MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

SEPTEMBER 2015

DECISION XXVI/9 UPDATE TASK FORCE REPORT
ADDITIONAL INFORMATION ON ALTERNATIVES TO OZONE-DEPLETING SUBSTANCES

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DECISION XXVI/9 UPDATE TASK FORCE REPORT ADDITIONAL INFORMATION ON ALTERNATIVES TO OZONE-DEPLETING SUBSTANCES

Montreal Protocol
On Substances that Deplete the Ozone Layer

Report of the
UNEP Technology and Economic Assessment Panel

September 2015

DECISION XXVI/9 UPDATE TASK FORCE REPORT:

ADDITIONAL INFORMATION ON ALTERNATIVES TO ODS

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Co-ordination:	**TEAP and its XXVI/9 Task Force**
Composition and layout:	Lambert Kuijpers
Final formatting:	Ozone Secretariat and Lambert Kuijpers
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The opinions expressed are those of the Panel and its Task Force and do not necessarily reflect the reviews of any sponsoring or supporting organisation.

Foreword

This report is an update of the June 2015 TEAP XXVI/9 Task Force Report, which was Volume 3 of the TEAP June reports published.

This September 2015 TEAP Update XXVI/9 Task Force report is being independently submitted by the TEAP to the 27th Meeting of the Parties, Dubai, November 2015.

The UNEP Technology and Economic Assessment Panel (TEAP):

Bella Maranion, co-chair	USA	Fabio Polonara	I
Marta Pizano, co-chair	COL	Roberto Peixoto	BRA
Ashley Woodcock, co-chair	UK	Jose Pons-Pons	VEN
Mohamed Besri	MOR	Ian Porter	AUS
David Catchpole	UK	Helen Tope	AUS
Marco Gonzalez	CR	Dan Verdonik	USA
Sergey Kopylov	RF	Masaaki Yamabe	J
Lambert Kuijpers	NL	Shiqiu Zhang	PRC
Kei-ichi Ohnishi	J	Jianjun Zhang	PRC

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Executive summary

ES1. Introduction

- In response to Decision XXVI/9, this September 2015 report provides an update from TEAP of information on alternatives to ozone-depleting substances listed in June 2015 XXVI/9 report. The report provides updates considering the specific parameters outlined in the current Decision for various sectors and sub-sectors of use. As these parameters were similar to past Decisions (XXIV/7 and XXV/5), TEAP followed the same methodological approach, where no quantitative threshold or importance of one parameter over others was necessarily assumed.
- With a specific focus on the refrigeration and air conditioning (R/AC) sector, particularly the dramatic, growing demand for this equipment in Article 5 Parties and the resulting increased refrigerant demand, the report also provides further consideration on topics related to energy efficiency and ongoing testing programs on the viability of low-GWP options at high ambient temperature conditions. It is important reiterating that decisions on the selection of alternative technologies may vary depending on the sector being addressed, and the outcomes, even within the same sector, may be very different depending on the local conditions. Ultimate alternative selection has to be made on a case-by-case basis.
- This September 2015 update report provides revised scenarios of avoiding high-GWP refrigerants to include updated assumptions on the GWP of the alternatives to be used and considers how the start date for conversion (2020 versus 2025), and the length of conversion (6 years versus 12 years) affect climate and overall costs. Technology transitions that coincide with other process upgrades are more likely to occur, and be more cost-effective. The costs will be lowest with early implementation of R/AC manufacturing options that avoid high-GWP refrigerants. The scenario analyses indicate that by either delaying and/or extending the conversion period, the climate impacts and overall costs will be increased. Once conversion has taken place, the increased costs relate to continuing servicing needs for the extended period. Both early and rapid manufacturing conversion would reduce overall costs and minimize climate impacts.
- Finally, this September 2015 update report also provides further, new information on the alternatives listed in the previous Decision XXV/5 report for the fire protection sector, metered dose inhalers (MDIs), other medical, and non-medical aerosols sectors.

The following section ES2 provides key highlights of this report, and sections ES3 to ES9 further elaborate on the highlights and provide the technical summaries of the report's main chapters.

ES2. Key highlights

- **Refrigerant options**: New information on existing refrigerant options has been obtained from assessments of additional reports and publications. Updates include the following:
  - Information is presented on 70 fluids under consideration for testing in industry test programs or proposed for inclusion in standards, with emphasis on the commercial refrigeration and stationary AC subsectors.
  - By 2020 about 75% of new domestic refrigeration production will use HC-600a.
  - In supermarket refrigeration systems CO_2 system costs are decreasing, and strong growth is continuing.
  - Split AC systems using HFC-32 are being commercialized in Japan and other countries. HCFC-22 equipment production capacity is being converted to HC-290 in China and HFC-161 is being tested there.

