refrigerant.

Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-404A (3 922) HFC-134a (1 430)
Lower GWP fluorocarbon	Non-flammable blends R-448A, R-449A (1 400) Lower flammability blends e.g. R-454A (239)
Not-in-kind	R-744 (CO_2, 1)

Currently a difficult market to find a very low GWP option – equipment often too big to use flammable refrigerants but too small to use CO_2 cost effectively. Likely to become a good market for lower flammability HFO blends.

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Food and drink retail refrigeration: small sealed systems

Small factory built systems e.g. stand-alone bottle coolers, ice cream displays, serve-over counters, typically containing 0.1 to 1 kg refrigerant

Typical ODS (GWP)	R-502 (4 657) CFC-12 (10 900)
Typical HFC	R-404A (3 922) HFC-134a (1 430)
Lower GWP fluorocarbon	HFO-1234yf (4) Lower flammability blends e.g. R-455A (148)
Not-in-kind	HC-290 (propane, 3) R-744 (CO_2, 1)

Growing usage of hydrocarbons as refrigerant charge is low enough to meet safety standards in many applications. Millions of HC units already operating by 2017. CO_2 systems developed for bottle coolers and other small systems for markets where a flammable fluid is not acceptable. Lower flammability fluids (e.g. HFO-1234yf and R-455A) will also be used in this market sector.

Industrial refrigeration

Wide variety of medium and large sized systems (<50 kg to >1 000 kg of refrigerant), including indirect systems (with liquid chillers) and direct use of refrigerant (e.g. direct expansion, flooded or pumped systems).

Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-404A (3 922) HFC-134a (1 430)
Lower GWP fluorocarbon	Non-flammable and lower flammability blends For chillers: HFO-1234ze (4) HFO-1233zd (7)
Not-in-kind	R-717 (ammonia, 0) R-744 (CO_2, 1)

Safety issues can be cost-effectively dealt with on large plants, so ammonia is popular. New HFOs likely to grow in usage for industrial chillers.

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Transport refrigeration

Road transport and container refrigeration units, containing 3 to 10 kg of refrigerant and mainly used for transporting chilled and frozen food.

Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-404A (3 922) HFC-134a (1 430)
Lower GWP fluorocarbon	Non-flammable blends R-452A (2 140)
Not-in-kind	R-744 (CO_2, 1)

Safety issues important, so current alternatives are all non-flammable. Lower flammability blends may also enter this market if safety issues can be resolved.

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Small and medium sized single split air-conditioning

Single evaporator in room being cooled connected to outdoor condensing unit (compressor / condenser) containing 0.5 to 5 kg refrigerant. Used for residential and small commercial applications (e.g. shops, offices)

Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-410A (2 088)
Lower GWP fluorocarbon	HFC-32 (675) Lower flammability blends e.g. R454B (466)
Not-in-kind	HC-290 (propane, 3)

Currently a difficult market to find a very low GWP option – propane can only safely be used in very small systems at the bottom end of the size range for this market sector. Use of the lower flammability HFC-32 has grown rapidly in some markets, especially Japan. Tens of millions of HFC-32 units in operation by 2017. Blends of HFOs with HFC-32 also being developed by some equipment manufacturers.

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Large sized multi-split, VRF and packaged air-conditioning

Multiple room evaporators connected to large outdoor condensing units. VRF (variable refrigerant flow) systems can offer simultaneous heating and cooling in different rooms. Packaged units used with ducted air systems. Typically contain 5 to 50 kg refrigerant.

Typical ODS (GWP)	HCFC-22 (1 810)
Typical HFC	R-410A (2 088)
Lower GWP fluorocarbon	HFC-32 (675) Non-flammable blends e.g. R-450A (605) Lower flammability blends e.g. R454B (466)
Not-in-kind	None

Lower flammability refrigerants (HFC-32 and HFO blends) being used in smaller systems where safety codes allow. Larger VRF systems currently a problem as they require non-flammable refrigerant and nothing currently available with a GWP below that of R-410A. Larger packaged systems can use non-flammable blends such as R-450A.

Air-conditioning water chillers

Medium and large sized factory built water chillers used for cooling of large buildings. Typically contain 50 to 500 kg refrigerant.

Typical ODS (GWP)	HCFC-22 (1 810) HCFC-123 (77)
Typical HFC	HFC-134a (1 430) R-410A (2 088)
Lower GWP fluorocarbon	HFO-1234ze (7) HFO-1233zd (4) R-514A (5) HFC-32 (675) R-450A (605)
Not-in-kind	HC-290 (propane) R-717 (ammonia)

Water chillers are usually located in areas with restricted access e.g. a special machinery room or a roof-top. The refrigerant is only used in this restricted access location. This makes it easier to make use of flammable or toxic refrigerants. Various ultra-low GWP options are becoming widely available including several HFOs. HFO-1234ze is an alternative to HFC-134a in medium pressure chillers. It has lower flammability. HFO-1233zd and a recently introduced blend R-514A are alternatives to HCFC-123 in low pressure chillers – they are both non-flammable. In addition, it is also possible to consider using ammonia or propane.

Technical aerosols

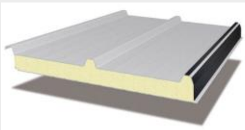
Non-domestic aerosols e.g. for supplying lubricants, solvents, foam, air dusters	
Typical ODS (GWP)	CFC-12 (10 900)
Typical HFC	HFC-134a (1 430)
Lower GWP fluorocarbon	HFO-1234ze (7)
Not-in-kind	Hydrocarbons (3), DME (dimethyl ether, 1)
Historically most aerosols used CFC propellants. After CFC phase-out, a large part of market, especially consumer products, moved to NIK. Some of the remaining market requires a non-flammable propellant. HFO-1234ze likely to become dominant where this is a requirement. HCs and DME can be used safely in some current HFC applications.	

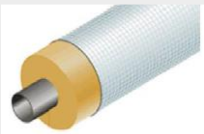
Medical aerosols (MDIs)

MDIs (metered dose inhalers) are small aerosols used to administer drugs for lung diseases such as asthma. Each MDI contains around 20 grammes of HFC propellant.	
Typical ODS (GWP)	CFC-12 (10 900)
Typical HFC	HFC-134a (1 430) HFC-227ea (3 220)
Lower GWP fluorocarbon	None currently available
Not-in-kind	Many MDI drugs can be administered via dry powder inhalers (DPIs).
Currently MDIs are being excluded from HFC phase-down regulations, such as that in EU, as the costs and timescales to develop alternatives to HFCs in MDIs are very high / long. This situation may change if an alternative low GWP fluorocarbon can be identified (trials are on-going).	

Polyurethane (PU) type insulation foam

Various types of closed cell foam including PU, PIR (polyisocyanurate) and phenolic foams. A “blowing agent” is used to create cells in a polymer matrix. Blowing agent is trapped in the cells and can make significant contribution to the thermal resistance of the product. Used in a wide range of applications including steel faced panels, laminated panels, spray foam, pipe and vessel insulation and domestic appliance insulation.	
Typical ODS (GWP)	HCFC-141b (725)
Typical HFC	HFC-245fa (1 030) HFC-365mfc (794)
Lower GWP fluorocarbon	HFO-1233zd (4) HFO-1336mzz (9)
Not-in-kind	Hydrocarbons (pentane, 5)
Hydrocarbons replaced a significant proportion of ODS blowing agents as properties were acceptable and raw material cost low. Part of the market has moved from HCFCs to HFCs. New ultra-low GWP HFO blowing agents showing very promising thermal performance (i.e. very low thermal conductivity) which may justify use despite higher cost.	





Extruded polystyrene (XPS) insulation foam

XPS closed cell foam is used for making boards for wall, floor and ceiling insulation.	
Typical ODS (GWP)	HCFC-142b (2 310)
Typical HFC	HFC-134a (1 430)
Lower GWP fluorocarbon	HFO-1234ze (7)
Not-in-kind	CO_2 (1)
Parts of the market moved to CO_2 but this is a difficult blowing agent to use. New HFO blowing agents showing good performance, but cost is a potential barrier.	

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OzonAction Kigali Fact Sheet 5

HFC Baselines and Phase-down Timetable

UN environment

Background: The Kigali Amendment specifies how to calculate the baseline for HFC consumption and production and the timetable of HFC[1] phase-down steps. There are four different country groupings, each with a different baseline and phase-down timetable. This Fact Sheet provides a summary of the timetables and explains how to calculate the HFC baseline.

Country Groups: The Montreal Protocol Parties are split into four Kigali Amendment groups:

Non-A5, earlier start	Most non-Article 5 countries
Non-A5, later start	Russia, Belarus, Kazakhstan, Tajikistan, Uzbekistan
A5, Group 1	Most Article 5 countries
A5, Group 2	Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, UAE

HFC Baseline: The baseline for each country group is summarised below. The same baselines apply to consumption and production. All data is measured in tonnes CO_2e (see Kigali Fact Sheet 3 for details of how to calculate tonnes CO_2e for different HFCs and HCFCs). The baseline is made up of two components:

- the average annual HFC quantity consumed (or produced) during a 3-year baseline period
- a proportion of the baseline for the control of HCFCs under the Montreal Protocol

Two components are required because A5 countries are only in the early stages of HCFC phase-out.

	Non-A5, earlier	Non-A5, later	A5 Group 1	A5 Group 2
HFC component Average HFCs in period	2011 to 2013		2020 to 2022	2024 to 2026
HCFC component % of HCFC baseline	15%	25%	65%	

The HCFC baselines referred to above are defined in the Montreal Protocol as:

1) For all Article 5 countries: average HCFC consumption in 2009 and 2010
2) For all non-Article 5 countries: HCFC consumption in 1989 plus 2.8% of CFC consumption in 1989

To calculate the baseline, consumption and production data is required for each individual type of HFC and HCFC fluid used in the appropriate base years. In the example at right, the baseline is calculated to be 33.7 million tonnes CO_2e

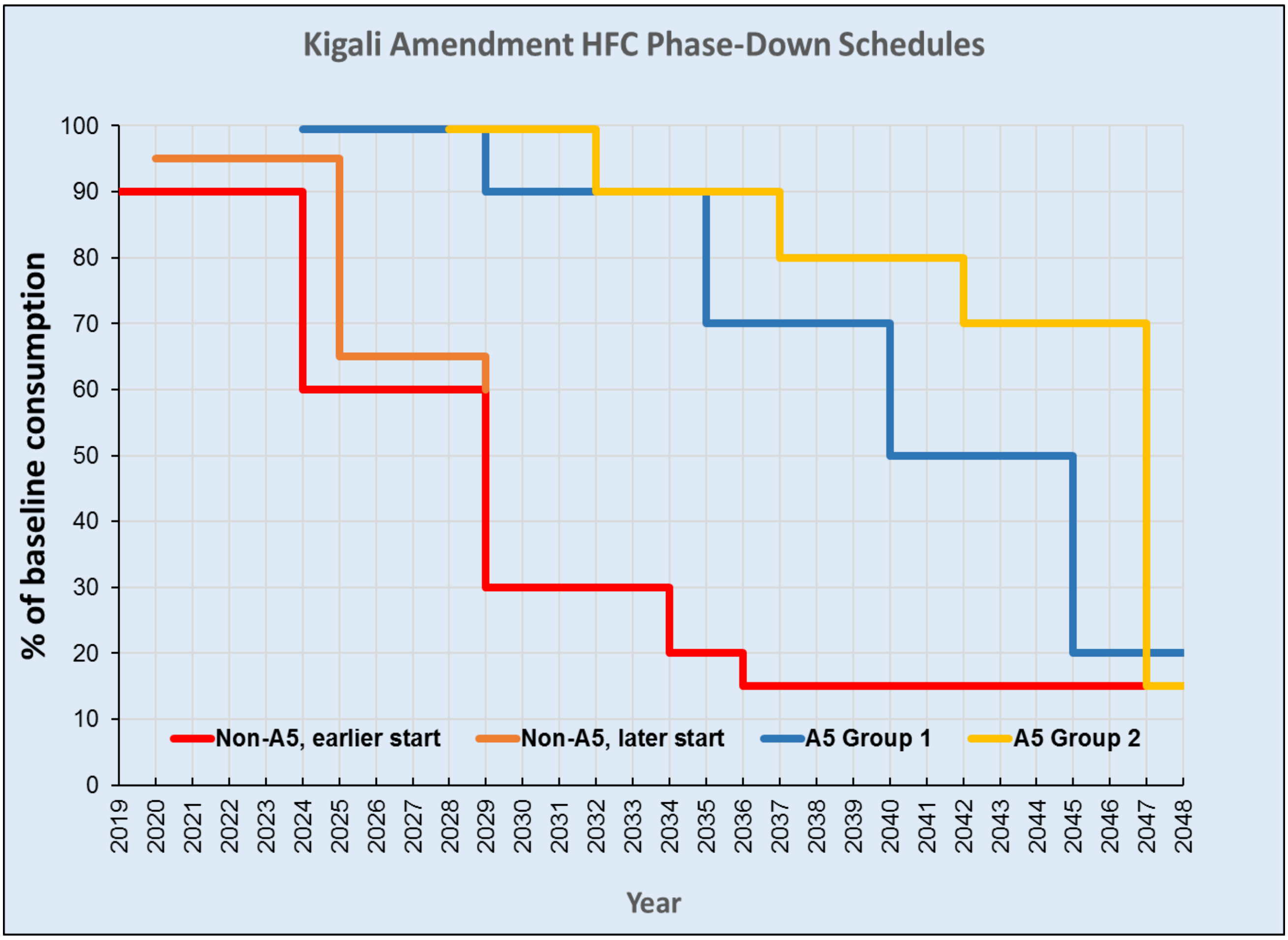
Example Baseline Calculation for a fictional Country in A5 Group 1

Fluid	Average annual tonnes	GWP	Tonnes CO_2e (000s)
	2020 to 2022		
HFC-134a	5 000	1 430	7 150
R-404A	2 500	3 922	9 805
R-410A	3 300	2 088	6 890
	2009 to 2010		
HCFC-22	8 000	1 810	14 480
HCFC-141b	1 000	725	725
Total Baseline, thousand tonnes CO_2e HFC component + 65% HCFC component			**33 730**

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

HFC Phase-down Timetables: The HFC phase-down steps for each country group are summarised in the table and graph below. The same steps apply to both consumption and production of HFCs. All data is measured in tonnes.

	Non-A5 Countries		A5 Countries	
	Earlier start	Later start	Group 1	Group 2
Freeze	-	-	2024	2028
5% reduction	-	2020	-	-
10% reduction	2019	-	2029	2032
20% reduction	-	-	-	2037
30% reduction	-	-	2035	2042
35% reduction	-	2025	-	-
40% reduction	2024	-	-	-
50% reduction	-		2040	-
70% reduction	2029		-	-
80% reduction	2034		2045	-
85% reduction	2036		-	2047



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Next Steps: HFC Phase-Down Strategy

UN environment

Background: An important aspect of Kigali Amendment implementation is for each country to consider its optimum phase-down strategy. Numerous questions need to be considered to develop a good strategy. These include:

a) How is the current consumption of HFCs[1] and HCFCs split between market sectors?
b) How might these markets develop in a "business-as-usual" scenario, taking into account factors such plans to phase-out HCFCs and economic growth?
c) What type of actions can be taken to reduce future HFC consumption?
d) Which fluids and technologies need to be adopted to achieve the phase-down targets?
e) Which market sectors have the greatest potential for cost-effective actions?
f) Which industry stakeholders need to make a contribution to strategy development?
g) What support do industry stakeholders require for implementation (e.g. improved training)?
h) What is the best way of prioritising different actions over the coming years?

This Fact Sheet summarises actions that can be taken to develop a national HFC phase-down strategy.

Action 1: Understanding Consumption The first action is to understand the current requirements for HCFCs and HFCs and to build a picture of how consumption might change over the next 10 years if there was no Kigali Amendment i.e. a business-as-usual (BAU) forecast. To do this you need to build a **national HCFC and HFC consumption model**. The more detail that you can make available through such a model, the easier it is to analyse an appropriate phase-down strategy. A national HCFC and HFC consumption model needs to be based on two distinct types of data:

1) Top-down data on the bulk consumption of HCFCs and HFCs. For HCFCs this is a simple process – the relevant data is already reported to the Ozone Secretariat on an annual basis. Data should be available for each individual HCFC over a period of many years. Similar data will need to be collected and reported for HFCs under the Kigali Amendment – although at this stage many A5 countries may have little historic top-down data on HFCs.

2) Bottom-up data on key market sectors and sub-sectors. Top-down data is useful, but it does not help understanding in detail the way that consumption is split between different market sectors and sub-sectors. Kigali Fact Sheet 2 provides an overview of the complex mixture of market sectors that make use of HCFCs and HFCs. It shows that the technical options for using low GWP alternatives vary significantly between different sub-sectors of the market. A bottom-up analysis requires the market to be split into appropriate sub-sectors. Each sub-sector is modelled based on the type of equipment used and the typical lifecycle of individual products. See Box 1 for an example.

Data from bottom-up modelling can be "calibrated" against top-down data to confirm that the input assumptions (e.g. annual leakage rates) are reasonable. When a model of this type has been created, it can act as a powerful tool to support analysis of future options.

Box 1: Bottom-up model of car air-conditioning

In 2015 a fictional A5 country had 0.5 million cars with air-conditioning. The market has grown rapidly, from 0.2 million in 2005 and is expected to reach 1 million by 2025. Each car can be represented by a "standard" car air-conditioning system:

- Refrigerant used: 0.7 kg HFC-134a
- Average annual leakage rate: 8%
- Average car life: 10 years

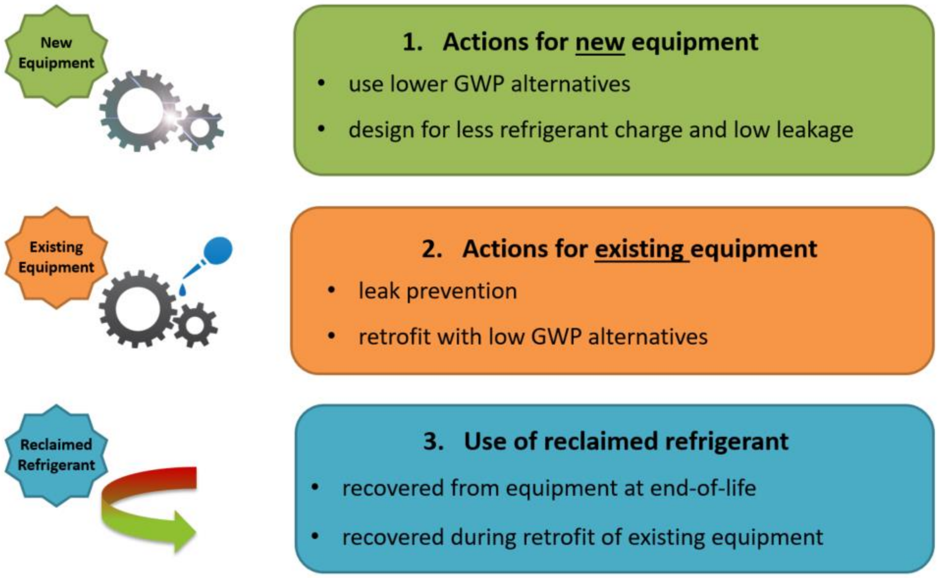
From this information, a bottom-up model can be created to show information such as:

a) The total bank of HFCs in all cars
b) Annual amount of HFCs for new cars
c) Annual amount of HFCs for servicing
d) HFC emissions in use and at end-of-life

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

Action 2: Understanding "Core Actions"

There are a number of different ways in which future HFC consumption can be reduced. These can be treated as a set of core actions that can be considered for each market sub-sector.