- **Revised R/AC scenarios**: The revised scenarios in this report include new assumptions on the GWPs of alternatives to be used and an analysis on the impact of the conversion period of new manufacturing
    - MIT-3: conversion of new manufacturing by 2020 (start in Article 5 Parties)
    - MIT-4: same as MIT-3 with delayed conversion of stationary AC to 2025
    - MIT-5: conversion of new manufacturing by 2025 (start in Article 5 Parties)
  - These scenarios for the R/AC sector were cross-checked against the best estimated global 2015 production of the four main high-GWP HFCs, used in the R/AC sector.
  - BAU predicts a large growth in the demand for HFCs between 2015 and 2030 for the R/AC sector (i.e., 300% further increase in Article 5 Parties, mainly in stationary air conditioning).
  - The longer the conversion period, the greater the climate impacts (see MIT-3 from 6 to 12 years) and the overall costs because of continuing servicing needs.
  - The later the conversion starts, the greater the climate impact and overall costs. MIT-3 assumes that conversion in all sub-sectors starts in 2020, MIT-5 assumes that conversion starts in 2025. In terms of overall climate impact, the *total* integrated HFC demand for the R/AC sector in Article 5 Parties over the period 2020-2030 has been estimated in the different scenarios. The approximate values are:
    - BAU: 16,000 Mt CO_2 eq.
    - MIT-3: 6,500 Mt CO_2 eq.
    - MIT-4: 9,800 Mt CO_2 eq.
    - MIT-5: 12,000 Mt CO_2 eq.
  - Total estimated costs for the manufacturing conversion alone in Article 5 Parties are estimated at
    - MIT-3: US$ 2300 ± 310 million
    - MIT-4: US$ 3010 ± 370 million
    - MIT-5: US$ 3220 ± 430 million
  - Servicing provides an additional cost, estimated at US$ 40-60 million per three year period for MIT-3, US$ 100-150 million per three year period for MIT-5.
  - The proportion of costs for the conversion of new manufacturing in MIT-3 (more or less the same in case of MIT-5) in Article 5 Parties are estimated to be 78% for stationary air conditioning, 7% for commercial industrial and transport refrigeration, and 11% for mobile air conditioning.
- **High ambient temperature conditions:** Designing for high ambient temperature conditions needs special care to avoid extreme operating conditions, which would complicate meeting minimum standards. This report details advantages and limitations of the available refrigerants suitable for use in high ambient temperature conditions. Four separate testing projects are assessing refrigerant performance at high ambient temperature conditions. Data will not become available until late in 2015.
- **Fire protection, Metered Dose Inhalers (MDIs), other medical and non-medical aerosols:** Even with the halon transition well underway for new installations in fire protection (with the exception of civil aviation), some reliance on high-GWP HFC solutions is expected for the foreseeable future. Similarly, at present, it is not technically or economically feasible to avoid HFC MDIs, even though all classes of drugs are available in Dry Powder Inhalers (DPIs). While consumption of HFCs in non-medical and technical aerosols sector is the third largest after the R/AC and foams sectors, low-GWP propellants and solvents are commercially and widely available, and "not-in-kind" alternatives are commercially available where they are suited for the purpose.

ES3. Status of ODS alternatives in refrigeration, air conditioning and heat pumps applications

- The options for replacing ODS and high-GWP refrigerants have not changed since the finalization of the XXV/5 Task Force report in October 2014 and the completion of this XXVI/9 (update) Task Force report. Nevertheless, new information on these existing options has been obtained from Parties and assessments of additional reports and publications.
- In summary, in the period available for the development of this report the following updates are highlighted:
    - Information is presented on 70 fluids under consideration for testing in industry test programs or for inclusion in the ASHRAE 34 and ISO 817 standards, including recently published thermodynamic data for 11 of the fluids taking part in the high ambient test programs (with 5 of these refrigerants proposed to replace HCFC-22, while 6 are proposed to replace R-410A).
    - The testing activities of unsaturated HFCs (HFOs), and blends containing these compounds, continue to be carried out in many companies, independent laboratories, and systems manufacturers.
    - Special test programs are being performed with a focus on high ambient temperature conditions.
    - Some refrigerants have now been assigned a refrigerant number and their composition now publicly disclosed.
    - Regarding R/AC applications, the main points are:
        - ***Domestic refrigeration****:* No new ODS alternatives have emerged. By 2020 about 75% of new production is predicted to use HC-600a.
        - ***Commercial refrigeration****:* No new ODS alternatives have emerged; hydro-carbons are being used in condensing units for smaller capacities; in supermarket refrigeration systems there is confirmation of the strong growth in CO_2 systems; information is available that CO_2 system costs are decreasing.
        - ***Transport refrigeration****:* blends containing unsaturated HFCs are considered to play a role for retrofitting and new systems, and non-conventional eutectic systems are becoming more applied.
        - ***Air conditioners****:* Split systems using HFC-32 are being commercialized in Japan and other countries; a wide range of blends containing unsaturated HFCs are also being proposed. Split units using HC-290 have been available in Europe and Australia, and are in production in India. HCFC-22 equipment production capacity is being converted to HC-290 in China and HFC-161 is being tested there.
        - ***MAC****:* Industry is now reporting more testing data on the blend R-445A.

ES4. BAU and mitigation demand scenarios

- Decision XXV/5 requested an assessment of various scenarios of avoiding high-GWP alternatives to ODS, and the TEAP Task Force report which responded to that Decision provided projections for high-GWP HFC use for BAU, and two mitigation scenarios (MIT-1 and MIT-2), for R/AC and foams sectors, and for non-Article 5 and Article 5 Parties. MIT-1 and MIT-2 assumed a phase-out date of 2020 for the use of high GWP substances in manufacturing for most R/AC sub-sectors. The XXVI/9 Task Force is unaware of any significant technical uptake that would require a complete revision of these parameters in the scenarios. However, the XXVI/9 Task Force has revised the scenarios for the R/AC sector to include the following new assumptions:
    - specific GWPs for specific low-GWP refrigerants and an average GWP of 300 for a range of low-GWP refrigerant blends of which a number are expected to be used;

- manufacturing conversion periods of 3 years for non-Article 5 Parties, and 6 years for Article 5 Parties;
- conversion commencing in 2020 to make the MIT-3 scenario, and delayed conversion of manufacturing for all sub-sectors to 2025 to make a new scenario, MIT-5. The scenario MIT-4 considers the specific delay of manufacturing conversion in the stationary AC sector and can be considered as an "intermediate" one.

- In the preparation of this report, these scenarios (in principle for the R/AC sector only) were cross-checked against current estimated HFC production data that became available in May 2015 (June XXVI/9 TF report) and shortly thereafter. Estimates made for the 2015 global production of the four main HFCs[1] are presented in the table below; it shows an upper limit for the combined totals of about 475 ktonnes.

Chemical	Best estimate for global HFC production in year 2015 (ktonnes)
HFC-32	94
HFC-125	130
HFC-134a	223
HFC-143a	28

- BAU: Over the period 2015-2030, the revised BAU scenario shows a 50% growth in the demand for high GWP HFCs in non-Article 5 Parties, and an almost 300% growth in Article 5 Parties, particularly in the stationary AC and commercial refrigeration sub-sectors, where the stationary AC sub-sector is the important one for determining the total HFC demand for the (four) main HFCs. The total demand is calculated to be about 510 ktonnes for the year 2015 for these four HFCs.

- By 2030, under a BAU scenario, the high-GWP HFC demand for the R/AC sector, expressed in CO_2 eq., is expected to be 25-30 times larger than the HFC demand for foams.

- In terms of overall climate impact, the *total* integrated HFC demand in Article 5 Parties over the period 2020-2030 has been determined. The approximate values are:
  - BAU: 16,000 Mt CO_2 eq.
  - MIT-3: 6,500 Mt CO_2 eq.; a 60% reduction to BAU (2020-2030)
  - MIT-4: 9,800 Mt CO_2 eq.; a 40% reduction to BAU (2020-2030)
  - MIT-5: 12,000 Mt CO_2 eq.; a 30% reduction to BAU (2020-2030)

  Different percentages (for the reduction to BAU) can be calculated for different time periods (other than 2020-2030) for these three mitigation scenarios.

- The MIT-3 and MIT-5 scenarios are given for all Parties, but focus on demand in Article 5 Parties:
  - MIT-3 substantially reduces the high-GWP HFC demand compared to BAU since it addresses all manufacturing conversions in all R/AC sub-sectors as of 2020. As manufacturing with high-GWP refrigerants is phased down, the servicing demand becomes dominant. The stationary AC sub-sector is determining the HFC demand.
  - MIT-5 delays manufacturing conversion of all sub-sectors, including the rapidly expanding stationary AC sector from 2020 until 2025, so that HFC demand initially rises, but then falls as of the year 2025. Servicing rises substantially as a consequence, and persists for much longer than MIT-3. MIT-5 defers the conversion periods for R/AC sub-sectors and shows the impact of the pertaining servicing needs as a result..

- The following is also of importance:

[1] These are the four main HFCs used in the R/AC sector; HFC-134a is also used in foams, MDIs, aerosols.