The most important long-term core action is to use low GWP alternatives to HFCs in all new equipment. For example, if new supermarket refrigeration uses an ultra-low GWP refrigerant such as CO_2 (GWP=1) there are big reductions in HFC use compared to using the popular HFC, R-404A (GWP=3 922).

However, other core actions such as leak prevention measures are also worth considering as they may be the most cost-effective ways of reducing HFC usage, especially in the early years of the phase-down process. The most appropriate core actions vary across different parts of the HFC market. For example:

- In market sectors with high leakage rates and long equipment life (e.g. industrial refrigeration or large central supermarket refrigeration) it is important to consider the actions that apply to existing equipment e.g. leak prevention or equipment retrofit.
- In market sectors that use small sealed equipment (e.g. domestic refrigerators, stand-alone retail refrigerators) it is not practical or cost-effective to modify existing equipment. For these sectors the priority is to introduce low GWP refrigerants in new equipment as soon as possible.

Action 3: Development of future consumption scenarios

The national HCFC and HFC consumption model can be used to investigate future scenarios that forecast the national requirements for HFCs. The modelling assumptions for each market sub-sector can be adjusted to predict future HFC demand from that sector. For example, if the car air-conditioning market switches from HFC-134a to an ultra-low GWP alternative, the future demand for HFC-134a will fall, initially in new equipment and, over a period of time, in the car maintenance market. The total HFC forecasts for all market sectors can then be compared to the steps in the Kigali HFC phase-down schedule. For each scenario this shows:

a) Whether the Kigali Amendment targets are being met
b) The proportion of the cuts in HFC consumption being delivered by each market sector and by the different core actions.

This is very powerful information that enables national policy makers to identify different routes to achieving the phase-down targets and to assess which are the most practical and cost-effective ways of prioritising future action.

Box 2: Scenario Modelling for Car Air-conditioning

Using data such as that shown in Box 1, a national HCFC and HFC consumption model can indicate the annual demand for HFC-134a in car air-conditioning, both for the gas required to fill air-conditioning in new vehicles and for the gas required to top-up leaks from all existing cars. The model can then be used to forecast future consumption using different scenarios. In this example, three scenarios have been defined and used to calculate HFC demand. These scenarios are:

Business-as-usual: all new cars continue to use HFC-134a

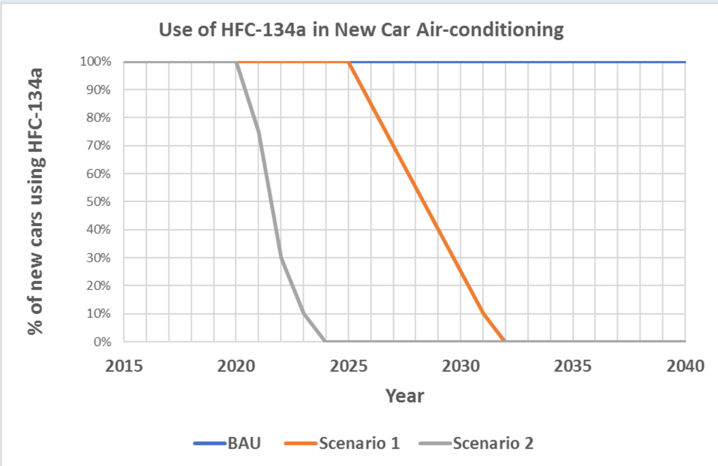
Phase-down Scenario 1: over a 7-year period from 2026, car air-conditioning in new cars switches from HFC-134a to an ultra-low GWP non-HFC alternative (e.g. HFO-1234yf). Scenario 1 can be considered as a "conservative" phase-down strategy, with a late starting date and a slow switch away from HFC-134a in new cars.

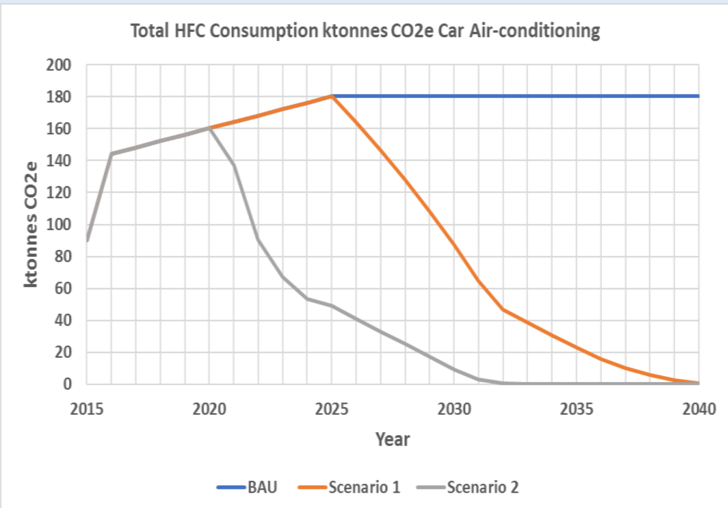
Phase-down Scenario 2: over a 5-year period from 2020, car air-conditioning in new cars switches from HFC-134a to a non-HFC alternative. Scenario 2 is a more aggressive scenario, with an earlier start and a faster switch to a low GWP alternative.

The first graph below illustrates the switch away from HFC-134a in new cars for each of the three scenarios. Based on the scenario assumptions, the second graph shows the results from the model: the annual HFC demand from this market sector, expressed in tonnes CO_2e (see Kigali Fact Sheet 3 for information about GWP and tonnes CO_2e).

The benefits of an early switch to a low GWP alternative are clear from the second graph. In the period to 2040, Scenario 2 saves around 3 million tonnes CO_2e whereas Scenario 1 only saves 1.8 million tonnes CO_2e.

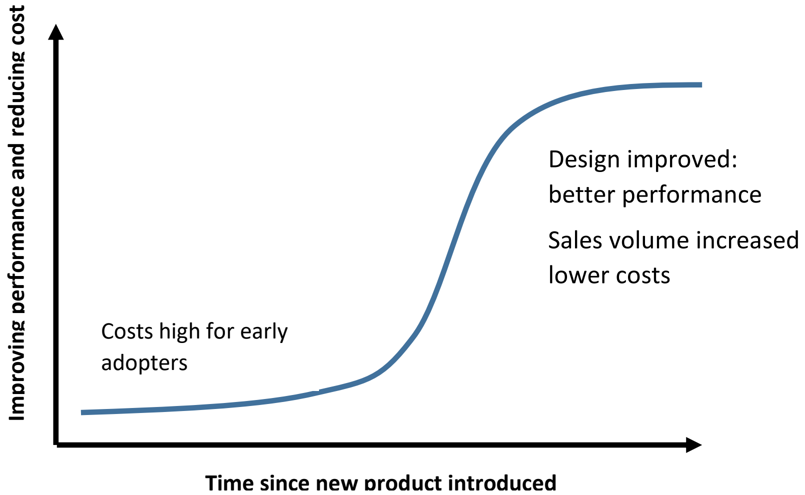
It is interesting to note how the consumption of HFC-134a continues for 10 years after the switch away from HFC-134a in new cars – this is because there are older cars in the fleet that continue to need to be maintained using HFC-134a because of leakage.





Scenario modelling provides very powerful insights into the usage of HFCs and alternatives. Individual assumptions can be made for each market sector or sub-sector, e.g. in terms of the date at which lower GWP gases are introduced. All the different core actions can be modelled, e.g. leak reduction or retrofit of existing equipment as well as switching to low GWP alternatives in new equipment. A range of different scenarios can be tested, helping to identify the actions that will have the greatest impact. The UN OzonAction team can provide National Ozone Units with further guidance on scenario modelling.

Action 4: Consideration of all technical options and timelines Closely linked to Action 3 (the development of future consumption scenarios) it is necessary to consider the various technical options available in each market sector. Kigali Fact Sheet 4 provides a summary of many of the technical options available for new equipment. Other core actions must also be considered in some sectors (e.g. leakage prevention for industrial refrigeration and supermarket refrigeration). National circumstances must be considered e.g. will the new low GWP alternatives be available and does the workforce have the skills to use them.



The selection of an appropriate timeline is an important consideration as it is likely to influence environmental impact and cost. The analysis in Box 2 shows, in a fictional example, the benefits of an early start to the phase-down process. However, you also need to consider the potential cost impact of starting too early. The adjacent diagram illustrates the typical maturity curve for products and equipment. Early adopters pay more and may not get optimum performance. As a product becomes more mature it usually gets cheaper and provides better performance. Most of the early adopter costs are being absorbed in non-A5 countries. By the early 2020s there will be many products using low GWP alternatives that have reached maturity in terms of low cost and high performance. The car air-conditioning market is a good example. Regulations in the European Union mean that since January 2017 all new cars in the EU must use a low GWP alternative. Costs are still high, but over the next three to five years they are likely to fall rapidly.

It is worth noting that a "late start" to a phase-down action could create extra costs over an "optimum start". Most innovation by manufacturers will be directed towards products and equipment that use low GWP alternatives. Improvements such as higher energy efficiency will be made to these products, while the older products using high GWP fluids might "stagnate" and create higher running costs and worse environmental impact.

Action 5: Stakeholder input and support National Ozone Units should carefully consider their engagement with stakeholders. This is a 2-way process:

- **Support from stakeholders:** some stakeholders can make a big contribution to the strategy development by providing insights into the current markets and opinions on the best technical options and timelines
- **Support to stakeholders:** some stakeholders need lots of support to help them understand the Kigali Amendment and the new products and technologies. There may be a need to support training and to assist in the setup of new infrastructure (e.g. national capability to recover and recycle refrigerants from old equipment reaching end-of-life).

Kigali Fact Sheet 8 provides further details about stakeholder engagement.

Action 6: Strategy reviews The strategy needs regular review and updating. The availability of low GWP alternatives is changing rapidly. New alternatives are being introduced at a rapid rate by chemical producers and new products using these fluids are being commercialised by equipment manufacturers. The geographical availability of low GWP fluids and equipment is also changing rapidly. Currently the focus is to supply those countries with the most challenging HFC phase-down schedules – in particular, the European Union. However, with the Kigali Amendment in place this is likely to change rapidly and Article 5 countries can expect that access to low GWP technologies will quickly improve. The national strategy should be re-evaluated on an annual basis to assess whether any changes are required.

OzonAction

OzonAction Kigali Fact Sheet 7

Next Steps: Legislation and Administration

UN environment

Background: The Kigali Amendment was agreed by all Montreal Protocol Parties at the 27th Meeting of the Parties in October 2016. Each Party now needs to take steps to ratify and implement the Kigali Amendment. This Fact Sheet provides a summary of what each Party needs to do in relation to introducing new national legislation and setting up appropriate administrative procedures.

The Kigali Amendment is simply an extension to the Montreal Protocol. All Parties to the Protocol already have legislation and administrative procedures in place to support ratification, implementation and compliance with the current Montreal Protocol. The requirements for the Kigali Amendment can be considered as extensions to existing legislation and administrative procedures.

Required Legislation: The legislation that must be put into place falls into 2 parts:

a) **Ratification of the Kigali Amendment:** a ratification instrument must be prepared by each Party and lodged with the United Nations Depositary.

b) **National enabling legislation:** in each country, laws must be enacted to enable implementation of the Kigali Amendment.

Required Administration Systems: The following systems are required:

a) **Monitoring and reporting of HFCs[1]:** a system to monitor the production, import and export of HFCs is required. Annual data will need to be reported to the Montreal Protocol Secretariat.

b) **Licensing of and quotas for production and import of HFCs:** a system to licence the production and import of HFCs is required to ensure that the phase-down targets are met. This also requires a quota allocation method to define which companies are allowed to produce or import HFCs.

c) **Verification of imports:** customs officials need an administrative system to check that imports are being made only by companies holding a suitable quota allocation.

Who is responsible for legislation and administration? Each Party has the freedom to select the most appropriate ministry or government agency to carry out the required tasks. For most Parties, it is likely that the bodies that are currently responsible for the legal and administrative aspects of the ODS phase-out process will also be responsible for HFC phase-down under the Kigali Amendment.

Ratification: The Kigali Amendment is intended to be a binding international treaty, which creates rights and obligations in international law. Once the Amendment enters into force for a Party, that Party assumes legal obligations under the Amendment.

The Kigali Amendment itself will enter into force on January 1st 2019, if at least 20 Parties have ratified the amendment. If 20 Parties have not ratified the Kigali Amendment by that date (this is highly unlikely) it enters into force on the 90th day following the 20th ratification. The trade controls referred to in Article VI(2) enter into force on January 1st 2033, provided that at least 70 Protocol Parties have ratified the Amendment by that date.

The Amendment is not legally binding on a party until it enters into force for that Party. For an individual Party, the Kigali Amendment enters into force on January 1st 2019 if ratification is completed before that date, or 90 days after the Party has ratified.

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[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

Ratification of the Kigali Amendment by a Montreal Protocol Party is carried out by depositing an "Instrument of Ratification" with the depositary of the Montreal Protocol, which is the Secretary General of the United Nations in New York. The Instrument of Ratification is likely to be a very simple document that should follow the design of the original ratification of the Montreal Protocol and its subsequent amendments.

The process of preparing the Instrument of ratification will vary between different parties. A "treaty unit", normally within a Ministry of Foreign Affairs, will be responsible for ratification of international treaties. The officials who lead on Kigali Amendment policy should contact the treaty unit to commence the process for ratification.

The treaty unit can advise on the national processes to be followed before formal ratification. They can explain what documentation needs to be prepared and what decision-making processes should be followed. Political authority is required to ratify. It will depend on national processes who can give that authority.

Example Instrument of Ratification

WHEREAS at the Twenty-Eighth Meeting of the Parties to Montreal Protocol on Substances that Deplete the Ozone Layer, held in Kigali from 10 to 15 October 2016, the Parties adopted, in accordance with the procedure laid down in paragraph 4 of article 9 of the 1985 Vienna Convention for the Protection of the Ozone Layer, a further amendment to the Montreal Protocol.

NOW THEREFORE I, *[name and title of the Head of State, Head of Government or Minister of Foreign Affairs]* declare that the Government of *[name of State]*, having considered the above mentioned amendment, ratifies the same and undertakes faithfully to perform and carry out the stipulations therein contained.

IN WITNESS WHEREOF, I have signed this instrument of ratification at [place] on [date].

[Signature]

More details about ratification can be found at in the Ozone Secretariat Briefing Note available at:
http://conf.montreal-protocol.org/meeting/oewg/oewg-39/presession/briefingnotes/ratification_kigali.pdf

National Enabling Legislation:

The enabling legislation that is required must allow the appropriate control of the production and consumption of HFCs to ensure compliance with the Kigali Amendment. The relevant legislation can be an extension of the existing legislation that is used to control the production and consumption of ozone depleting substances (ODS). Key features of the Kigali Amendment that will require changes to current national enabling legislation include:

1) Powers to control the Party's production and consumption of HFCs, as specified in Article 2J and Article 5, paragraph *8qua* of the amended Montreal Protocol. The HFCs to be controlled are listed in Annex F of the amended Protocol.

2) Recognition that the HFC phase-down process is based on tonnes CO_2e (see Kigali Fact Sheet 3 for an explanation of GWP and tonnes CO_2e). The control of ODS was measured in ODP tonnes – legislation will need to be modified to define tonnes CO_2e.

3) Specification of the Party's baseline level from which the HFC phase-down is measured (see Kigali Fact Sheet 5 for details of the calculation of the HFC baseline for Article 5 and non-Article 5 parties).

   The baseline is measured in tonnes CO_2e and requires the use of GWP values for each relevant gas. The GWPs of HFCs are listed in Annex F of the Protocol. The baseline calculation for Article 5 countries includes an HCFC component – the GWP values for commonly used HCFCs have been added to Annex C of the Protocol. For non-Article 5 countries the baseline also includes a CFC component – the GWP values for CFCs have been added to Annex A of the Protocol.

4) Specification of the Party's phase-down steps for production and consumption of HFCs. They need to be specified in tonnes CO_2e values, based on percentage cuts from the baseline during relevant years (see Kigali Fact Sheet 5 for details of the phase-down steps).

5) Powers to set up a licencing system for production and consumption of HFCs, as specified in Article 4B, paragraph 2bis of the amended Protocol.

6) Powers to set up a quota allocation system for production and consumption of HFCs.

7) For any Party that produces HCFCs or HFCs, powers to ensure by-product emissions of HFC-23 does not exceed 0.1% of the mass of HCFCs and HFCs manufactured, from 1st January 2020.

8) Powers to collect data on HFC production, import and export, based on Article 7, paragraphs 2 and 3 of the amended Protocol. For any Party that produces HCFCs or HFCs, powers to collect data on HFC-23 emissions, based on Article 7, paragraph *3ter* of the amended Protocol

9) Powers to enable customs officials to prevent illegal import of HFCs.

10) Powers to ban trade (import and export of HFCs) with states that have not ratified the Kigali Amendment, from 1st January 2033 (as specified in Article 4, Paragraph 1 *sept* and *2 sept* of the amended Protocol).

Monitoring and Reporting: Under the existing Montreal Protocol, each Party collects data on production, import and export of bulk ODS and reports summary data on an annual basis to the Montreal Protocol Secretariat. The administrative systems to collect this data must be extended to include data about all the HFCs listed in Annex F of the amended Protocol.

Reporting must start no later than for the beginning of the baseline period and must be carried out annually thereafter. See Kigali Fact Sheet 5 for details of the baseline periods for each group of countries under the Kigali Amendment. For most Article 5 countries (A5 Group 1) the baseline period is 2020 to 2022. For A5 Group 2 countries the baseline period is 2024 to 2026.