- MIT-3 results in a reduction of about 80% *in the year 2030*, if compared with BAU, down to a level of 400 Mt CO_2-eq. (on a BAU 2030 total of about 2,030 Mt CO_2-eq.).
- By shifting the start of the conversion of all sectors including stationary AC to the year 2025 in the MIT-5 scenario, the reduction in HFC demand, if compared to BAU, is reduced to 1,200 Mt CO_2-eq. *in the year 2030*, to the level of 850 Mt CO_2-eq. per year (compare to MIT-3 above, where the reduction is slightly more than 1,600 Mt CO_2-eq.).
- Delaying and extending the conversion period especially for the dominant stationary AC sector significantly increases the climate impact. Until the year 2025 the effect is somewhat modest, but the longer term impact of the delayed conversion is substantial (2025-2030 and beyond).

ES5. Demand, benefits and costs

- Costs have been determined from bottom-up calculations for the R/AC sector conversion in Article 5 Parties. The total demand determined for non-Article 5 and Article 5 Parties for the R/AC sector has been shown to be somewhat higher than expected based on currently available HFC production estimates. For stationary AC, this may have a certain impact on estimated costs.
- For MIT-3, the HFC amounts estimated for the year 2020 are taken to be the HFC amounts in new manufacturing that require conversion. The conversion can be modelled during 6-12 years; it does not make a difference how long the conversion period would be for the total amounts to be converted. The conversion period, however, would have major impacts on the servicing amounts. Estimates for the conversion in US$ per kg that vary from US$ 4-7 for commercial refrigeration field assembly, to US$ 11-13 for stationary AC. All conversions are based on conversion to low GWP refrigerants, with an average GWP for a number of refrigerant blends of 300. For the costs of the conversion of new manufacturing, 78% is estimated to be for stationary air conditioning, 7% for commercial, industrial and transport refrigeration, and 11% for mobile air conditioning, for all Article 5 Parties.
- *Costs for manufacturing conversion only.* The total costs calculated for manufacturing conversion in Article 5 Parties are estimated as follows

MIT-3	US$ 2300 ± 310 million
MIT-4	US$ 3010 ± 370 million
MIT-5	US$ 3220 ± 430 million

- *Additional costs for servicing.* Costs for reducing the demand via the servicing demand can be estimated on the basis of estimates for the period 2020-2030 (and beyond). Estimates are based on current experience and are done on the basis of US$ 4.5 per kg reduction.
- For MIT-3, with early conversion, the servicing amounts are in the order of 100-200 ktonnes during 2020-2030. The amounts decrease substantially between 2025 and 2030, due to the fact that equipment has reached its end of life. Provided that 40-60 ktonnes of high-GWP HFC consumption can be reduced in the servicing sector, spread over at least four triennia, it would imply costs of US$ 40-60 million per triennium.
- For MIT-5, with conversion delayed until 2025, the costs for (necessary) reductions in the servicing sector increase to US$ 100-150 million per triennium.

ES6. Considerations for high ambient temperature conditions

- A definition is given for temperature zones, including high ambient temperatures, following an ASHRAE definition. A world map defining which zones fall in certain temperature ranges is presented. Further options on how to define high ambient temperatures and high ambient temperature zones will be studied and these could be elaborated upon in future.

- Designing for high ambient temperature conditions needs special care to avoid excessively high condensing temperatures and approaching the critical temperature for each type of refrigerant considered in order to meet minimum energy performance standards. Other issues, such as safety and refrigerant charge quantity, also have to be taken into consideration.
- The range of suitable refrigerants for high ambient temperatures has not changed since the Task Force XXV/5 report in October 2014. Additional research and assessment of those refrigerants at high ambient temperatures has been undertaken, for example, through the recent project by the US Department of Energy (DoE), the UNEP/UNIDO PRAHA and EGYPRA projects, and the AHRI initiative of AREP-II for high ambient temperature conditions.
- The schedule for completion of the mentioned projects are as follows:
  - AHRI-AREP II: Autumn 2015;
  - US DoE: Preliminary report - July 2015; Final report - October 2015;
  - UNEP/ UNIDO - PRAHA: 4th quarter 2015;
  - UNEP/ UNIDO - EGYPRA: Early 2016.
- This report details advantages and limitations of the available refrigerants suitable for use in high ambient temperatures and they are discussed as follows:
  - ***For air conditioners**:* R-407C, R-410A, HFC-32, HC-290, HC-1270, R-446A and R-447A, and R-444B. The use of HFC-1234yf, and especially HFC-1234ze(E), has not been seriously considered for ACs because their volumetric capacity is low, which would require bulkier systems along with high anticipated refrigerant price.
  - ***For chillers**:* R-447A, R-410A, R-717, R-718, and HCFC-1233zd(E). The use of R-744 is not suitable for high temperature climates due to excessive cost.
  - ***For commercial refrigeration**:* Refrigeration systems at high ambient temperature conditions have the same issues as air conditioning systems; compressor discharge temperatures increase with increasing ambient and condensing temperatures, leading to possible reliability issues and lower efficiency. Unlike AC, refrigeration applications are already subject to high discharge temperatures and use mitigation methods like compressor liquid or vapor injection to improve performance and reliability.