There are significant benefits to setting up a reporting system as soon as possible, without waiting for the start of the baseline period. Without good data on current HFC consumption it will be very difficult to start making plans for the HFC phase-down. See Kigali Fact Sheet 6 for guidance on the data required to develop an HFC phase-down strategy.

Licensing and allocation of quotas: An administrative system to monitor and control the levels of HFC production and consumption is required in order to meet the Kigali Amendment phase-down obligations. The required system will be an extension to the existing system used to control the phase-out of ODS.

The Montreal Protocol specifies the need for a licencing system. Article 4B, paragraph 2bis states:

"Each Party shall, by 1 January 2019 or within three months of the date of entry into force of this paragraph for it, whichever is later, establish and implement a system for licensing the import and export of new, used, recycled and reclaimed controlled substances in Annex F. Any Party operating under paragraph 1 of Article 5 that decides it is not in a position to establish and implement such a system by 1 January 2019 may delay taking those actions until 1 January 2021".

The requirements to licence the import and export of new, used, recycled and reclaimed HFCs are precisely the same as the current requirements for licencing of HCFCs.

The licencing system needs to be linked to a methodology for allocating the rights to produce or import HFCs to individual companies. The method of doing this is not prescribed in the Montreal Protocol – each Party is free to implement a suitable system – often referred to as a quota allocation method. It is likely that the quota allocation method currently used for HCFCs can be extended for the control of HFCs. The most commonly used allocation method is "grandfathering", which creates an allocation based on the activities of individual producers or importers during the baseline period. However, other methods such as auctions can also be considered.

Verification of imports: It is important that all HFCs being imported have received a quota allocation via the licencing system. An administrative system needs to be put in place to enable customs officials to check that importers hold the required licence. This can be developed as an extension to existing customs procedures for checking HCFC imports. New customs codes are required to help officials identify HFCs and the officials will need access to a licencing database that specifies which companies have the legal right to import HFCs.

Import Quota Allocation by "Grandfathering"

Imports of bulk HFCs and HCFCs during the baseline period into Country X were carried out by 4 different companies, A, B, C, and D. In this simple example, it is assumed that there was no production of HFCs and HCFCs in Country X and there was no re-export of these gases. The imports by each company are shown in the Table. Company D is the largest importer during the baseline period, with 33% of total imports measured in tonnes CO_2e. There are a variety of methodologies by which the quotas can be allocated. Under a 'grandfathering methodology', Company D would receive a quota allocation equal to 33% of the amount of imports allowed. Assuming that the baseline is 40,000 tonnes CO_2e for Country X, Company D would receive 33% of the 40,000 baseline in 2024 (a "freeze year") and 33% of 28,000 tonnes CO_2e in 2035 (a year with a 30% cut in the phase-down schedule).

A variant of grandfathering is to create an allocation for "new entrants". This would allow new companies to enter the market. A proportion of the total quota (e.g. 10%) would be reserved for new entrants. In this situation Companies A to D would each "give up" 10% of their allocation for the new entrants.

Fluid	Annual average imports by company (metric tonnes) 2020 to 2022				GWP	tonnes CO_2e (000s)			
	A	B	C	D		A	B	C	D
HFC-134a	1,000	2,000	2,500	3,000	1430	1,430	2,860	3,575	4,290
R-404A	500	750	1,000	1,000	3922	1,961	2,942	3,922	3,922
R-410A	750	1,000	1,000	1,250	2088	1,566	2,088	2,088	2,610
HCFC--22	2,500	2,000	1,500	3,000	1810	4,525	3,620	2,715	5,430
Total tonnes CO_2						**9,482**	**11,510**	**12,300**	**16,252**
% of total tonnes CO_2						**19%**	**23%**	**25%**	**33%**
Allocation, 2024 = 40,000 tonnes CO_2e					2024 quotas	**7,655**	**9,292**	**9,931**	**13,121**
Allocation, 2035 = 28,000 tonnes CO_2e					2035 quotas	**5,359**	**6,505**	**6,951**	**9,185**

Comprehensive details about setting up an import quota system for HCFCs were published by OzonAction in 2012. The approach described for HCFCs is also likely to be appropriate for HFC quotas. This reference can be found at: http://www.unep.fr/ozonaction/information/mmcfiles/7531-e-HCFC_Quota_system.pdf

Engagement with stakeholders:

During the process of setting up the required legislation and administrative systems it will be important to engage with relevant stakeholders for different parts of these processes. In particular:

a) Government officials in the "treaty unit", normally within a Ministry of Foreign Affairs
b) Customs officials
c) Private sector companies that produce or import HFCs

See Kigali Fact Sheet 8 for further information on stakeholder engagement.

OzonAction Kigali Fact Sheet 8

Next Steps: Stakeholder Engagement

Background: To ensure that ratification and implementation of the Kigali Amendment takes place in the most effective way, it is important to set up a mechanism for on-going stakeholder engagement. Each Party already has arrangements in place for the implementation of the Montreal Protocol. In most countries it will be appropriate for the same team that carries out the existing Montreal Protocol activities to be the focal point for Kigali Amendment implementation (e.g. the National Ozone Unit). This team needs to engage with the following different groups of stakeholders:

a) Other government officials

b) Private sector experts and representatives of civil society

c) Experts and support agencies from other countries

Engagement with Government Officials:

The requirements for legislative and administrative actions are described in Kigali Fact Sheet 7. These steps need to be taken in conjunction with Government officials from the following departments:

- the Treaty Unit of the Ministry of Foreign Affairs (or similar), for support on the ratification process
- the Trade Ministry (or similar) for support on HFC licencing, quota allocation and monitoring of production, imports and exports of HFCs
- the Environment Ministry (or similar) for support on modifications to the existing national enabling legislation for the Montreal Protocol
- Customs and Border Control for support related to monitoring of imports of HFCs.

Various barriers to the successful phase-down of HFCs are discussed in Kigali Fact Sheet 11. To overcome these barriers, it will be very helpful to address key issues with relevant officials including:

- Safety experts for support related to national legislation, safety codes and standards that may prevent the use of some lower GWP alternatives
- Training experts for support related to technician training

The HFC phase-down will create an important contribution towards national targets for reducing greenhouse gas emissions. Interaction between the Kigali Amendment and other climate change policies are discussed in Kigali Fact Sheet 12. It is helpful to engage with:

- Officials responsible for implementing the UN FCCC Paris Agreement on climate change
- Energy efficiency experts for support related to the interaction between the policy to reduce use of HFCs and the impact that might have on energy efficiency policies.

Engagement with the Private Sector and Civil Society: An important first step in the Kigali Amendment implementation process is the development of a national HFC phase-down strategy. This is described in Kigali Fact Sheet 6. The strategy requires a thorough understanding of existing markets for HCFCs and HFCs, together with the identification of the most appropriate and cost-effective actions that can be taken to reduce demand for HFCs. Engagement with the private sector is an essential part of the process of developing and implementing a phase-down strategy. As discussed in Kigali Fact Sheet 6, this is a “2-way process”:

- Some stakeholders can make a positive contribution to the strategy development by providing insights into the current markets and opinions on the best technical options and timelines.
- Some stakeholders need support to help them understand the new products and technologies. In particular, there may be a need to support training and to assist in the setup of new infrastructure for the supply of lower GWP alternatives.

It is recommended that each Party sets up a consultation forum to engage with key experts in the private sector. The organisations and companies that should be invited to such a forum might vary considerably, depending on the circumstances in each country. The following may be appropriate:

Sector	Possible Stakeholders
Supply of fluids including refrigerants, propellants and foam blowing agents	Producers and importers of HCFCs, HFCs and lower GWP gases
	Other companies in the supply chain for HCFCs and HFCs (e.g. companies that fill refrigerant cylinders and refrigerant wholesalers)
	Companies that recycle / reclaim / destroy used refrigerants
Refrigeration, Air-conditioning and Heat Pumps (RACHP)	Trade Associations representing different parts of the RACHP market
	Equipment manufacturers and importers supplying RACHP equipment
	Installation and maintenance contractors for RACHP equipment
	Major end users of RACHP (e.g. supermarkets)
	Other RACHP experts (e.g. design consultants, safety specialists)
Other HFC markets: foam insulation, aerosols, fire protection	Trade Associations representing other HFC markets
	Product manufacturers and importers in these markets
Civil Society	NGOs and other bodies with expertise related to HFCs and climate/ozone issues

In the early stages of Kigali Amendment implementation, the key role of a consultation forum would be to use the expertise of the private sector and NGOs to support development of the national HFC phase-down strategy. Once the strategy has been clarified, the forum could be used as a vehicle to raise awareness amongst a wider range of stakeholders and to identify further support required.

Engagement with experts / support agencies from other countries: Many countries will be developing their own HFC phase-down strategies. In many cases these strategies will have similar components and there could be significant saving of time and effort through engagement with experts from other countries and from international organisations.

The Ozone Secretariat and four Multilateral Fund implementing agencies (UNEP OzonAction, UNDP, UNIDO and the World Bank) will be regularly producing useful resource materials on the Kigali Amendment (such as these Kigali Fact Sheets). Two good places to search for relevant materials are:

UNEP OzonAction Website: www.unep.org/ozonaction

Montreal Protocol Ozone Secretariat Website: www.ozone.unep.org

Technology trends related to the latest lower GWP alternatives can be monitored via information published and regularly updated on the websites above. This includes information about the alternatives available in each sector and sub-sector of the HFC market.

Support for national strategy development that is more customised to a specific country may be available from independent international experts funded via the Multilateral Fund.

Some non-Article 5 countries already have national policies in place for the rapid phase-down of HFC use. For example, in the European Union there will be an HFC consumption cut of around 40% by 2018. Equipment designers and manufacturers are rapidly introducing new products that use the many lower GWP alternatives that are on the market. Useful information is available from equipment manufacturers and from producers of lower GWP fluids. Some of this information can be accessed via the above websites. See Kigali Fact Sheet 14 for further references and links to resource materials.

OzonAction Kigali Fact Sheet 9

Technical Issues: High Ambient Temperature

OzonAction

UN environment

Background:

The main use of HCFCs and HFCs is in refrigeration, air-conditioning and heat pump applications (RACHP). These sectors represent around 86% of the GWP-weighted use of HCFCs and HFCs (see Kigali Fact Sheet 2). It is recognised in the Kigali Amendment that designing RACHP systems for operation at extremely high ambient temperature (HAT) creates several special challenges. For air-conditioning systems, these challenges include:

a) The heat loads are higher than in milder climates

b) Heat is rejected by the air-conditioning system at a higher condensing temperature than in milder climates

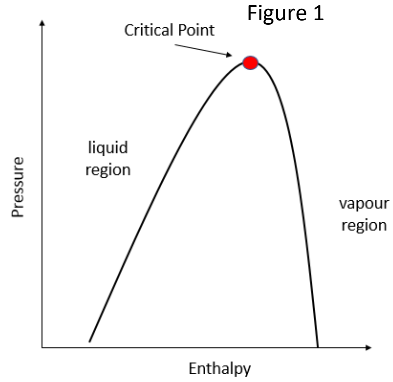
These factors mean that air-conditioning systems operating at high ambient temperature need to have a greater cooling capacity for a given room size and that they use more energy than equivalent air-conditioning systems that operate in milder climates.

In this Fact Sheet some of the technical issues related to the operation of air-conditioning systems at high ambient temperature are discussed. This Fact Sheet also provides information about the HAT Exemption that is part of the Kigali Amendment.

These challenges can apply to all refrigerants:

It is important to recognise that the technical challenges related to operation under HAT conditions are not caused by the proposed phase-down of HFC refrigerants. Many refrigerants, including some of the high GWP HFCs are not ideally suited to operation at high ambient temperature. Designers of refrigeration and air-conditioning equipment have always had to take ambient temperature into account and ensure the refrigerant selected can operate efficiently and reliably. Equipment that is specified for use in countries with HAT conditions has to be designed in a slightly different way to the equipment used in milder climates. Two characteristics of the refrigerant selected are especially important:

Figure 1



Critical temperature. A property of all refrigerants is the "critical temperature". This is the temperature at the critical point for the refrigerant, as illustrated in Figure 1, which is a pressure-enthalpy diagram[1] for a refrigerant. For an air-conditioning cycle to have good efficiency it is important that the condensing temperature is not too close to the critical temperature. The condensing temperature is always higher than the ambient temperature, so the condensing temperature under HAT conditions will be higher than in a milder climate; hence it will be closer to the critical temperature and less energy efficient.

Figure 2

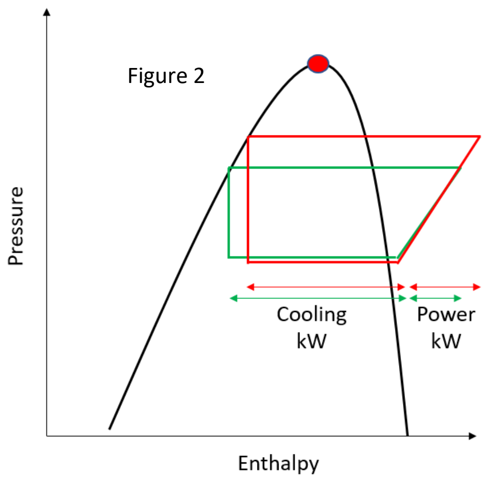


Figure 2 shows two air-conditioning cycles plotted on the diagram. The green cycle is for operation in a mild climate and the red cycle is operating at higher ambient temperature. When operating at high ambient temperature the air-conditioning system:

- does less cooling (the red cooling kW line is shorter)
- needs more electric power (the red power kW line is longer)

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used including pressure – enthalpy diagram

This illustrates why all air-conditioning systems operating at high ambient will use more electricity than a unit running in cooler conditions.

The loss of energy efficiency becomes especially severe if the critical temperature of the refrigerant being used is low. The adjacent table lists the critical temperature of a number of refrigerants that are used in air-conditioning systems.

Refrigerant	Critical Temperature ºC
HFO-1233zd	165
R-717 (ammonia)	132
HFO-1234ze	110
HFC-134a	101
R-290 (propane)	96.7
HCFC-22	96.1
HFC-32	78.1
R-410A	71.4
R-744 (CO_2)	31.0

It is important to note that HCFC-22 has a reasonably high critical temperature. The most commonly used high GWP HFC that has replaced HCFC-22 is R-410A. This has one of the lowest critical temperatures and it is likely to perform less efficiently at high ambient temperature than HCFC-22.

For small split and ducted air-conditioning units HFC-32 has been introduced as a lower GWP alternative to R-410A – it has a GWP of 675, compared to 2,088 for R-410A. The critical temperature of HFC-32 is higher than R-410A, so a move to this lower GWP alternative will have benefits under HAT conditions. However, HFC-32 is an A2L lower flammability refrigerant (see Kigali Fact Sheet 10 for details about flammability) and it may not be applicable in larger systems in many countries.

Propane can offer high efficiency, but it is an A3 higher flammability refrigerant and can only be considered for very small systems.

R-744 has a much lower critical temperature than any other commonly used refrigerant. For air-conditioning it needs to operate as a "transcritical" cycle[2] (heat is rejected above the critical temperature). This makes R-744 less efficient and hence unsuited to most air-conditioning in HAT conditions.

The biggest challenge is for medium and large sized multi-split air-conditioning equipment, including variable refrigerant flow (VRF) systems, where a flammable refrigerant might not be applicable and where R-410A is not well suited to high ambient operation.

Larger chilled water plants for building air-conditioning pose much less of a problem. As the water chiller is usually located in a restricted access location (e.g. a special machinery room or a roof-top) it is possible to consider a range of refrigerants including flammable options such as HFO-1234ze or R-290. These have reasonably high critical temperatures which make then well suited to operation at high ambient temperature. For very large chillers, low pressure refrigerants such as HFO-1233zd are applicable. These have very high critical temperatures and can have very high energy efficiency.

Compressor discharge temperature. Another important characteristic is the compressor discharge temperature. Under HAT conditions the compressor of an air-conditioning system needs to operate across a greater pressure ratio than would occur in a milder climate. This causes the discharge temperature from the compressor to reach a higher level. In some circumstances this creates extra technical problems that can reduce the reliability of the compressor.

Very high discharge temperatures can be mitigated with extra cooling of the compressor, although this adds to capital cost and can reduce energy efficiency. It is important that designers ensure that the compressor discharge temperature remains within acceptable limits.

[2] See Kigali Fact Sheet 14 for a description of transcritical, sub-critical and cascade cycles

On-going Research, Testing and Development:

In recognition of the importance of finding a high efficiency low GWP option for air-conditioning systems, there is a lot of development work being undertaken by equipment manufacturers and refrigerant producers. There are also several independent testing programmes underway, including:

- PRAHA: Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries
- EGYPRA: Egyptian Project for Refrigerant Alternatives
- ORNL: the Oak Ridge National Laboratory High-Ambient-Temperature Evaluation Program for Low-Global Warming Potential (Low-GWP) Refrigerants
- AREP: the AHRI Low GWP Alternative Refrigerants Evaluation Program

These independent tests show how different refrigerants perform under HAT conditions. The latest results from these test programmes can be accessed via http://ozone.unep.org

The HAT Exemption:

The Kigali Amendment includes an exemption mechanism that can be used in countries with high ambient temperatures for certain applications that cannot use low GWP alternatives. The HAT exemption is an additional exemption process to the Critical Use and Essential Use exemptions that are included in the Montreal Protocol and could be applied to HFC applications.

Definition of HAT: For the HAT exemption to apply, a country must have an average of at least two months per year over ten consecutive years with a peak monthly average temperature above 35ºC[3].

Countries identified: The following countries have been assessed as meeting the above HAT definition: Algeria, Bahrain, Benin, Burkina Faso, Central African Republic, Chad, Côte d'Ivoire, Djibouti, Egypt, Eritrea, Gambia, Ghana, Guinea, Guinea-Bissau, Iran (Islamic Republic of), Iraq, Jordan, Kuwait, Libya, Mali, Mauritania, Niger, Nigeria, Oman, Pakistan, Qatar, Saudi Arabia, Senegal, Sudan, Syrian Arab Republic, Togo, Tunisia, Turkmenistan, United Arab Emirates.

Registering for the HAT exemption: to use the exemption a Party must be in the list above and must have formally notified the Secretariat of its intent to use this exemption no later than one year before the HFC freeze date, and every four years thereafter should it wish to extend the exemption.