ES7. Fire protection

- The process for assessing and qualifying new fire protection agents for use is complex, time consuming, and is also application specific. Whilst the phase-out of ODS in this sector is well underway, there will be some reliance of high-GWP HFC solutions for the foreseeable future. Control of avoidable emissions continues to improve, thereby minimising impacts.
- Two chemicals are at an advanced stage of testing and development and may be commercialised as fire extinguishing agents in the future. It is not anticipated that high ambient temperatures or high urban densities will affect market uptake of these agents. These new chemicals are
  - FK-6-1-14
  - 2-Bromo-3,3,3-trifluoropropene

  Note, civil aviation is trying to meet the International Civil Aviation Organisation's (ICAO) 31st December 2016 deadline for the replacement of halon handheld portable extinguishers using 2-Bromo-3,3,3-trifluoropropene. The required regulatory process for commercialisation / manufacturing in Europe (*Registration, Evaluation, Authorisation and Restriction of Chemicals* - REACH registration) has been completed but in the United States the required listing as acceptable under the Significant New Alternatives Policy (SNAP) program and approval under the Toxic Substances Control Act (TSCA) is not yet completed. If successful, from a performance and environmental perspective, this agent will likely be the most effective replacement for halon 1211 applications. However, according to its manufacturer, the agent is anticipated to be at least double the cost of other clean agent alternatives, and will require stabilisers to maintain the material in long-term storage. For these reasons, the agent is only likely to fill the needs of niche applications where its lower weight and superior fire protection performance justify the higher cost.

ES8. Medical uses

- ***Metered dose inhalers****:* Inhaled therapy is essential for the treatment of asthma and chronic obstructive pulmonary disease (COPD). There are two main types of inhalers for the delivery of respiratory drugs: the metered dose inhaler (MDI) and the dry powder inhaler (DPI). HFC MDI and DPI alternatives are available for all key classes of drugs used in the treatment of asthma and COPD. Under a business as usual model, for the period 2015 to 2030, cumulative HFC consumption in MDI manufacture is estimated as 249,000 tonnes (232,000 tonnes HFC-134a; 17,000 tonnes HFC- 227ea), corresponding to direct emissions with a climate impact of approximately 360 Mt CO_2-eq. This impact would be significantly less than the climate impact of CFC MDIs had they not been replaced. At present, it is not yet technically or economically feasible to avoid HFC MDIs completely in this sector.
- ***Other medical aerosols****:* Medical aerosols, excluding MDIs, are estimated as a small percentage (1-2 per cent) of total aerosol production. These medical aerosols include a wide range of uses from simple numbing of pain, nasal inhalation, to the dosage of corticosteroids for the treatment of colitis. Technically and economically feasible alternatives to ozone-depleting propellants and solvents (CFCs and HCFCs) used in non-MDI medical aerosols are available. Most aerosols use hydrocarbons and DME propellants. HFCs are used where a non-flammable or safe to inhale propellant is needed, or where emissions of volatile organic compounds (VOCs) are controlled. It is estimated that less than 10 per cent of non-MDI medical aerosols use HFC propellants (-134a, -152a), i.e., less than 1,000 tonnes per year.
- ***Sterilants:*** There is almost non-existent use of HFCs in the sterilants sector, where a wide variety of alternatives available and the impact of avoiding HFCs would be minimal.

ES9. Aerosols

- Aerosols can be divided into three main categories: consumer aerosols; technical aerosols; and medical aerosols. Technically and economically feasible alternatives to ozone-depleting propellants and solvents (CFCs and HCFCs) are available for aerosol products.
- In 2010, the total GWP-weighted amount of HFCs used in aerosol production was estimated as 54 Mt CO_2-eq., or 5 per cent of total GWP-weighted HFC consumption. Consumer and technical aerosols are estimated to account for about three-quarters of GWP-weighted HFC consumption in aerosol production, and medical aerosols, including MDIs, for the remaining quarter. Global production of HFC-containing aerosols is likely to be growing very slowly, if at all. Nevertheless, there may be individual countries where HFC aerosol production is growing. Production is likely to increase in Article 5 Parties while it flattens or declines in non-Article 5 Parties.
- HFC consumption in this sector is ranked as the third largest after the R/AC and foams sectors, and aerosols are a totally emissive use. There could be significant environment benefits in avoiding high-GWP propellants and solvents. Low-GWP propellants and solvents are commercially and widely available, and “not-in-kind” alternatives are commercially available where they are suited for the purpose. In some markets or for some products there may be significant challenges in adopting low-GWP options, and their use may not be feasible. Reformulation would incur costs to industry.