Equipment types covered by HAT exemption:

(a) Multi-split air conditioners (commercial and residential)

(b) Split ducted air conditioners (commercial and residential)

(c) Ducted commercial packaged (self-contained) air-conditioners

Adjustment of equipment covered: the Technology and Economic Assessment Panel and outside experts on high ambient temperatures will assess the suitability of HFC alternatives and recommend sub-sectors to be added to or removed from the above list and report this information to the Meeting of the Parties. These assessments will take place periodically starting four years from the HFC freeze date and every four years thereafter.

Reporting: any party operating under the HAT exemption must report separately its production and consumption data for the sub-sectors to which the exemption applies.

[3] This definition is based on spatially weighted average temperatures deriving the daily highest temperatures, using the Centre for Environmental Data Archival: http://browse.ceda.ac.uk/browse/badc/cru/data/cru_cy/cru_cy_3.22/data/tmx

OzonAction Kigali Fact Sheet 10

OzonAction

UN environment

Technical Issues: Flammability

Background: The phase-down in the production and consumption of HFCs under the Kigali Amendment will ultimately lead to an 85% cut in the amount of HFCs that can be sold globally. To achieve such significant cuts, the users of HFCs will need to start utilising alternative fluids with much lower global warming potentials (GWPs[1]) than the current HFCs. Many of the low GWP alternatives[2] to HFCs are flammable – this creates potential safety issues and may restrict their usage. Safe and successful application of flammable refrigerants can be achieved providing the related safety issues are properly addressed. This Fact Sheet provides guidance on the impact of using flammable HFC alternatives.

Most HFCs are non-flammable and this is a characteristic that makes HFCs a popular choice for many end user applications. Being non-flammable makes it relatively easy to manufacture, install and maintain equipment such as refrigeration and air-conditioning (RACHP) systems. If some non-flammable refrigerant leaks, there will be no risk of fire. Similarly, an aerosol using a non-flammable HFC propellant may be safer to use in circumstances where there may be a source of ignition.

One of the reasons that most HFCs are non-flammable is that their molecular structure is very stable. Unfortunately, this property also gives HFCs a high GWP. Low GWP alternatives usually have less stable molecules – this results in many alternatives being flammable.

The Spectrum of Flammability: Prior to the Kigali Amendment there were plenty of non-flammable fluids available and a simplistic approach to flammability was used. If a flammable fluid is undesirable, many safety codes and standards took a conservative view and stated that flammable fluids cannot be used.

This simplistic approach is not ideal when there are fewer non-flammable fluids to choose from. To make more widespread use of low GWP alternatives, it is important to recognise that there are widely varying "levels of flammability". There is a continuous spectrum of flammability which includes:

- **Higher flammability fluids** – these are very easy to ignite and can burn with explosive impacts.
- **Flammable fluids** – these are more difficult to ignite, but once ignited will continue to burn and could create a significant hazard.
- **Lower flammability fluids** – these are very difficult to ignite, burn "gently" and might be extinguished when the source of ignition is removed. Mildly flammable fluids create a smaller fire risk than an equivalent amount of a more flammable fluid.
- **Non-flammable fluids** – cannot be ignited.

Some important international refrigeration safety codes recognise this spectrum of flammability. For example ISO 817, ISO 5149 and EN 378 include four distinct flammability classes. Unfortunately, not all standards take this approach; some simply refer to substances as being either non-flammable or flammable. This means that lower flammability fluids are treated in the same way as higher flammability ones, severely restricting the safe application of some flammable fluids.

Flammability Parameters:

A problem faced by both the authors of safety codes and users of flammable fluids, is that flammability is a complex issue and it is not easy to find a simple way of defining a safe operating envelope for each fluid. Flammability can be measured in a number of ways. The most important parameters include:

1. **LFL, lower flammability limit.** LFL is the minimum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.
2. **UFL, upper flammability limit.** UFL is the maximum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.

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[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

[2] See Kigali Fact Sheet 3 for further information on low GWP alternatives

3. **HoC, heat of combustion**. HoC is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions.
4. **BV, burning velocity**. The BV is the speed at which a flame propagates.
5. **MIE, minimum ignition energy**. The MIE indicates how much energy must be in an ignition source (e.g. a spark or naked flame) to initiate ignition of a gas or vapour.

Some safety codes use LFL, HoC and BV to define the four flammability classes, summarised in Table 1.

Table 1: Flammability Classes in ISO 817, ISO 5149 and EN 378

Flammability Class		**Lower Flammability Limit** **LFL** kg/m^3	**Heat of Combustion** **HoC** MJ/kg	**Burning Velocity** **BV** cm/s
3	Higher flammability	<0.1	or >19	n/a
2	Flammable	>0.1	and <19	n/a
2L	Lower flammability	>0.1	and <19	<10
1	Non-flammable	Cannot be ignited		

The flammability issue is made even more complicated by various other effects that influence combustion. Three important examples are:

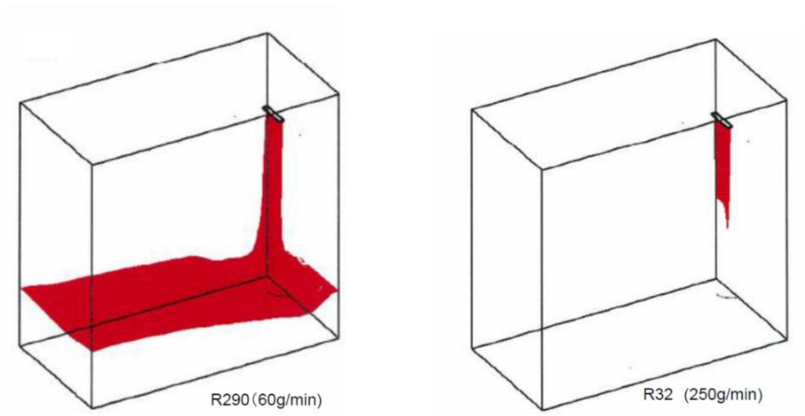
1. The exact geometry of an ignition source can change the MIE.
2. High air humidity can increase the burning velocity of some fluids.
3. A dilution effect occurs when a leaking gas mixes with the air around it.

Figure 1 illustrates how dilution occurs. For a Class 3, higher flammability vapour, the LFL is low (i.e. there only needs to be a small amount of the gas mixed with air for ignition to be possible) and a lot of dilution must occur before the gas concentration drops to below the LFL. For Class 2L lower flammability vapour, the LFL is much higher and dilution below the LFL can occur much more quickly. In this example, the higher flammability propane leak rate is only a quarter of the leak rate for lower flammability HFC-32, but it creates a much greater “ignition risk footprint” (the red area).

These issues have been discussed to illustrate the high complexity of the flammability issue. Safety codes must take a conservative approach in the absence of sufficient technical data.

Figure 1: Modelling of leakage and areas of gas concentration above the LFL[3]

Prediction of the extent of the flammable region, when R-290 (propane, flammability class 3) and HFC-32 (flammability class 2L) leak from a wall-mounted RACHP unit. The areas shown in red represents the zone where the vapour could ignite. Note, the R-290 leak is 60 g/min, whilst the HFC 32 leak is over 4 times larger at 250 g/min.



[3] Osami Kataoka, JRAIA, January 2013, “Flammability of 2L Class Refrigerants “

Likelihood and Severity of Risks: It is important to distinguish between the **likelihood** of ignition and the **severity of the consequences** of ignition. The likelihood of ignition depends significantly on the LFL and the MIE:

- A higher flammability fluid has a low LFL (i.e. there only needs to be a small amount of the gas mixed with air for ignition to be possible) and a low MIE (i.e. a low energy ignition source such as a small spark will cause ignition).
- A lower flammability fluid has a higher LFL – this means there will be a smaller area in which there is risk of ignition (in most normal circumstances, as illustrated in Figure 1). It also requires a much higher MIE, which means there needs to be a much more powerful ignition source located in the risk of ignition area.

The severity of the consequences of ignition depends significantly on the BV and HoC:

- A higher flammability fluid has a high BV – this can lead to explosive ignition within a cloud of gas that is above the LFL. If the HoC is also high, significant damage might be caused.
- A lower flammability fluid has a low BV – if ignition occurs, the burning takes place slowly. Often burning cannot be sustained if the ignition source is removed.

Flammability Class 3 gases (higher flammability) such as propane exhibit both a high likelihood of ignition and a high severity of consequences following ignition.

Flammability Class 2L gases (lower flammability) such as HFO-1234yf or HFC-32 are difficult to ignite (high LFL and high MIE) and their low BV makes the consequences of ignition much less severe.

Table 2 illustrates the variation in some of the key flammability characteristics discussed above.

Table 2: Examples of Key Parameters

Fluid	Flammability class	LFL kg/m^3	MIE [4] mJ	HoC MJ/kg	BV cm/s
Propane	3	0.038	0.3	46	43
HFC-152a	2	0.130	10	16	23
Ammonia	2L	0.116	100	19	7
HFC-32	2L	0.307	1000	9	6
HFO-1234yf	2L	0.289	5000	9	1.5

It is interesting to note that ammonia has been widely used in large industrial systems for many years. It is a Class 2L, lower flammability fluid. There are very few documented cases of fire following an ammonia leak (due to the difficulty of ignition).

Ultra-low GWP fluids such as HFO-1234yf and moderate GWP fluids like HFC-32 are important alternatives that could help meet the Kigali Amendment HFC phase down targets. The data in Table 2 indicates that these fluids are much more difficult to ignite than ammonia (much higher MIE and LFL) and that consequences of ignition are more limited (low BV and low HoC). These are encouraging characteristics, although it must be stressed that until there is more operating experience with these new refrigerants it is difficult to define the safe "operating envelope" for fluids of this type.

HFC-152a has a higher LFL and lower HoC than ammonia. Based on previous safety codes that would indicate that HFC-152a is "less flammable" than ammonia. However, practical experience indicates that HFC-152a is much more readily flammable than ammonia. This can be explained by the low MIE (making ignition much easier) and the high BV (making the consequences more severe). This shows the importance of avoiding a simplistic way of categorising flammability.

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[4] These MIE values are only approximate – they can vary considerably depending on test conditions

Current Use of Flammable Fluids: There is already widespread use of flammable fluids as alternatives to both ODS and HFCs. Some well-established examples include the use of:

Higher flammability fluids:

a) iso-butane in domestic refrigerators
b) propane in stand-alone commercial refrigerators
c) pentane for manufacture of PU insulation foam
d) hydrocarbon mixtures as propellants in aerosols

Lower flammability fluids

a) Ammonia in industrial refrigeration plants
b) HFO-1234yf in car air-conditioning
c) HFO-1234ze in water chillers
d) HFC-32 in small split air-conditioning

For the Kigali Amendment to be a success it will be necessary for considerable growth in the use of flammable fluids requiring concerted efforts at both international and national levels.

Dangers related to retrofitting existing equipment: New equipment can be properly designed to use flammable fluids, taking relevant safety issues fully into account. Using a flammable refrigerant to retrofit existing equipment that was designed for a non-flammable fluid, creates significant safety risks and is generally not recommended. At a recent meeting of the Executive Committee, Decision 72/17 was agreed, which stated: "*anyone engaging in retrofitting HCFC-based refrigeration and air-conditioning equipment to flammable or toxic refrigerants and associated servicing, does so on the understanding that they assume all associated responsibilities and risks*"[5]. Bodies under the Montreal Protocol will not take responsibility for any adverse consequences arising from the choice to use flammable refrigerants in equipment not intended for their use.

Actions Required at International Level: Several actions are required including:

1) International standards bodies need to make continuing efforts to update standards to properly reflect the opportunities to safely use flammable fluids in a range of applications, especially in the refrigeration and air-conditioning market. Those standards that do not recognise the spectrum of flammability need to be reconsidered.

2) Research bodies need to carry out more in-depth investigations into the effective and safe use of flammable fluids, to provide evidence to support the update of standards.

3) Equipment manufacturers need to redesign some of their products to make safe use of flammable fluids.

4) Data on the successful use of flammable fluids needs to be disseminated to increase confidence in their further application.

Actions Required in Article 5 Countries: Many A5 countries need to take further actions to support increased use of flammable fluids. In particular:

1) Raise awareness and improve understanding, to explain that flammable fluids can be used safely and were widely introduced in some markets during CFC phase-out.

2) Ensure that training is available for installation and maintenance technicians

3) Ensure that specialised equipment and tools are available (e.g. tools that are design to be used safely in an area where a flammable vapour may be present)

4) Assess any national or local legislation / standards that may need to be updated to be harmonised with updated international safety standards.

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[5] See www.multilateralfund.org/72/English/1/7247.pdf

Barriers to Successful Implementation

Background:

It is recommended that Montreal Protocol Parties each prepare a national HFC phase-down strategy as part of the Kigali Amendment implementation process. Details about doing this are given in Kigali Fact Sheet 6. It is useful to understand some of the most common barriers to implementation, so that these can be addressed as early as possible. The most important barriers are discussed in this Fact Sheet, including:

1) Unavailability of new fluids and technologies
2) High costs of new fluids and technologies
3) Lack of technician training
4) Restrictive safety codes and standards

Unavailability of fluids and technologies:

The various lower GWP[1] alternatives to HCFCs and HFCs have been summarised in Kigali Fact Sheet 4. The markets using HCFCs and HFCs are quite complex and there are numerous lower GWP fluids (both as pure substances and blends) being used in the wide range of different applications. A key concern that has been raised by many Article 5 countries is whether the latest lower GWP technologies will be available outside of the non-Article 5 countries with the fastest HFC phase-down schedules.
This is a reasonable concern and must be addressed during the development of an HFC phase-down strategy. This is a "chicken and egg" situation; if there is no demand for a low GWP product in a specific country, then equipment suppliers will not market such products. However, if there are no products being marketed, there will be no demand! Refrigerant manufacturers and equipment suppliers are keen to sell their products in new markets – but they need sufficient demand to justify the investments.

This barrier can be overcome by carefully targeting appropriate markets during the development of the HFC phase-down strategy. It is possible to identify several markets where low GWP alternatives are already well established in some non-Article 5 markets. For example:

- Domestic refrigerators using hydrocarbon refrigerants
- Small integral refrigerated retail displays (e.g. ice cream freezers and bottle coolers) using hydrocarbon or CO_2 refrigerants
- Small split air-conditioning using HFC-32
- Car air-conditioning using HFO-1234yf

With the encouragement of the National Ozone Unit and the cooperation of key equipment supply stakeholders from these market sectors, it will be possible to stimulate demand in a new geographic region. Some of these markets have the additional benefit that they are dominated by large international equipment suppliers (especially the car air-conditioning and small split air-conditioning markets). These companies are already supplying low GWP technologies in large quantities to certain non-Article 5 countries and will be keen to use their latest technologies in new markets. Small refrigerated retail displays are often supplied directly by major food and drink manufacturers (e.g. ice cream and soft drink manufacturers) that have global environmental programmes that include avoiding the use of HFCs[2]. There would also be benefits for neighbouring countries to cooperate to engage with relevant stakeholders to stimulate the market in a larger geographic area.

This approach may not be appropriate in all circumstances (e.g. for markets where lower GWP technologies are currently less mature or in very isolated geographic areas), but it highlights the potential benefits of developing a good phase-down strategy and of good stakeholder engagement.

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[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

[2] For example, **Refrigerants, Naturally!** is an initiative of international companies (including Coke, Pepsi, Unilever and Red Bull) which promote a shift in technology towards ultra-low GWP natural refrigerants and high energy efficiency. www.refrigerantsnaturally.com

High costs of new fluids and technologies:

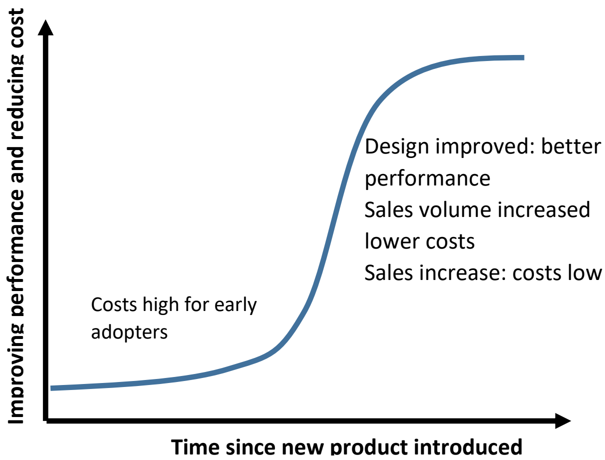
Linked to the concern that low GWP technologies will be unavailable is a further concern that even if they are available, they will be prohibitively expensive. Again, this is a reasonable concern that can be overcome if (a) the technology is reasonably mature and (b) there is a high demand for the low GWP products.

It should not be assumed that all low GWP products will cost more than the high GWP products being replaced. Some of the low GWP alternatives already used have been introduced voluntarily, with drivers such as reduced cost and improved efficiency. For example, domestic refrigerators using iso-butane in place of HFC-134a can be manufactured at slightly reduced cost and with improved energy efficiency. The switch away from CFC propellants in many aerosol products was also done at reduced cost. If the demand for these products is high, cost should not be a barrier.

This situation is not true for all low GWP technologies. In the car air-conditioning market, HFO-1234yf has been introduced as a low GWP alternative to HFC-134a. Currently it is much more expensive than HFC-134a. However, the new HFO refrigerant has only been produced in large volumes for around 3 years and there is currently a supply shortage. Over the next three to five years it is expected that several new production plants will come on stream and the price is expected to fall significantly.

In Kigali Fact Sheet 6 a “product-maturity curve” was used to illustrate the importance of optimum timing for the introduction of new low GWP products:

- Early adopters face extra costs – Article 5 countries can wait until these costs have been absorbed
- The optimum time to adopt the new technology is when costs are low and performance is improved
- A “late start” to a phase-down action could create extra costs over an “optimum start”. Innovation by manufacturers will be directed towards products and equipment that use low GWP alternatives. Improvements such as higher energy efficiency will be made to these products, while the older products using high GWP fluids might “stagnate” and create higher running costs and worse environmental impact.



These issues emphasise the importance of developing a good phase-down strategy, of engaging with relevant stakeholders and, where possible, engaging in regional initiatives with neighbouring countries.

Lack of technician training: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An important barrier relates to the need for improved training, especially for technicians carrying out installation and maintenance work. Most technicians working on RACHP equipment are only familiar with non-flammable and non-toxic HCFC and HFC refrigerants. Many of the low GWP alternatives have more “difficult” properties related to flammability, toxicity and operating pressure. The most important areas for training relate to:

1) Using higher flammability refrigerants such as R-290 (propane) and R-1270 (propylene).
2) Using lower flammability refrigerants such as HFO-1234yf and HFC-32.
3) Using toxic refrigerants such as R-717 (ammonia)
4) Using high pressure refrigerants, in particular R-744 (CO_2)
5) Using unfamiliar refrigeration cycles, in particular transcritical cycles using R-744 (CO_2)

In a similar way to the discussion above on the availability of low GWP technologies, there is a “chicken and egg” situation in relation to training. Trained technicians are required before some of the new technologies can be widely used, but training will be ineffective if there is no market demand for the newly trained technicians. This dilemma needs to be considered in the development of the HFC phase-down plan.