1 Scope

Decision XXVI/9 is the latest in a series of Decisions on alternatives to ozone depleting substances to request TEAP to develop and assess - on the basis of latest information on alternatives to ODS - the impact of specific mitigation scenarios as part of its reporting back to the Parties. In responding to this mandate, TEAP is seeking to draw from its earlier evaluations of alternatives (Decisions XXIII/9, XXIV/7 and XXV/5 and the various TOC assessment reports). The information is being updated where appropriate, although the principle changes are generally expected to be minor because of the short time period between the finalisation of the June XXVI/9 Task Force report.

It should be noted that quantitative information on (HFC) consumption was only available for the refrigeration, air conditioning, foam, and medical use sectors in the June report. Discussion on fire protection and solvents is more qualitative. Nevertheless, for each of these sectors, efforts have been on-going to address major inputs requested from TEAP in the Decision XXVI/9, namely:

- An update on alternatives available, highlighting significant differences between non-Article 5 and Article 5 regions (para 1(a)) in the Decision)
- A revision of scenarios and an update of the (qualitative/quantitative) discussion on future demand for alternatives to ozone depleting substances (para 1(c) in the Decision)
- A (qualitative/quantitative) discussion on the costs and environmental benefits of various (mitigation) scenarios (para 1(c) in the Decision).

The XXVI/9 Decision contains a specific request related to high ambient temperature countries in para 1(b) in the Decision. This XXVI/9 update Task Force report contains first information on the definition of high ambient temperatures (and zones), on refrigerants for high ambient temperature conditions, plus an elaboration on the design of equipment as well as an explanation on experimental information to be obtained shortly in various demonstration projects.

The XXVI/9 report provided updated information and expanded on topics primarily related to the refrigeration and air conditioning sector as outlined in the decision. While many of the options for replacing ODS and high-GWP refrigerants did not change since the finalization of the XXV/5 TEAP Task Force report in October 2014 and the completion of the June 2015 report, the XXVI/9 Task Force considered updated information on these existing options obtained through comments from Parties and review of information from several additional reports and publications: the 2014 RTOC Assessment report, and several reports from workshops and conferences including documents from the “2015 Workshop on Management of Hydro fluorocarbons (HFCs)”. Updated information was also provided for the fire protection, medical uses, and non-medical aerosols sectors.

Parties gave comments and suggestions for an updated version of the June XXVI/9 Task Force report during the OEWG-36 plenary, both in writing and during informal consultations on Wednesday 22 July. All these comments have been taken into consideration when deciding on how to draft this September 2015 Update XXVI/9 Task Force report. A complete rewrite has been done for chapters 5 and 6, additional information is provided in chapter 7 on high ambient temperature conditions, and updated information is provided in the refrigerants chapter 3 as well as in the medical uses and non-medical aerosols sector chapters. No additional updates were available for the foams and solvents sector, but these may be considered in any future reports of this kind. This report is being submitted to the 27th Meeting of the Parties in Dubai, November 2015.

2 Introduction

2.1 Terms of Reference for the XXVI/9 Task Force report

Decision XXVI/9 of the Twenty-sixth Meeting of the Parties requested the Technology and Economic Assessment Panel (TEAP) to prepare a draft report for consideration by the Open-ended Working Group at its 36th meeting and an updated report for the Twenty-seventh Meeting of the Parties in 2015.

2.2 Scope and coverage

The text of Decision XXVI/9 ("Response to the report by the Technology and Economic Assessment Panel on information on alternatives to ozone-depleting substances"), as it relates to this report is as follows:

Noting with appreciation volume 2 of the 2012 task force progress report which responded to decision XXIII/9, volume 2 of the 2013 progress report of the Technology and Economic Assessment Panel which responded to decision XXIV/7 and volume 4 of the 2014 progress report which responded to decision XXV/5

1. To request the Technology and Economic Assessment Panel, if necessary in consultation with external experts, to prepare a report identifying the full range of alternatives, including not-in-kind technologies, and identifying applications where alternatives fulfilling the criteria identified in paragraph 1 (a) of the present decision are not available, and to make that report available for consideration by the Open-ended Working Group at its thirty fifth-meeting and an updated report to be submitted to the Twenty-Seventh Meeting of the Parties that would:

(a) Update information on alternatives to ozone-depleting substances in various sectors and sub-sectors and differentiating between parties operating under paragraph 1 of Article 5 and parties not so operating, considering energy efficiency, regional differences and high ambient temperature conditions in particular, and assessing whether they are:

- (i) Commercially available;
- (ii) Technically proven;
- (iii) Environmentally sound;
- (iv) Economically viable and cost effective;
- (v) Safe to use in areas with high urban densities considering flammability and toxicity issues, including, where possible, risk characterization;
- (vi) Easy to service and maintain;

  and describe the potential limitations of their use and their implications for the different sectors, in terms of, but not limited to, servicing and maintenance requirements, and international design and safety standards;