There is plenty of excellent training material available that addresses the five requirements listed above, together with other related training issues. Three particularly good sources of training material are:

- **UN Environment OzonAction Training Guides:** Several useful guide books on refrigerant handling and training of technicians have been produced by OzonAction. See Kigali Fact Sheet 14 for references to these publications
- **REAL Alternatives**: blended learning for alternative refrigerants. This is an excellent set of resources developed to address the training barrier in Europe. The free multi-lingual learning materials were launched in 2015 and are now available for individual on-line training or for use as classroom training materials. They include e-learning content, electronic tools and a comprehensive library gathered from existing resources. The e-library contains over 100 useful industry resources. Details can be found at: www.realalternatives.eu
- **Equipment manufacturers training:** companies that supply equipment using low GWP alternatives usually have good training materials available that is targeted at their specific designs of equipment. Training from equipment manufacturers can be an excellent way of “kick-starting” technician training in certain market sectors. For example, some manufacturers of small split air-conditioning using HFC-32 (a lower flammability refrigerant) will only sell their products via contractors that have been on their in-house technician training. This approach has also been adopted by manufacturers of transcritical CO_2 refrigeration systems for supermarkets.

Restrictive safety codes and standards:

The phase-down of HFCs will require end users in the RACHP, foam and aerosol markets to use alternative fluids with lower GWPs. In many cases this necessitates a switch from a non-flammable / non-toxic fluid to a fluid that will require some technical adaptations of the equipment. In particular, many of the low GWP alternatives being proposed might be flammable, toxic or operate at high pressure.

Various standards and pieces of legislation that affect the use of lower GWP alternatives were written at a time when there was no restriction on the GWP or ODP of the fluids available. This often led to a conservative approach being adopted by standards committees; for example, in certain specific applications the conservative approach to ban the use of any flammable fluid was adopted because a non-flammable option was widely available.

It is widely recognised that many current safety standards will restrict the use of low GWP alternatives. At the 28th Meeting of the Parties of the Montreal Protocol in Kigali, it was agreed that this is a priority issue and there are significant international efforts underway to try and revise relevant standards to help maximise the uptake of low GWP alternatives.

In relation to implementation of the Kigali Amendment in an individual country, it is important to recognise that there might be two different “levels” of safety standards / legislation to take into account:

- At international level, there are various safety standards that relate to the use of RACHP equipment. Some examples of important standards are listed in the table on the next page.
- At national level there are two different possibilities:
  1. The international safety standards are used directly, without any national-level changes
  2. National safety standards, national safety legislation or more localised rules are in place, which take precedence over the international standards.

During the development of the national HFC phase-down strategy it will be important to understand how RACHP safety standards are defined. If international standards are used directly the situation is relatively simple – the revised international standards can be adopted as soon as they are published (see details of international revision plans below).

The situation can be more difficult if national or local legislation applies. In many cases, national legislation will make reference to relevant international standards, but may be more restrictive because:

a) National legislation is harmonised with an out-of-date version of an international standard. It is common for national legislation to lag several years behind changes to international standards.

b) National legislation includes extra restrictions and bans which are not in the international standards.

It is recommended that the National Ozone Unit liaises closely with the Government officials responsible for safety legislation to establish what rules apply and whether these create barriers that are more restrictive than the current international standards. A situation that exists in some countries is that local (e.g. municipal) fire departments have authority to ban types of equipment that create a fire risk. The rules being applied could vary from one municipality to another, meaning that a piece of RACHP equipment with a flammable refrigerant might be banned in one town but allowed in another. This is clearly not a desirable situation.

It must be stressed that maintaining high standards of safety remains a priority. Safety standards will not be revised to allow significantly higher levels of risk. The proposed revisions are intended to remove unnecessarily conservative restrictions, whilst still ensuring a suitable level of safety.

International Safety Standards

The landscape of international safety standards for RACHP applications is very complex. The relevant standards fall into three main groups:

a) Generic refrigeration safety standards, which can be applied to any RACHP application
b) Product standards that apply to a narrow range of RACHP products
c) General standards that apply to RACHP and other types of equipment

Following the concerns about standards identified at the Kigali MOP, various initiatives are underway to investigate suitable revisions to the international RACHP standards. The Montreal Protocol Technical and Economic Assessment Panel (TEAP) have set up a special Task Force to review safety standards and the Ozone Secretariat is organising a workshop on safety standards to be held in July 2017 before OEWG 39 in Bangkok. These are important opportunities to cooperate with the relevant standards committees. However, it must be recognised that the process of updating safety standards is usually very slow and laborious.

Examples[3] of International Safety Standards for RACHP Applications		
Generic RACHP standards	ISO 5149	Refrigerating systems and heat pumps -- Safety and environmental requirements
	EN 378	
RACHP Product standards	IEC 60335-2-24	Safety requirements for household and similar electrical appliances
	IEC 60335-2-40	Safety requirements for heat pumps, air conditioners, dehumidifiers
	IEC 60335-2-89	Safety requirements for commercial refrigerating appliances
Other Standards	ISO 13971, ISO 14903	Pressure equipment (vessels, pipes, valves, etc.)
	ISO 4126	Pressure safety devices
	IEC 60079	Protection of equipment within potentially flammable areas

[3] Note: this is a short list of some important standards – numerous other standards may be applicable. See Kigali Fact Sheet 14 for further references on safety standards and on barriers to implementation

OzonAction Kigali Fact Sheet 12

Interactions with Other Policy Measures

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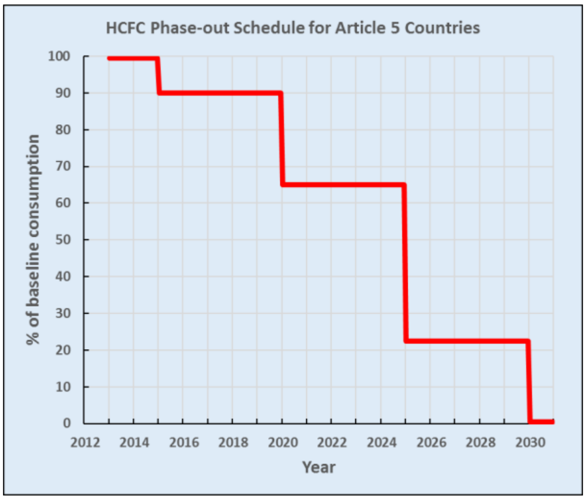
Background: The Kigali Amendment to the Montreal Protocol specifically targets the use of high GWP HFC refrigerants and will lead to an 85% reduction in the production and consumption of HFCs. This new policy interacts with a number of other existing policy measures. In this Fact Sheet the most important interactions are described; in particular interactions with:

1) The phase-out of HCFCs
2) Climate change polices
3) Energy efficiency policies
4) Safety legislation.

During the development of a national HFC phase-down strategy (see Kigali Fact Sheet 6 for further details), National Ozone Officers and other government officials responsible for the Kigali Amendment need to ensure that they engage with the government and private sector stakeholders who are involved in the implementation of these other policies.

HCFC phase-out: During the development of a national HFC phase-down strategy, it is very important to understand the interaction of the Kigali Amendment with the plans for the ongoing phase-out of HCFCs under the Montreal Protocol.

All Parties already have legally binding commitments to phase-out consumption of HCFCs. In the case of non-Article 5 countries the HCFC phase-out is already virtually complete. However, Article 5 (A5) countries have only recently begun the phase-out of HCFCs. The phase-out schedule for HCFCs in A5 countries is illustrated in the chart. In the period 2015 to 2019 there is a 10% cut from the HCFC baseline, followed by a 35% cut between 2020 and 2024. In most A5 countries HCFC consumption is currently still high and is not scheduled to fall substantially until after 2024.



Almost all A5 countries have an HCFC phase-out management plan (HPMP) which provides a strategy for switching end user markets away from using HCFCs. In many markets, the non-ODS alternative identified in the HPMP is a high GWP HFC. There is potential for conflict between the existing plans to phase-out HCFCs and the new plans to phase-down the use of high GWP HFCs. It is strongly recommended that the new planning process includes a re-assessment of the timing of HCFC phase-out initiatives to ensure that costs are minimised and that the environmental benefits of both policies are maximised.

As discussed in Kigali Fact Sheet 13, most non-A5 countries have undertaken a 2-step process, first moving from HCFCs to high GWP HFCs and now doing a second conversion to lower GWP alternatives. This was not the best way forward in terms of costs and environmental benefits, but it was logical given the much earlier timetable for phase-out of HCFCs[1] and the availability of non-ODS alternatives at that time. This situation has changed significantly and Article 5 countries can "leap-frog" the high GWP stage and move directly from HCFCs to lower GWP alternatives. In some situations this may require a short delay in the phase-out of HCFCs (see Box 1).

[1] Non-Article 5 countries had their first big cut in HCFC consumption in 2004. At that time the most cost effective HCFC alternatives in many end-use markets were high GWP HFCs.

Box 1: Extract from Montreal Protocol Decision XXVIII/2 (Kigali Amendment)

The importance of the interaction between these policies is recognised in the following extracts from the Decision made in Kigali. This indicates that revisions to HPMP schedules for HCFC phase-out may be acceptable if they allow leap-frogging of the high GWP HFC stage:

To acknowledge the linkage between the HFC and HCFC reduction schedules …. and the preference to avoid transitions from HCFCs to high-GWP HFCs ….;

To also acknowledge these linkages with respect to certain sectors, in particular industrial process refrigeration, … and to be willing to provide flexibility, if no other alternatives are available, in cases where:

a) *HCFC supply may be unavailable from existing allowable consumption…*
b) *it would allow for a direct transition at a later date from HCFCs to low-GWP or zero-GWP alternatives;*

Climate Change Polices: The Kigali Amendment has been put in place to achieve cost-effective greenhouse gas (GHG) reductions. The HFC emission reductions will make a small but useful contribution to each country's target to reduce GHG emissions under the 2015 Paris Agreement of the UN Framework Convention on climate change. It has been estimated that the Kigali Amendment could result in as much as 0.5 degrees centigrade reduction in global temperatures compared to business-as-usual. The National Ozone Units should coordinate closely with the broader climate change policy unit and ensure that there is recognition of any HFC emission reductions in the country's target for GHG emission reductions, via the Intended Nationally Determined Contribution (INDC).

Energy Efficiency Policies: It is very important to recognise the interaction between measures under the Kigali Amendment and national energy efficiency policies. The largest user of HFCs are the wide range of different appliances used for refrigeration, air-conditioning and heat pumps (RACHP). These appliances are also significant users of electricity. The electricity used is a dominant part of the lifecycle cost of all RACHP systems. It is also a significant source of GHG emissions. RACHP systems have two distinct types of GHG emission:

- **Direct GHG emissions** created by leakage of refrigerants with a high GWP, during normal operation, maintenance and servicing and at equipment end-of-life.
- **Indirect GHG emissions** created at the power stations supplying the electricity.

It is the indirect emission that is dominant for most RACHP equipment – even if high GWP refrigerants are used, providing leakage rates are not excessively high. When HCFCs and high GWP HFCs are replaced by lower GWP alternatives it is essential to have energy efficiency policies in place that ensure equal or, preferably, improved energy efficiency. If this does not happen there is a risk that the reduction in HFC usage could lead to an "environmentally perverse" result where the total GHG emissions actually go up. Using high GWP HFCs such as R-404A in supermarket refrigeration systems and R-410A in small air-conditioning systems is no longer the optimum choice in terms of energy efficiency. Lower GWP alternatives that are already used in some non-Article 5 countries will deliver improved efficiency, resulting in lower electricity costs and lower GHG emissions.

Safety Legislation: Some of the low GWP alternatives to HCFCs and HFCs are flammable. The issue of flammability is discussed in Kigali Fact Sheet 10. Some international safety codes and national safety legislation create barriers to the widespread uptake of flammable refrigerants. These barriers are discussed in Kigali Fact Sheet 11. A significant effort is being made at international level to update international safety codes to allow more widespread use of flammable refrigerants whilst also maintaining a high level of safety. It will be important for each party to identify whether any barriers exist at national level e.g. national safety legislation or regional / municipal fire safety standards. National Ozone Officers need to engage with the government department responsible for such legislation to try and ensure rapid harmonisation of national legislation with updated international safety codes.

OzonAction Kigali Fact Sheet 13

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UN environment

Benefits of Rapid Action

Background: The timetable for the phase-down of HFCs agreed under the Kigali Amendment is described in Kigali Fact Sheet 5. For non-Article 5 countries the phase-down begins with the first cut in HFC consumption in 2019, based on a baseline consumption for the period 2011 to 2013. For Article 5 countries, the phase-down timetable is delayed, to allow extra time for:

a) baseline data to be collected (many Article 5 countries do not have historic data for HFC usage, so a later baseline period is required)

b) lower GWP technologies to reach maturity and become widely available in Article 5 countries.

As detailed in Kigali Fact Sheet 5, there are two groups of Article 5 countries:

- A5 Group 1 has a baseline period 2020 to 2022, a freeze in HFC consumption in 2024 and a first cut in consumption in 2029.
- A5 Group 2 has a baseline period 2024 to 2026, a freeze in HFC consumption in 2028 and a first cut in consumption in 2032.

Some Article 5 countries consider these timetables to be rather conservative and are investigating the possibility of achieving a faster transition away from HFCs. This Fact Sheet highlights the benefits of rapid action in terms of the potential to avoid costs and to achieve an improved environmental outcome.

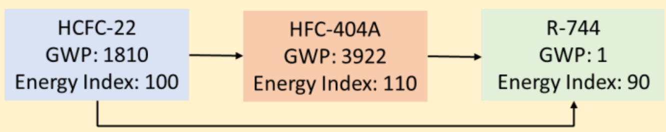
High GWP technologies can be avoided: It is very important to recognise that the "journey" from ozone depleting substances to zero OPD low GWP alternatives adopted in non-Article 5 countries was far from optimal. Because of the rapid phase-out of ODS in non-Article 5 countries there was an urgent need for alternatives and this led to the introduction of high GWP HFCs. Non-Article 5 countries are now going through a second technology transition to replace high GWP gases with lower GWP alternatives. As illustrated in the adjacent box, the use of high GWP HFCs not only led to significant direct global warming emissions, but also created extra energy consumption, leading to the emission of further CO_2 from power stations.

Article 5 countries are at a different stage on their ODS phase-out journey. HCFCs are still in widespread use and the high GWP HFCs have only recently begun to be introduced in these countries. Article 5 countries can significantly benefit by not repeating the mistakes made in non-Article 5 countries and avoiding the use of high GWP refrigerants.

At the time that refrigerants such as R-404A were first adopted, they represented the best technical option available. This is no longer the case. There are much better alternatives with lower GWP and improved energy efficiency. High GWP refrigerants should be avoided when better options are readily available. Article 5 countries should avoid using old and inefficient technologies that are no longer used in non-A5 countries.

Transition from HCFC-22 in food retail refrigeration

In most non-Article 5 countries supermarket refrigeration systems switched from HFC-22 to HFC-404A in the late 1990s, resulting in the use of a very high GWP refrigerant and poor energy efficiency. A second transition is now underway to ultra-low GWP options



Article 5 countries should consider a single step transition avoiding use of the high GWP R-404A. A crucial secondary benefit is that energy efficiency can be improved if R-404A is avoided. In Article 5 countries with a shortage of electricity supply this could reduce future investment in power stations.

High GWP technologies will not be "state-of-the-art": Refrigeration and air-conditioning products are steadily being improved in performance by equipment producers that want to ensure that their products are the best available in the market. In particular, energy efficiency of the latest products can be considerably better than the efficiency of products designed a few years earlier.

Equipment producers are working hard to produce new products that use lower GWP refrigerants, in response to the Kigali Amendment and to other regional legislation on HFCs, such as the rapid phase-down of HFCs in the European Union. Most producers are taking the opportunity to upgrade their products in relation to energy efficiency as well as to use lower GWP refrigerants. The older products using HCFCs or high GWP HFCs are not upgraded and become a "stagnant" out-of-date design. If Article 5 countries continue to use high GWP products for the next 10 years, there is a big risk that the new equipment being purchased will fall a long way short of state-of-the-art designs in terms of energy efficiency and other design features.

This issue is especially important for small air-conditioning systems. There is massive growth in the use of air-conditioning systems in many Article 5 countries. The electrical load from air-conditioning systems is a significant proportion of the total electrical load for the whole country. To minimise the investments required in power stations and electricity distribution it is important that state-of-the-art high efficiency air-conditioning units are being purchased. In the adjacent example, the 25% energy saving created through use of the latest lower GWP technology is typical of the improvements made over recent years. Older technologies must be avoided.

Efficiency of small split air-conditioning

Split air-conditioning units are widely used for cooling of domestic and commercial buildings. In Article 5 countries HCFC-22 is still widely used in new equipment, but it has become a "stagnant" technology. Most HCFC-22 systems use fixed speed compressors and old heat exchanger designs. The latest split air-conditioning units use the lower GWP HFC-32 refrigerant and include many new design features such as variable speed compressors and micro-channel heat exchangers. The latest units have considerably better energy efficiency. In the example illustrated below the state-of-the-art unit is 25% more efficient than the old technology.

Old technology	State-of-the-art
HCFC-22	HFC-32
GWP: 1810	GWP: 675
Energy Index: 100	Energy Index: 75

Getting early access to financial support: Article 5 countries that plan to take rapid action over HFC phase-down will be able to get best access to funding support.

In September 2016, a group of philanthropic organisations and other donors pledged US$ 80 million to help countries in need of assistance to implement an ambitious HFC amendment and improve energy efficiency. This funding will be targeted specifically at countries taking early action.

The Montreal Protocol Multilateral Fund (MLF) will provide funding to help Article 5 countries with the transition to low GWP alternatives. The precise details of new MLF funding arrangements are still being developed. However, the considerable amount of extra funding will be targeted at projects that involve the use of low GWP alternatives. Countries wishing to make use of this funding in the early years need to be making plans for rapid action.

Early contribution to national climate change targets: It is recognised that reducing use of high GWP HFCs and HCFCs is one of the most cost effective ways of reducing greenhouse gas emissions. Under the Paris Agreement on climate change, all countries have made an Intended Nationally Determined Contribution (INDC) specifying the level of GHG emission reduction that the country will aim to achieve. Reducing the use and emissions of HFCs and HCFCs through rapid action can make a useful early contribution to these emission reduction targets.

OzonAction Kigali Fact Sheet 14

Glossary and References

This Fact Sheet provides definitions of terms and acronyms used in OzonAction Kigali Fact Sheets together with a list of links to useful sources of information. The Fact Sheet is split into 2 sections:

Part A: Glossary of terms related to fluid properties

Part B: Glossary of other terms used in the Kigali Fact Sheets

Part C: References to further information sources

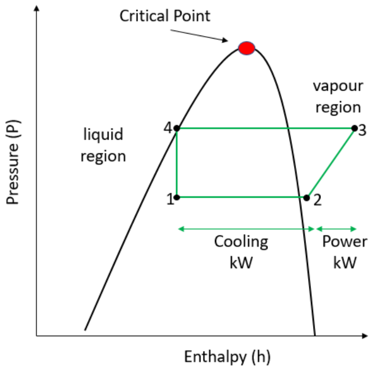
Part A: Fluid properties

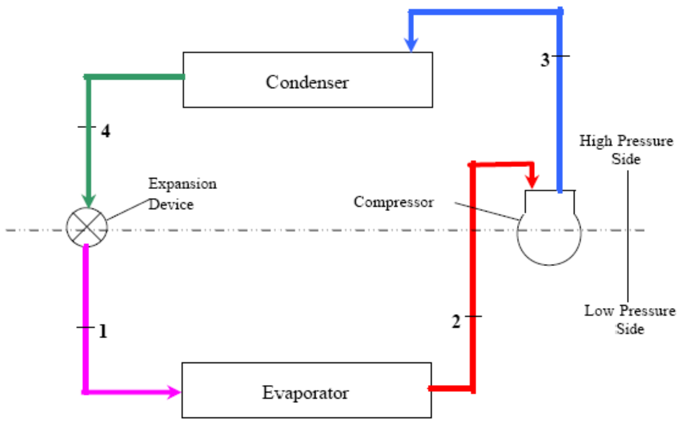
Term / Acronym	Definition
Fluorocarbons	
CFC	Chlorofluorocarbon: a family of chemicals containing chlorine, fluorine and carbon.
HCFC	Hydrochlorofluorocarbon: a family of chemicals containing hydrogen, chlorine, fluorine and carbon.
HFC	Hydrofluorocarbon: a family of chemicals containing hydrogen, fluorine and carbon.
HFO	Hydrofluoroolefin: a family of chemicals containing hydrogen, fluorine and carbon, with a double bond in the molecule.
Other fluids	
HC	Hydrocarbon: a family of chemicals containing hydrogen and carbon.
DME	Dimethyl ether: an HFC alternative used in foams and aerosols
Non-organic fluids	Non-organic chemicals e.g. ammonia (R-717) and CO_2 (R-744)
Environmental impacts	
GHG	Greenhouse gas A gas that makes a contribution to global warming.
GWP	Global Warming Potential. The GWP compares the global warming impact of a gas to CO_2 which is defined as having a GWP of 1. The GWPs of fluorocarbons are not certain and have been updated by scientists on a regular basis during the last 20 years. The Intergovernmental Panel on Climate Change has published a number of sets of GWPs in their Assessment Reports. The GWP values used in the Kigali Amendment and in the Kigali Fact Sheets are based on the 100 year AR 4 (Assessment Report 4) values.
GWP-weighted	An alternative term for tonnes CO_2e (see definition below)

Term / Acronym	Definition
ODP	Ozone Depletion Potential The ODP compares the impact on the ozone layer of a gas compared to CFC-11 which is defined as having an ODP of 1.
ODP tonnes	A way of presenting the total amount of ozone damage caused by a quantity of an ODS. ODP tonnes = tonnes of gas x ODP
ODS	Ozone Depleting Substance A gas that can cause damage to the stratospheric ozone layer.
Tonnes CO_2 equivalent	A way of presenting the total contribution to climate change caused by a quantity of a GHG. Tonnes CO_2e = tonnes of gas * GWP
Safety related terms (from refrigeration safety standards)	
Toxicity classes	Refrigeration safety standards use 2 toxicity classes: A lower toxicity e.g. HFC-134a; HC-290 B higher toxicity e.g. R-717 (ammonia)
Flammability categories	Refrigeration standards (e.g. ISO 5149) use 4 flammability categories: 1 No flame propagation e.g. HFC-134a; R-410A 2L lower flammability e.g. HFC-32; HFO-1234yf; R-717 2 flammable e.g. HFC-152a 3 higher flammability e.g. HC-290; HC-600a Category 2L fluids are distinguished from Category 2 by having a low flame velocity (<10 cm/s). The 2L category has only recently been added to ISO 5149 and EN 378 and is not yet referred to in some older standards. Aerosol and foam markets use different flammability categories
BV	Burning velocity
EN	Euro-Norm
HoC	Heat of combustion
IEC	International Electrotechnical Commission
ISO	International Standards Organisation
LFL	Lower flammability limit
MEI	Minimum ignition energy
UFL	Upper flammability limit

Part B: Other terms used in the Kigali Fact Sheets

Term / Acronym	Definition
Article 5 (A5)	Parties meeting the definition given in Article 5 of the Montreal Protocol – in general these are economically developing countries
BAU	Business as usual
Cascade refrigeration cycle	A type of refrigeration cycle, usually used for very low temperature applications, using two separate circuits, each with a different refrigerant.
Condensing unit	A combination of a condenser and compressor. Used in split systems connected to an evaporator in a separate location.
Critical temperature	The critical temperature is a property of a refrigerant fluid. Above the critical temperature there is no distinction between liquid and vapour. Most refrigerants operate below the critical temperature, with change of phase from liquid to vapour an important aspect of the system design. R-744 (CO_2) has a very low critical temperature (31^{o}C) and when used in a vapour compression refrigeration cycle may need to reject heat at a temperature above the critical temperature.
HAT	High ambient temperature. Used in reference to the HAT exemption in the Kigali Amendment, recognising the potential difficulties of designing air-conditioning systems for operation at very high ambient temperatures.
Hermetically sealed	A factory built refrigeration system with all brazed or welded joints. Usually this refers to domestic refrigerators or small stand-alone commercial systems.
HPMP	HCFC phase-out management plan
INDC	Intended Nationally Determined Contribution A country's declared targets for reduction of GHG emissions under the Paris Agreement of the UN FCCC
IPCC	Intergovernmental Panel on Climate Change
MAC	Mobile air-conditioning. This refers to any air-conditioning system used in a vehicle including MACs in cars, buses and trains.
MDI	Metered Dose Inhaler. A specialised aerosol used to deliver respiratory drugs. MDIs use HFC aerosol propellants.
MLF	Multi-lateral fund of the Montreal Protocol
NIK	Not-in-kind. Used to refer to alternative technologies that can replace HFC applications.
Non-Article 5 (non-A5)	Parties not meeting the definition given in Article 5 of the Montreal Protocol – in general these are economically developed countries

Term / Acronym	Definition
Pressure-enthalpy (P-h) diagram	P-h diagrams are widely used by RACHP system designers to represent a refrigeration cycle and to illustrate performance parameters. The vertical axis shows the pressure and the horizontal axis shows “enthalpy” which is related to energy content of the refrigerant. Each refrigerant has a unique P-h diagram, the curved black line representing the boundary between liquid and vapour. The refrigerant under the curve is a mixture of liquid and vapour. The top of the curve is referred to as the critical point. The green lines plotted on the P-h diagram represent a vapour compression refrigeration cycle (see definition and diagram below, which uses the same 4 numbers to represent different parts of the cycle. The enthalpy difference between points 1 and 2 represent the amount of cooling being carried out and the enthalpy difference between points 2 and 3 represent the electric power used by the compressor. 
PU foam	Polyurethane insulation foam
RACHP	Refrigeration, air-conditioning and heat pumps
Split system	A type of refrigeration or air-conditioning system with a cooling evaporator in one location and a compressor / condenser in a different location. Usually used with reference to small air-conditioning systems that use an indoor unit and an outdoor unit.
Stand-alone system	Small factory built refrigeration units that simply need to be connected to an electricity supply. A domestic refrigerator is a stand-alone system. Various types of stand-alone unit are used in food retail and food service.
Sub-critical refrigeration cycle	A refrigeration system with both the evaporator and the condenser operating at a temperature below the critical temperature. Most refrigeration systems operate in this way.
TEAP	Technical and Economic Assessment Panel of the Montreal Protocol
Transcritical refrigeration cycle	A refrigeration system where the evaporator operates below the critical temperature, but the condenser operates as a gas cooler at above the critical temperature. CO_2 systems operate in transcritical mode when the ambient temperature is above around 20°C. They can operate in sub-critical mode at lower ambient temperatures.
UN FCCC	United Nations Framework Convention on Climate Change

Term / Acronym	Definition
Vapour compression cycle	Most refrigeration and air-conditioning systems operate with a vapour compression cycle. The simplest designs consist of 4 main components as shown in the diagram. Low temperature liquid refrigerant (at low pressure) is fed to an evaporator (point 1). It provides cooling as liquid is boiled to vapour (point 2). The vapour is compressed (point 3) and is then able to reject heat in a condenser as it turns from vapour to liquid (point 4). The high pressure liquid passes through an expansion device where the pressure and temperature fall (and a proportion of the liquid flashes off into vapour). The cycle is then repeated. 
VRF	Variable refrigerant flow: a type of split system air-conditioning system used in medium and large sized air-to-air applications. One or more condensing units are connected to a number of indoor units (up to 64). Each indoor unit can be selected for either cooling or heating. Variable speed compressors provide control flexibility.
XPS foam	Extruded polystyrene insulation foam

Part C: References and Source Material

A significant amount of useful background material can be found on the following two websites:

UN Environment OzonAction Website: www.unep.org/ozonaction

Montreal Protocol Ozone Secretariat Website: www.ozone.unep.org

From the **Montreal Protocol Ozone Secretariat**, some documents of particular interest:
Full text of the Montreal Protocol, including the Kigali Amendment: http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/5
15 Technical Fact Sheets about low GWP alternatives to HFCs http://ozone.unep.org/en/hfc-management-documents-2014-onwards
Briefing Note on Ratification of the Kigali Amendment: http://conf.montreal-protocol.org/meeting/oewg/oewg-39/presession/briefingnotes/ratification_kigali.pdf
Frequently asked questions relating to the Kigali Amendment to the Montreal Protocol http://ozone.unep.org/sites/ozone/files/pdfs/FAQs_Kigali_Amendment.pdf
What's next for the Kigali deal to curb potent greenhouse gases? http://web.unep.org/newscentre/whats-next-kigali-deal-curb-potent-greenhouse-gases
Decision XXVII/4: TEAP Task Force Update Report Further Information on Alternatives to Ozone-Depleting Substances http://conf.montreal-protocol.org/meeting/mop/mop-28/presession/Background%20Documents%20are%20available%20in%20English%20only/TEAP_TFXXVII-4_Report_September2016.pdf

From **UNEP OzonAction**, some documents of particular interest:
Good Servicing Practices Phasing out HCFCs in the Refrigeration and Air-Conditioning Servicing Sector (2015) http://www.unep.fr/ozonaction/index.asp#
GTZ Proklima, Good Practices in Refrigeration, second edition 2010 http://www.unep.fr/ozonaction/information/mmcfiles/7431-e-GTZ_refrigeration_manual_2010.pdf
Safe Use of HCFC Alternatives in Refrigeration and Air-conditioning: An Overview for Developing Countries (2015) http://www.unep.fr/ozonaction/information/mmcfiles/7740-e-SafeUseofHCFCAlternativesinRefrigerationandAir-conditioning.pdf

International Standards in Refrigeration and Air-Conditioning - An introduction to their role in the context of the HCFC phase-out in developing countries (2014) http://www.unep.org/ozonaction/Portals/105/documents/7679-e-International_Standards_in_RAC.pdf
National Certification Schemes for Refrigeration and Air-Conditioning Service Technicians: Examples of strategies and requirements for their establishment and operation. (2015) http://www.unep.org/ozonaction/Portals/105/documents/7756-e-UNEP_ASHRAE_National_Certification_Schemes.pdf
Lower-GWP Alternatives in Commercial and Transport Refrigeration: An Expanded Compilation of Propane, CO2, Ammonia and HFO Case Studies (2016) http://www.unep.org/ozonaction/Portals/105/documents/oewg37/1611979_UNEP%20CCAC_2016.pdf
Barriers to the use of Low-GWP Refrigerants in Developing Countries & Opportunities to Overcome These (2010) http://www.unep.fr/ozonaction/information/mmcfiles/7476-e-Report-low-GWPbarriers.pdf
Establishing an HCFC Import Quota System. 2012 http://www.unep.fr/ozonaction/information/mmcfiles/7531-e-HCFC_Quota_system.pdf

OzonAction

OzonAction Kigali Fact Sheet 15

Substances Not Controlled Under the Montreal Protocol

UN environment

NEW

Background:

The Montreal Protocol controls the production and consumption of a range of chemicals that damage the ozone layer (i.e. ozone depleting substances, ODS). In the Kigali Amendment the Protocol was extended to control the production and consumption of HFCs. These are not ODS, but they are very powerful greenhouse gases (GHGs). This Fact Sheet provides details of which substances are controlled under the Montreal Protocol and gives examples of related substances that are not included in these controls.

Controlled Substances:

The Montreal Protocol contains the following definition:

"Controlled substance" means a substance in Annex A, Annex B, Annex C, Annex E or Annex F to this Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance.

The only controlled substances in the original 1987 Montreal Protocol were in Annex A. Annexes B, C, E and F were added as amendments were made to the original Montreal Protocol. For example, under the Kigali Amendment, Annex F was added to include a list of controlled HFCs.

The ODS phase-out schedules vary between substance types and which Annex each substance is listed in. The number of substances listed in relevant Annexes is summarised in the table below. For a full list of each substance see:

http://ozone.unep.org/en/handbook-montreal-protocol-substances-deplete-ozone-layer/5

Table 1: Number of Controlled Substances in Montreal Protocol Annexes

Families of substances	Annex A	Annex B	Annex C	Annex E	Annex F
Chlorofluorocarbons (CFCs)	5	10			
Bromochlorofluorocarbons (Halons)	3				
Hydrochlorofluorocarbons (HCFCs)			40		
Hydrobromofluorocarbons (HBFCs)			34		
Hydrofluorocarbons (HFCs)					18
Single Substances					
Carbon tetrachloride		1			
1,1,1-trichloroethane		1			
Methyl Bromide				1	
Bromochloromethane			1		

The Annexes include reasonably comprehensive lists of substances including many that are used in only tiny quantities. For example, just 5 of the 40 HCFCs listed in Annex C represent well over 95% of world consumption (excluding feedstock applications). However, the Annexes do not include every relevant substance and they do not include other families of gases that might be used as replacements for controlled substances. The most widely used substances in the families listed above are summarised in Table 2.

Table 2: Most commonly used controlled substances	
Chlorofluorocarbons (CFCs)	CFC-11, CFC-12, CFC-113, CFC-114, CFC-115
Bromochlorofluorocarbons (Halons)	Halon-1211, Halon 1301
Hydrochlorofluorocarbons (HCFCs)	HCFC-22, HCFC-123, HCFC-124, HCFC-141b, HCFC-142b
Hydrofluorocarbons (HFCs)	HFC-134a, HFC-125, HFC-143a, HFC-23, HFC-32, HFC-152a, HFC-227ea, HFC-245fa, HFC-365mfc

Substances not controlled under the Montreal Protocol:

There are a small number of ODS and HFCs that are not controlled under the Montreal Protocol. These are therefore not listed in the Protocol's Annexes. These chemicals can be identified as two main categories illustrated with some examples below:

1. **Annual use is negligible and/or the ozone depletion potential (ODP) or global warming potential (GWP) is extremely low**

   Hydrofluoroolefins (HFOs): HFOs are unsaturated fluorocarbons (i.e. molecules with a double bond between two carbon atoms). The presence of the double bond makes the molecule have a very short atmospheric life and a very low GWP. The majority of HFOs are unsaturated HFCs and have GWPs in the range of 4 to 9 and are not controlled under the Protocol. For example, HFO-1234yf, increasingly used in mobile air-conditioning has a GWP of 4.

   Some HFOs are unsaturated HCFCs, with similar very low GWPs and a very low ODP. For example, one of the non-controlled low GWP alternatives to HFCs, HFO-1233zd, is an unsaturated HCFC with an ODP of 0.0003 which is around 100 times lower than the ODP of HCFC-22 and 3000 times lower than CFC-12.

   Other low GWP HFCs: Not all HFCs are covered by the Kigali Amendment, only those listed in the relevant Annex are controlled. For example, HFC-161 (GWP=12) is not listed in Annex F and is therefore not under the control of the Montreal Protocol.

   Dichloromethane (DCM): While previously thought to have little impact on ozone depletion, dichloromethane (DCM) is very rapidly growing in use. Levels in the atmosphere have increased by 60% over the past decade. DCM is a chemical which is a component of some paint stripper solvents and has an ODP of 0.4% of that of CFC-11.

   1,2-Dichloroethane: 1,2-Dichloroethane (with an ODP of less than 0.001) is used in the manufacture of vinyl chloride (principally for PVC pipe) and also as an additive in motor vehicles fuels.

2. **The families of chemical are very different in terms of source and usage to those controlled by the Montreal Protocol**

   Nitrous oxide (N_2O): The most significant ozone depleting chemical not covered by the Montreal Protocol is N_2O. The major anthropogenic source of N_2O is agriculture as well as from industry and the burning of fossil fuels and biomass.

GWPs of mixtures with controlled and uncontrolled substances:

When a refrigerant mixture contains different categories of substance, the Montreal Protocol reporting process makes use of adjusted values for GWPs. This includes:

a) Mixtures of HCFCs and HFCs. Under Kigali Amendment reporting, the GWP of the HCFCs in a mixture are ignored, because HCFCs are already subject to phase-out controls under the Protocol.

b) Mixtures of HFCs and uncontrolled substances (including high GWP substances such as PFCs and low GWP substances such as HCs). Under Kigali Amendment reporting, the GWP of the non-HFCs in a mixture are ignored, because they are not controlled under the Protocol.

See Kigali Fact Sheet 16 for further details about the GWP of mixtures.

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OzonAction Kigali Fact Sheet 16

GWPs of Refrigerant Mixtures: Kigali Context

UN environment

NEW

Background:

Many of the commonly used refrigerants are mixtures of several pure fluids. For example, R-410A, a widely used refrigerant in air-conditioning applications is a mixture of HFC-32 and HFC-125. The Kigali Amendment controls the use of HFCs, including those used in refrigerant mixtures. This Fact Sheet provides details about the GWP of refrigerant mixtures.