(b) Provide information on energy efficiency levels in the refrigeration and air-conditioning sector referring to high-ambient temperature zones in international standards;

(c) Taking into account the uptake of various existing technologies, revise the scenarios for current and future demand elaborated in the October 2014 final report on additional information on alternatives to ozone-depleting substances of the Technology and Economic Assessment Panel's task force on decision XXV/5, and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and stage II of HCFC phase-out management plans;

2. To convene a two-day workshop, back to back with an additional three-day meeting of the Open-Ended Working Group in 2015, to continue discussions on all issues in relation to hydrofluorocarbon management, including a focus on high-ambient temperature and safety

requirements as well as energy efficiency, taking into account the information requested in the present decision and other relevant information;

3. To encourage parties to continue to provide to the Secretariat, on a voluntary basis, information on their implementation of paragraph 9 of decision XIX/6, including information on available data, policies and initiatives pertaining to the promotion of a transition from ozone-depleting substances that minimizes environmental impact wherever the required technologies are available, and to request the Secretariat to compile any such submissions received;

4. To request the Executive Committee of the Multilateral Fund to consider providing additional funding to conduct inventories or surveys on alternatives to ozone-depleting substances in interested parties operating under paragraph 1 of Article 5 upon their request;

2.3 Composition of the Task Force

The TEAP established a Task Force to prepare the report and the update report responding to Decision XXVI/9. The composition of the Task Force is as follows:

Co-chairs

- Lambert Kuijpers (The Netherlands, co-chair RTOC)
- Bella Maranion (USA, co-chair TEAP)
- Roberto Peixoto (Brazil, co-chair RTOC)

Members:

- Daniel Colbourne (UK, member RTOC)
- Martin Dieryckx (Belgium, member RTOC)
- Rick Duncan (USA, member FTOC)
- Bassam Elassaad (Lebanon, member RTOC)
- Samir Hamed (Jordan, member RTOC)
- Yilhan Karaagac (Turkey, member FTOC)
- Tingxun Li (PR China, RTOC member)
- Richard Lord (USA, outside expert)
- Carloandrea Malvicino (Italy, member RTOC)
- Keiichi Ohnishi (Japan, co-chair CTOC)
- Alaa A. Olama (Egypt, RTOC member)
- Fabio Polonara (Italy, co-chair RTOC)
- Rajan Rajendran (USA, RTOC member)
- Helen Tope (Australia, co-chair MTOC)
- Dan Verdonik (USA, co-chair HTOC)
- Samuel Yana-Motta (Peru, outside expert)
- Asbjørn Vonsild (Denmark, member RTOC)
- Shiqiu Zhang (PR China, Senior Expert TEAP)

Denis Clodic (who resigned from the RTOC, January 2015) has been involved as an outside expert in revising the R/AC scenarios together with his assistant Xueqin Pan.

The structure of the TEAP XXVI/9 June Task Force Report was considered by the Task Force and also by TEAP prior to the final formulation of the Report. The factors considered include:

- The relatively short period between the delivery of the final XXV/5 Report (October 2014) and the preparation of the XXVI/9 Report (February-May 2015).

- The publication of the various TOC Assessment reports with a large amount of updated and well-reviewed technical information by January-February 2015.

- The similarity of the criteria set out within Decision XXV/5 and Decision XXVI/9 (and within the earlier Decision XXIV/7), already noted in the XXV/5 Task Force report.
- The importance of avoiding too much repetition and bringing focus on what is either new or of growing importance.
- Recognition that some sectors (specifically refrigeration, air conditioning and foam) have data which allow for the characterisation of a Business-As-Usual (BAU) case and related mitigation scenarios. Recognition that other sectors (specifically fire protection, solvents and medical uses) do not have reliable data from which relevant mitigation scenarios can be derived or for which mitigation scenarios were not derived.
- Recognition that Decision XXV/5 sought to generate an analysis of the Article 5 and non-Article 5 implications of avoiding high-GWP alternatives to ODS, and that this issue is further investigated in the XXVI/9 Task Force report.

This played a role in the finalisation of the June 2015 Task Force report. The above also applied to the composition of this September 2015 update report. The chapter layout of the June report has also been followed for this September 2015 Update XXVI/9 Task Force report:

Chapter 1 'Scope'

Chapter 2 'Introduction'

Chapter 3 'Update of the status on refrigerants'
…which gives information on alternatives, including for high ambient application.

Chapter 4 'Present status of alternatives for ODS in refrigeration, air conditioning and heat pumps applications
…which provides information on the trends in alternative selection within the refrigeration, air conditioning sector.