Calculating the GWP of a refrigerant mixture:

See Kigali Fact Sheet 3 for details about the definition of GWP and for GWP values used in the Montreal Protocol.

The GWP of a blend is the weighted average of the GWPs of the blend components. See Box 1 for an example calculation of a blend GWP.

Box 1: Calculating the GWP of a Blend

A widely-used blend is R-404A. It consists of three HFCs:

52% HFC-143a + 44% HFC-125 + 4% HFC-134a

GWPs: HFC-143a: 4470   HFC-125: 3500   HFC-134a: 1430

Blend GWP = 52% * 4470 + 44% * 3500 + 4% * 1430   **= 3922**

Types of refrigerant mixture affected by the Kigali Amendment:

There are three different types of refrigerant mixture that will be controlled under the Kigali Amendment:

1) Mixtures of HFCs
2) Mixtures of HFCs and HCFCs
3) Mixtures of HFCs and uncontrolled substances (e.g. HFOs or HCs).

Details about substances controlled by the Montreal Protocol are given in Kigali Fact Sheet 15.

When understanding and reporting the use of refrigerant mixtures, it is important to recognise that the Kigali Amendment only controls the use of HFCs. The "GWP-contribution" of non-HFCs does not count towards the GWP of a refrigerant mixture. Hence a refrigerant blend can be understood to have two different GWPs:

a) The Actual GWP, which is calculated using the actual GWP of ***all*** components
b) The 'Kigali Amendment GWP', which is calculated by treating non-HFCs as if they have a zero GWP.

The actual GWP and the 'Kigali Amendment GWP' for R-404A (see Box 1) is the same, as all the components are HFCs. However, the Kigali Amendment GWP for mixtures containing HCFCs or containing uncontrolled substances is always lower than the actual GWP. Box 2 shows two examples.

Box 2: Actual and 'Kigali Amendment GWPs'

Example 1: A mixture of HFCs and HCFCs

R-408A composition:	**46% HFC-143a + 7% HFC-125 + 47% HCFC-22**	
Actual Blend GWP =	46% * 4470 + 7% * 3500 + 47% * 1810	**= 3152**
'Kigali Amendment GWP' =	46% * 4470 + 7% * 3500 + 47% * 0	**= 2301**

Example 2: A mixture of HFCs, HFOs and R-744 (CO_2)

R-455A composition:	**21.5% HFC-32 + 75.5% HFO-1234yf + 3% R-744**	
Actual Blend GWP =	21.5% * 675 + 75.5% * 4 + 3% * 1	**= 148**
'Kigali Amendment GWP' =	21.5% * 675 + 75.5% * 0 + 3% * 0	**= 145**

It is worth noting that in Example 1, the ‘Kigali Amendment GWP’ is considerably lower than the actual GWP, as the HCFC-22 in the blend has a relatively high GWP. In Example 2, there is only a small difference between the actual and the ‘Kigali Amendment GWPs’, because the non-HFC components both have ultra-low GWP and only make a small contribution to the actual GWP.

The table below provides GWP data for a wide range of different refrigerant blends.

GWPs of Refrigerant Blends

Blend	Actual GWP	KA* GWP		Blend	Actual GWP	KA* GWP		Blend	Actual GWP	KA* GWP
R-401A	1 182	16		R-424A	2 440	2 440		R-450A	605	601
R-401B	1 288	14		R-425A	1 505	1 505		R-451A	149	146
R-402B	2 416	1 330		R-426A	1 508	1 508		R-451B	164	160
R-403A	3 124	0		R-427A	2 138	2 138		R-452A	2 140	2 139
R-403B	4 457	0		R-428A	3 607	3 607		R-452B	698	697
R-404A	3 922	3 922		R-429A	14	12		R-453A	1 765	1 765
R-407A	2 107	2 107		R-430A	95	94		R-454A	239	236
R-407C	1 774	1 774		R-431A	38	36		R-454B	466	465
R-407F	1 825	1 825		R-432A	2	0		R-454C	148	145
R-408A	3 152	2 301		R-433A	3	0		R-455A	148	145
R-409A	1 585	0		R-433B	3	0		R-456A	687	684
R-409B	1 560	0		R-433C	3	0		R-457A	139	136
R-410A	2 088	2 088		R-434A	3 245	3 245		R-458A	1 650	1 650
R-411A	1 597	14		R-435A	26	25		R-459A	460	459
R-412A	2 286	0		R-436A	3	0		R-459B	145	142
R-413A	2 053	1 258		R-436B	3	0		R-460A	2 103	2 101
R-415A	1 507	22		R-437A	1 805	1 805		R-461A	2 767	2 767
R-415B	546	93		R-438A	2 265	2 264		R-462A	2 249	2 249
R-416A	1 084	844		R-439A	1 983	1 983		R-502	4 657	0
R-417A	2 346	2 346		R-440A	144	144		R-507A	3 985	3 985
R-418A	1 741	3		R-441A	3	0		R-508A	13 214	5 772
R-419A	2 967	2 967		R-442A	1 888	1888		R-508B	13 396	6 808
R-420A	1 536	1 258		R-444A	93	87		R-510A	1	0
R-421A	2 631	2 631		R-444B	296	293		R-511A	3	0
R-421B	3 190	3 190		R-445A	135	129		R-512A	189	189
R-422A	3 143	3 143		R-446A	461	459		R-513A	631	629
R-422B	2 526	2 526		R-447A	583	582		R-513B	596	593
R-422C	3 085	3 085		R-448A	1 387	1386		R-514A	7	0
R-422D	2 729	2 729		R-449A	1 397	1396		R-515A	393	386
R-423A	2 280	2 280		R-449B	1 412	1411		R-516A	142	139

* the KA GWP is the “Kigali Amendment GWP” which excludes the GWP contributions from components that are not controlled under the Kigali Amendment (including HCFCs, HFOs, non-controlled HFCs, PFCs and non-fluorocarbons such as hydrocarbons).

OzonAction Kigali Fact Sheet 17

Refrigerant Trends in Mobile Air-Conditioning

OzonAction

UN environment

NEW

Background:

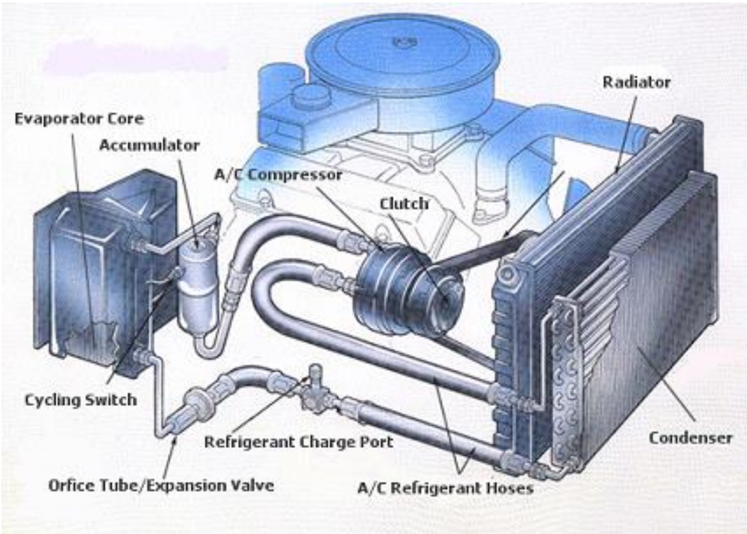
This market sector includes mobile air-conditioning (MAC) systems used to cool the driver and passengers in land transport including cars, vans, lorries, buses, agricultural vehicles and trains. Historically all car air-conditioning used the refrigerant CFC-12. This was completely phased-out during the 1990s in developing countries and around a decade later in developing countries and the global car market switched to HFC-134a, a refrigerant with a GWP of 1430. Larger vehicles such as buses and trains also use other HFC refrigerants such as R-407C (GWP 1774) and R-410A (GWP 2088).

During the last few years new ultra-low GWP alternatives have been introduced in some geographic regions in response to national and regional regulations. This Fact Sheet describes the progress being made towards the use of lower GWP refrigerants in the MAC sector.

Car Air-conditioning:

Passenger cars and other small vehicles such as vans and the cabs of lorries almost all use a very similar design of air-conditioning system. This utilises a compressor powered via a belt drive from the main engine, connected to an evaporator in the ventilation air inlet duct and a condenser located at the front of the car near the radiator. The main components are connected by flexible hoses. The system is assembled and charged on the main vehicle production line.

Some recent MAC designs use electrically driven compressors – these are a new requirement to ensure the function when the main engine is off (e.g. in hybrid vehicles) and for fully electric vehicles.



Car MAC systems contain between 0.4 kg and 0.8 kg of refrigerant. The annual demand for refrigerant in the MAC sector is split between refrigerant used in new cars and refrigerant used in the service sector to top-up systems that have leaked.

Historically car MAC systems suffered from high levels of leakage – it was common to re-charge the system with refrigerant on an annual basis. During the last 10 years there have been major design improvements, especially to the compressor shaft seal and to the materials used for flexible hoses. Modern MAC systems suffer from relatively low levels of leakage in normal use (although may suffer total refrigerant loss following a major car accident). It is now estimated that around 70% of annual refrigerant demand is for new cars and 30% for topping up existing systems.

Low GWP Refrigerant Options

Following the phase-out of CFCs in non-Article 5 countries the mid-1990s, all multinational car manufacturers switched from the use of CFC-12 to HFC-134a. Prior to 2012, all car MAC systems were being built using HFC-134a and in 2016 this was still the predominant refrigerant used in new car MAC systems.

The switch to a lower GWP refrigerant has been forced by legislation in some geographic regions. In particular, the 2006 EU “MAC Directive” required the use of a refrigerant with a GWP below 150, from 2013 for new models and from 2017 for all new vehicles sold in the EU. This legislation prompted a lot of work by MAC designers and car manufacturers to identify a suitable low GWP alternative to HFC-134a.

R-744 (CO_2, GWP 1) was originally the leading contender, although its properties required a major redesign of MAC systems (e.g. very high operating pressure and transcritical operation). There were considerable concerns about possible increase to capital cost and about energy efficiency.

In 2009 HFO-1234yf (GWP 4) was launched and it quickly became the more popular choice amongst car manufacturers as it has properties that closely match the properties of HFC-134a. A key concern about HFO-1234yf is that unlike HFC-134a and R-744 it is "mildly" flammable (safety class A2L). Car manufacturers have carried out extensive safety testing and the majority have concluded that HFO-1234yf can be safely used in car air-conditioning.

Cars using HFO-1234yf started to be introduced from 2013. From January 2017, all new cars in the EU were using HFO-1234yf and this refrigerant was also becoming used in other regions including the USA and Japan.

Legislation in various countries will force a switch to a low GWP refrigerant (e.g. Turkey from 2018, South Korea from 2020, USA and Canada from 2021 and Japan from 2022). This switch is likely to be achieved in these regions using HFO-1234yf and multinational car manufacturers are likely to standardise on use of a single refrigerant as they did in the 1990s when they switched to HFC-134a.

A few car manufacturers, especially in Germany, are still developing R-744 systems. A limited number of cars are being sold with R-744. It is not clear whether this will be a growing trend or whether the preference for a single global refrigerant for MACs will prevail.

The situation in Article 5 countries will initially depend on whether cars are imported or built locally. Countries that mainly import cars from major multi-national manufacturers are likely to make increasing use of HFO-1234yf as these manufacturers switch to a single global refrigerant. Large Article 5 countries with local manufacturing may decide to keep using HFC-134a as it is a lower cost refrigerant.

Bus and Train Air-conditioning:

Bus and train air-conditioning makes use of a number of different design configurations and uses a number of different HFC refrigerants. Larger MACs used in buses and trains are often located in a single unit containing all the system components. The unit is factory built and pre-charged with refrigerant. It is fitted by the vehicle constructor and is usually roof mounted.

The compressor is usually electrically driven with electricity from the main vehicle supply (e.g. from the track supply for an electric train or from a generator connected to the vehicle's main engine). Some units have a dedicated diesel engine to supply electricity or to directly drive the compressor. On some small bus and coach systems the compressor is located adjacent to the main vehicle engine and driven via a belt connection. The refrigerant charge on these large MAC systems is typically in the range of 2 to 20 kg.

As bus and train MAC systems have a much higher cooling capacity than car MACs (typically 5 to 10 times larger) they often utilise stationary air-conditioning refrigerants including R-410A (GWP 2088), R-407C (GWP 1774) and HCFC-22 (GWP 1810). There has been slower progress towards lower GWP alternatives because there is less regulatory pressure in relation to bus and train air-conditioning. However, under the Kigali Amendment, the phase-down of HFC usage will create a new policy driver.

A key issue regarding lower GWP alternatives will be the acceptability of a mildly flammable refrigerant. As the refrigerant charge is much higher than for car MACs, the safety issue is more complex. If A2L refrigerants are acceptable it is likely that HFC-32 (GWP 675) will be used in place of R-410A. HFO-1234yf (GWP 4) can also be considered. If a non-flammable refrigerant is required it will be possible to use R-513A or R-450A (both with GWPs around 600 and properties similar to HFC-134a). R-744 is also being trialled by some bus and train MAC manufacturers.

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OzonAction Kigali Fact Sheet 18

Use of HFCs in Fire Protection Systems

UN environment

NEW

Background:

A variety of different fire protection systems (FPS) are available to address the wide range of fire protection requirements. The most widely used FPS involve water based systems such as automatic sprinklers. An important category of FPS are chemical agents that can quickly extinguish a fire without creating some of the consequential damage that is created by water-based FPS.

Historically, the most important chemical agents were halons. These are compounds containing bromine that were extremely effective at extinguishing certain categories of fire. Halons are extremely powerful ozone depleting substances (ODS) also with very high global warming potentials (GWPs) and have now been completely phased out on a global basis (except for a few essential uses where reclaimed halons are still allowed to be used).

For the last 20 years certain HFCs, such as HFC-227ea (GWP 3220) have been used in place of halons for chemical FPS. As they have a very high GWP, end users are now seeking lower GWP alternatives to these HFCs. This Fact Sheet examines trends towards alternatives in the FPS market.

Types of fire protection system (fixed systems):

The main types of FPS used for protecting installations such as buildings, industrial installations and certain vehicles include:

1) Water sprinklers
2) Water mist systems (very small water droplets sprayed at high pressure)
3) Foam systems (foam water mixtures)
4) Inert gases (e.g. CO_2, and mixtures of nitrogen, argon and CO_2)
5) Dry powder chemical agents
6) Gaseous chemical agents (including halons and certain HFCs).

The choice of system depends on the type of fire that may be encountered and the type of installation being protected. Gaseous chemical agents are often used in specialised installations where highly effective fire suppression needs to be combined with limited property damage and limited risk to building occupants. Example applications include: computer rooms, data centres, telecommunication sites, control rooms, vaults, museums, art galleries, archives, uninterruptible power supply switchgear, process equipment and other industrial risks. Gaseous chemicals are also used in certain fixed installations for transport applications including aircraft cargo bays, aircraft engine nacelles (housings) and various military vehicles such as tanks and armoured cars.

Types of fire protection system (portable extinguishers):

Portable fire extinguishers are also available in a range of types including:

1) Water
2) Foam
3) CO_2
4) Dry powder
5) Gaseous chemical agents.

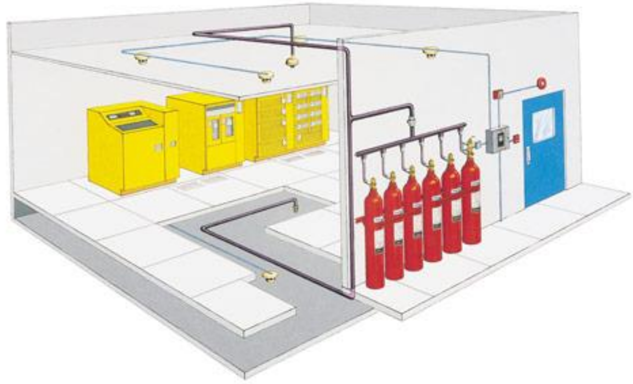
Gaseous agents, especially halons, are widely used for portable extinguishers on civil aircraft.

HFCs in current use for fire protection systems:

The table below illustrates the halons and HFCs used in gaseous chemical fire protection systems.

	Halon previously used	**HFCs in current use** (GWP)
Fixed	Halon 1301	HFC-227ea (3220); HFC-125 (3500); HFC-23 (14800)
Portable	Halon 1211; Halon 2402	HFC-236fa (9810); HFC-227ea (3220)

In fixed systems, HFC-227ea is the most widely used HFC agent. All the HFC agents have very high GWPs and specialist FPS companies are trying to provide lower GWP alternatives. In the EU, where HFC phase-down regulations are creating a much faster phase-down than under the Kigali Amendment, the use of HFCs in new FPS has already been eliminated, except in very specialised applications where the alternatives are considered inferior in performance.



Alternative chemical agents:

The most important low GWP chemical alternative is a fluoro-ketone molecule, FK-5-1-12. This has good fire suppression performance and is now being used in many new building applications in place of HFCs. It has a zero ozone depleting potential and a GWP of 1. A potential drawback of this fluid is that it has a relatively low vapour pressure. Systems using this chemical may need to be pressurised with alternatives substances such as nitrogen.

Another agent that is used in some applications is FIC-1311. This is a fluorocarbon containing iodine (CF_3I). It has a reasonable vapour pressure and good fire suppression performance. A potential drawback of this fluid is that it has a low human exposure limit, which makes it inappropriate for use in occupied spaces.

Inert gases: In many applications inert gases can provide similar advantages to gaseous chemicals – in particular, they can limit consequential damage. Mixtures with nitrogen, argon and CO_2 can be used in both occupied and unoccupied spaces. Pure CO_2 is an equally effective fire suppression agent, but it cannot be used in occupied spaces. Exposure to CO_2 at concentrations greater than 10 vol. % poses severe health risks, including risk of death. In some applications inert gases are considered less effective than gaseous chemical agents, especially if very rapid fire suppression is required.

Water mist: Water mist systems can be used in place of gaseous chemical systems in some applications. Through the use of a high pressure spray of very small droplets of water, the volumes of water used are low compared to more conventional sprinkler systems. Water mist can be an effective fire suppression agent and is much less likely to create consequential damage than sprinklers.

Fire avoidance: For new facilities, some companies are adopting an inherently safe design approach to the protection of their facilities. This means preventing the release of hydrocarbons and eliminating the availability of flammable or explosive materials. Only when all such measures have been considered, and a residual risk of the hazard still remains, are other risk reducing measures considered. In most cases, new technology detection systems are employed to shut-down and blow-down processes, and turn on high rate ventilation systems rather than closing up the space and trying to make it inert it with an extinguishing agent.

Continuing use of halons via reclaimed product: For some applications, especially in the civil and military aircraft sectors, halons are still considered the most effective fire protection agents. Banks of halon 1301 and halon 1211 have been created, using halons available in old FPS reaching end-of-life. These banks allow continuing halon use in these limited specialised applications.

OzonAction Kigali Fact Sheet 19

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Phase-down Strategy: Impact of Gas Choices

UN environment

Background:

In Kigali Fact Sheet 6 the development of a national HFC phase-down strategy is discussed. That Fact Sheet gives background information on the "core actions" that can be used to deliver the required cuts in HFC consumption. These actions include:

- Use of lower GWP refrigerants in new equipment
- Leak prevention
- Retrofit of existing equipment with lower GWP alternatives
- Use of reclaimed refrigerant

It was stressed that the most important long-term core action is to use lower GWP alternatives to HFCs in all new equipment. In this Fact Sheet we show how the choice of refrigerant selected in new equipment has a strong influence on the rate of HFC phase-down.

Lifecycle of RAC Equipment:

In most Article 5 countries the consumption of HFCs is dominated by the requirements in the refrigeration and air-conditioning sectors (RAC). An important characteristic of the RAC market is the relatively long life of equipment and the on-going demand for refrigerant for servicing. The consumption of HFCs by RAC equipment consists of:

a) The initial filling of new equipment

b) The top-up of any leaked refrigerant during plant servicing throughout the life of the equipment.

In many Article 5 countries, the majority of RAC equipment is imported. Much of this equipment is imported pre-charged with refrigerant (e.g. car air-conditioning, small room air-conditioners, large chillers). This means that in terms of Montreal Protocol consumption (which does not include ODS and will not include HFCs in pre-charged imports) demand for initial filling is quite low. A large proportion of annual refrigerant consumption is for the RAC service sector[1].

Most RAC equipment has a life in the 15 to 20 year range. Some equipment, such as car air-conditioning, has a shorter life of around 10 years, whilst industrial refrigeration and large air-conditioning water chillers can have a much longer life (in the 25 to 30 year range). This long lifecycle means that there is always a significant "bank" of refrigerant in existing RAC equipment. If there is a switch to a new refrigerant it takes many years before the bank of old refrigerant is replaced – leading to a long period with an on-going service demand for the old refrigerant.

Impact of a switch to high GWP HFCs:

Until recently a lot of new RAC equipment used HCFC refrigerants, in particular, HCFC-22. The HCFC phase-out Management Plans (HPMPs) Plans are in place to phase-out out the production and consumption of HCFCs in developing countries. In many situations in Article 5 countries this is leading to a switch from the use of HCFC-22 (GWP 1810) in new RAC equipment to an HFC with a high GWP. For example, R-410A (GWP 2088) is commonly being used in small air-conditioning systems and R-404A (GWP 3922) in food retail and industrial refrigeration. These are the same choices that were made in non-Article 5 countries during the last 20 years.

However, this results in a rapidly growing installed bank of high GWP HFCs. As discussed above, much of this equipment has a long life cycle and will require on-going top-up over the next 15 to 25 years. This makes it hard to achieve the Kigali Amendment HFC phase-down targets, especially in Article 5 countries that import a lot of pre-charged HFC equipment.

[1] Note, this is not the case for countries that have significant RAC equipment manufacture within the country.

A better strategy – an early switch to lower GWP alternatives:

During the last five years there has been significant development of lower GWP alternatives. Many of these are widely used in non-Article 5 countries in response to national or regional regulations that require reductions in HFC use. Many of these technologies are becoming available in Article 5 countries and the level of availability is rapidly increasing. In a national HFC phase-down plan, each country could consider how the lower GWP technologies can be introduced as early as possible.

Examples of RAC markets with lower GWP alternatives already widely available are shown in Table 1.

Table 1: RAC Markets with Lower GWP Alternatives

Market sector	High GWP HFC in common use (GWP)	Examples of lower GWP alternatives (GWP)
Domestic refrigerators	R-134a (1430)	R-600a (3)
Small split room air-conditioning	R-410A (2088)	R-32 (675)
Water chillers for air-conditioning	R-134a (1430)	R-1234ze (7), R-1233zd (4), R-514A (7)
Food retail systems	R-404A (3922)	R-744 (1), R-448A (1387), R-449A (1397)
Car air-conditioning	R-134a (1430)	R-1234yf (4)

During the development of a phase-down strategy it will be important to:

a) Engage with relevant stakeholders (e.g. RAC equipment importers) to identify the availability of lower GWP products (see Kigali Fact Sheet 8 for information on stakeholder engagement). If certain lower GWP technologies are not yet available it will be important to identify any barriers (e.g. lack of training) and take steps to overcome these barriers (see Kigali Fact Sheet 11 for information on barriers).

b) Do some scenario analysis to identify the potential benefits of an early switch to a lower GWP technology.

Carrying out scenario analysis:

Scenario analysis was briefly introduced in Kigali Fact Sheet 6, which included an example which assessed a switch from R-134a to R-1234yf in car air-conditioning. That Fact Sheet also explained the availability of "top-down" data showing national consumption of HCFCs and HFCs and the need to better understand the use of these gases in the various market sectors and sub-sectors.

To carry out good scenario modelling it is necessary to build a "bottom-up" national model of the use of HFCs, together with all relevant alternative fluids including HCFCs and the lower GWP alternatives that can be used in the future. This model should distinguish between the important sub-sectors of the market as these can each have different characteristics. In particular, the historic and future choices for refrigerants can vary significantly between each market sub-sector.

OzonAction has been developing a software tool, *HFC Outlook*, cooperating with Kuwait and Bahrain as a pilot. The tool will provide comprehensive bottom-up modelling for Article 5 countries, which will enable scenario analysis that compares different HFC phase-down strategies.

Figures 1 to 6 provide examples of modelling using this tool for a fictitious Article 5 country.

Figure 1 shows modelling of HCFC consumption (purple line) and HFC consumption (blue line). The modelled data is compared to the annually reported data (purple and blue dots). The bottom-up model is "tuned" to top-down reported data to ensure that the model represents a good starting point for making forecasts.

Figure 1: Historic Modelling

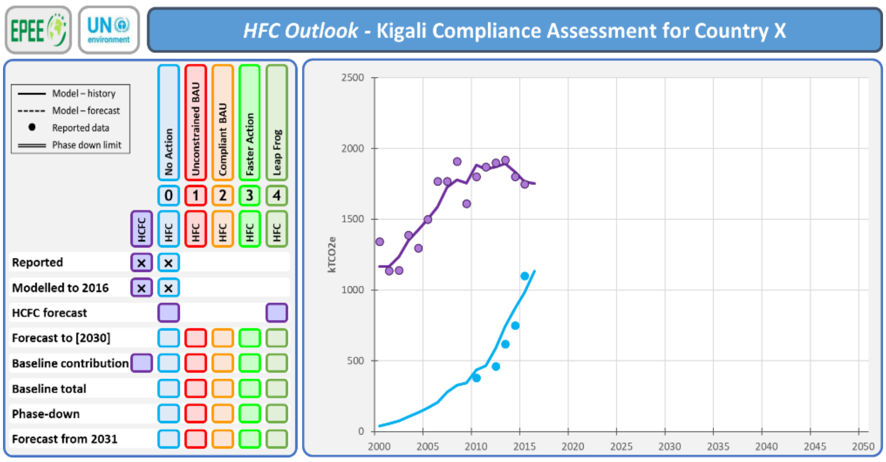
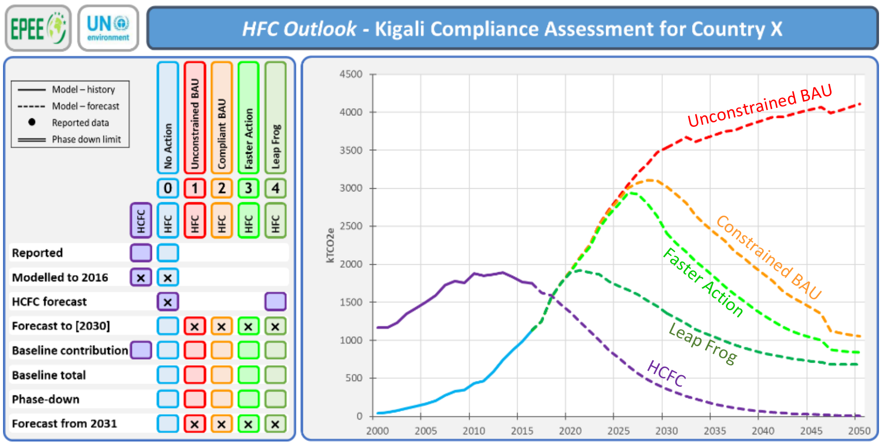


Figure 2 also shows forecasts for future consumption of HCFCs and HFCs.

There is a single HCFC forecast based on the expected changes under the HCFC phase-out programme (purple line).

There are four different HFC forecasts, each based on a different future scenario. The difference between each of these scenarios depends mainly on the choices for use of alternative refrigerants. The four scenarios follow the same path until around 2020. After that date different responses to the Kigali Amendment become apparent.

Figure 2: National Forecasts



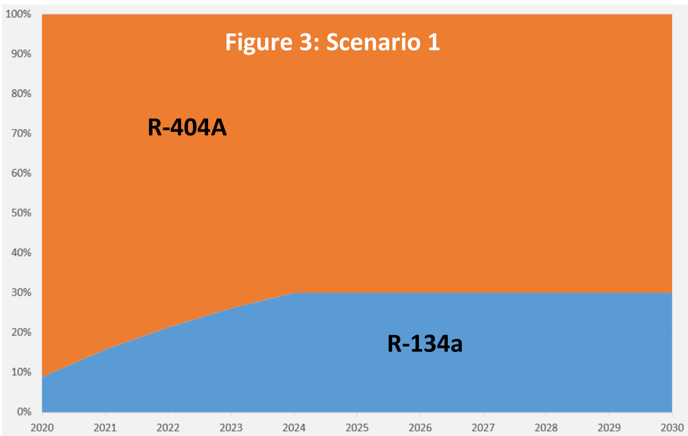
Scenario 1 (red line) is a "non-compliant" business-as-usual scenario, in which high GWP HFCs continue to be used in new equipment. The other scenarios lead to compliance with the Kigali Amendment, although the rate of HFC phase-down is highly dependent on the rate of introduction of lower GWP alternatives.

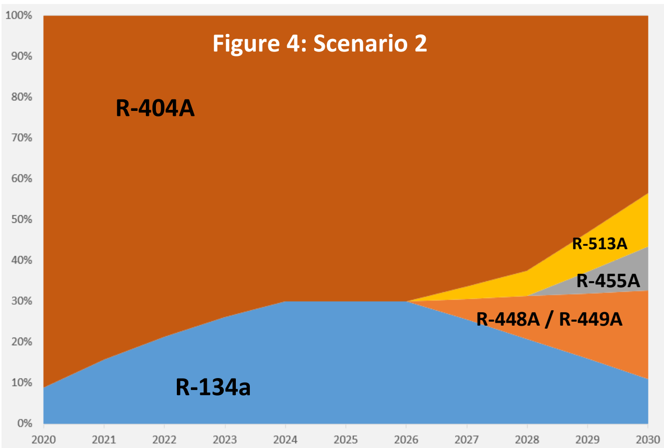
These forecasts are plotted in kTonnes CO_2 and the area under each curve indicates the total amount of CO_2 saved through each phase-down strategy. Table 2 shows the benefits of the 3 compliant scenarios compared to BAU. In the years between 2020 and 2050 the 'leap frog' scenario reduces HFC consumption by almost twice the amount that is achieved by the minimum compliance scenario. This clearly shows the potential benefits of an early switch to lower GWP refrigerants.

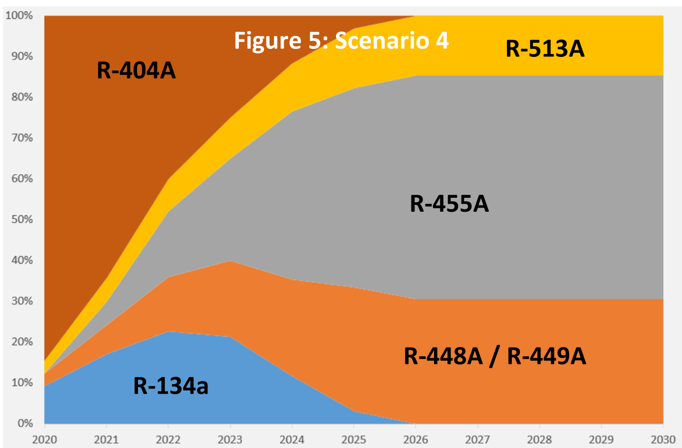
Table 2: Environmental Benefits of HFC Phase-Down, kT CO_2

	Scenario 2: Minimum compliance	Scenario 3: Faster Action	Scenario 4: Leap Frog
Reduction in consumption versus Scenario 1	41 000	53 000	72 000

The modelling in Figure 2 is based on numerous assumptions about the refrigerant choices made in different sectors of the market. The charts in Figures 3 to 5 illustrate the choices for new condensing units used in a selected example sub-sector: chilled food retail, between 2020 and 2030. Under the non-compliant Scenario 1, only high GWP HFCs are used, with R-404A being the dominant choice. Under the minimum compliance Scenario 2, the high GWP refrigerants are used in new equipment until 2026 and then 3 different lower GWP alternatives begin to be introduced. Under Scenario 4, the 'leap frog' scenario, the use of high GWP refrigerants in new equipment ends much more quickly and the lower GWP alternatives are introduced from 2020 onwards.



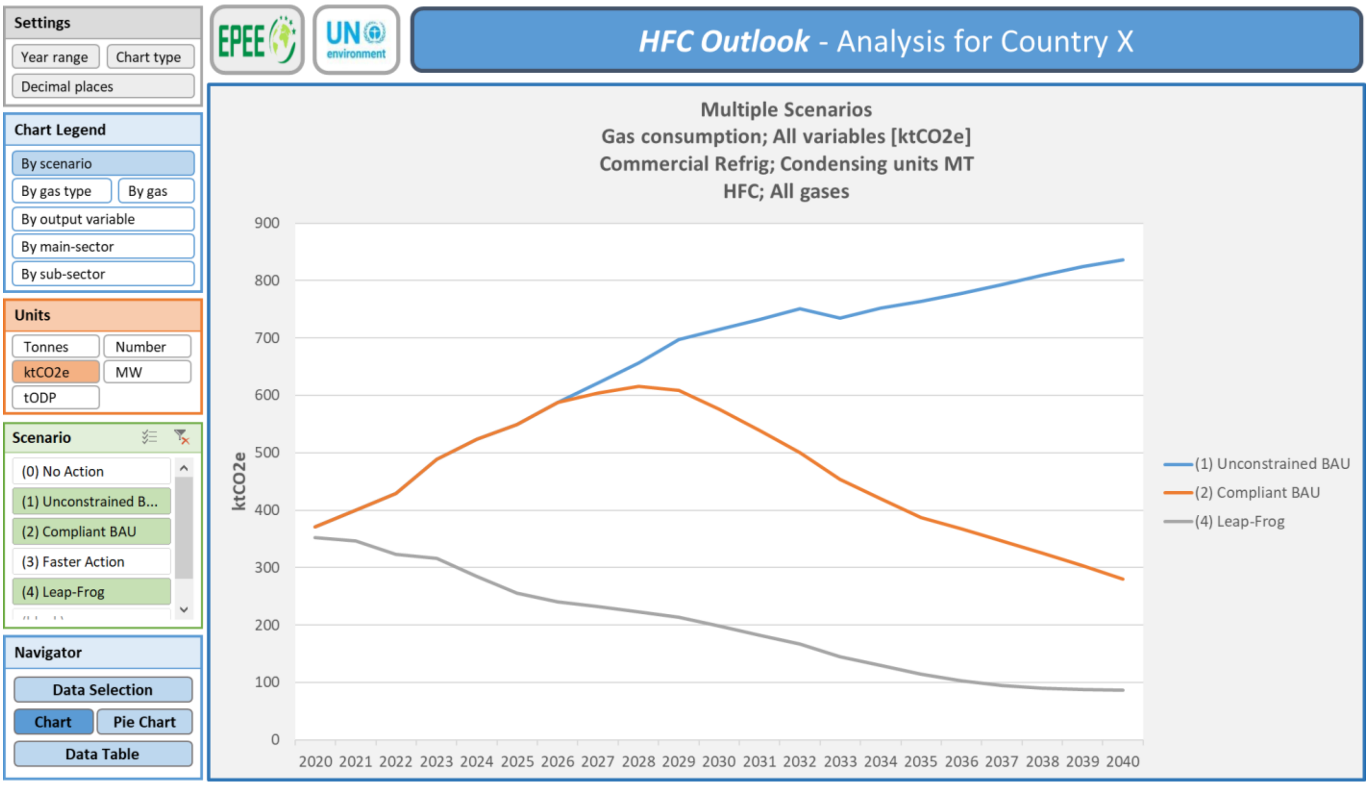




Using the refrigerant selections illustrated in Figures 3 to 5, the scenario modelling tool can estimate the future HFC consumption for each scenario, as illustrated in Figure 6. For this market sub-sector (condensing units for chilled food) there are currently no ultra-low GWP alternatives. However, there are good medium GWP options already in the market. R-448A and R-449A have virtually the same performance characteristics as R-404A, but have a GWP of around 1400 compared to 3922. Moving from HCFC-22 to R-404A for the next 10 years will not support an HFC phase-down initiative. In Figure 6, the non-compliant Scenario 1 and the minimum compliance Scenario 2 both create significant HFC consumption well into the 2030s.

By switching away from high GWP HFCs in the early 2020s (as in the leap frog Scenario 4), HFC consumption in this market sector falls much more quickly and makes compliance with the Kigali Amendment targets much easier in this example.

Figure 6: HFC Consumption Forecasts for a Small Market Sub-Sector



Stimulating Early Action:

The analysis illustrated in Figures 1 to 6 gives an insight into the power of scenario analysis and the importance of encouraging early uptake of lower GWP alternatives. The design of a national HFC phase-down strategy needs to include an evaluation of the availability of lower GWP technologies. A pro-active approach may be required to stimulate a move to these new technologies. Without good stakeholder engagement and encouragement, it is likely that high GWP HFCs will remain the popular choice for several more years. This can be avoided if the benefits of early action can be communicated to the industry and if the barriers to change can be identified and overcome.

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