Chapter 5 'BAU and MIT scenarios for Article 5 and non-Article 5 Parties'
…which considers the revision of the BAU and MIT-2 scenarios from the XXV/5 report for the R/AC sector. It describes the BAU and three mitigation scenarios (MIT-3, MIT-4 and MIT-5) for refrigeration and air conditioning, where the difference between MIT-3 and MIT-5 is related to different starting points in time for all R/AC sub-sectors. The BAU scenario for foams has not been adjusted comparted to the one published in the XXV/5 Task Force report.

Chapter 6 'Demand, benefits and costs'
…which provides quantitative information on the demand in non-Article 5 and Article 5 Parties for various scenarios, looks at the benefits in going to mitigation scenarios and derives the funding required to realise a MIT-3 and -5 mitigation scenario in Article 5 Parties (independent from conversion periods for new manufacturing) over a period of 6 and 12 years (2-4 triennia).

Chapter 7 'High ambient temperature conditions'
…which provides information on design of equipment for high ambient temperature conditions. It deals with the design conditions for a number of demonstration projects, and the refrigerants that were tested or that are going to be tested.

Chapter 8 'Information on alternatives to ODS in the fire protection sector'
…which provides information on the trends in alternative selection within the fire protection sector with reference to information previously contained in the Decision XXV/5 Task Force Report.

Chapter 9 'Information on alternatives to ODS in medical uses'

…which provides further information on the alternatives available for medical uses and the implications of technology choices. It also gives information on current and future demand as well as cost information.

Chapter 10 'Information on alternatives to ODS in non-medical aerosols'

…which provides information on the alternatives available for non-medical aerosols and the implications of technology choices. It also gives information on current and future demand as well as cost information.

2.4 The September 2015 Update XXVI/9 Task Force report

In the June XXVI/9 report, the Task Force summarised a number of aspects that could be considered in the September 2015 XXVI/9 report. During the OEWG-36 in July, an informal discussion session was organised for Parties to give comments and suggestions for the update September 2015 XXVI/9 report. The summary, which was also presented to the OEWG-36 plenary, can be found as Annex 1 to this report.

In this September 2015 XXVI/9 update report the major things that have changed, include:

- Additional updates on refrigerants in chapter 3;
- Adjustment of bottom-up calculations for the R/AC sector, in order to be in agreement with best guesses for production amounts, which means that all graphs and numbers have changed;
- Introduction of the three scenarios MIT-3, MIT-4 and MIT-5, the first two were already considered in the June 2015 report, MIT-5 considers a conversion of all R/AC sub-sectors by 2025;
- Revised cost calculations, specifically taking into account the MIT-3 and MIT-5 demand calculations (i.e., for conversion of new equipment manufacturing);
- Options to consider in defining high ambient temperature countries or regions in chapter 7; and
- Additional information provided in the chapters 9 and 10, on alternatives to ODS for medical uses and on alternatives to ODS in non-medical aerosols.

3 Update of the status on refrigerants

3.1 Introduction

Developing a fluid is a process where uncertainties are addressed, both regarding what is technically feasible and regarding what can be accepted by the market. The technical uncertainty includes how to produce the fluid, and whether the preferred properties can be attained. The market uncertainty includes uncertainty about what properties the customer prefers, and what fluids the competitors will market.

The development process requires a series of investments, such as researching the toxicity of candidate fluids, or doing field tests at potential customers with a candidate fluid. The investment pattern is similar from fluid to fluid, and companies therefor manage the process with a state-gate process (Cooper, 1988). The state-gate process is a process, where a “gate” is placed just in-front of each major investment, and a “gate” is simply a decision point where management evaluates whether or not to accept the next investment or stop the development project. While the exact gates are not visible from outside the company, some of the step will be visible in the market. Examples of such steps could be:

- Research, possibly in collaboration with a few selected system builders;
- Fluid released for small scale testing in industry test programs (with a research name);
- R-number applied for through ASHRAE 34 (or ISO 817) and is typically rewarded;
- Testing in the market to see whether the market is interested in larger capacities;
- Broad market launch (large scale production set-up);
- Market adoption, where the market actually starts using the refrigerant in larger quantities.

The investment sizes and time needed for each step for new molecules (pure refrigerants) are much larger and longer than for refrigerant mixtures. Especially the research and toxicity evaluation are expensive in the early phases, and the production set in the later stages, are expensive for new molecules. While for new mixtures, the major uncertainty is related to the market, and the large investments are primarily on research, especially market research, to find a composition which matches the needs of the customers as well as possible, and on the market launch with investments in marketing.

This means that the commercialisation of a new fluid can take 10 years, while for mixtures the commercialisation takes closer to 5 years. A complication for low-GWP mixtures is that many are based on two new molecules (HFC-1234yf and HFC-1234ze(E)).

3. 2 Overview of proposed refrigerants

A total of 70 fluids have been proposed for testing or are being tested in industry programmes or are pending publication in ISO 817 (ISO 817:2014) or ASHRAE 34 (ASHRAE 34:2013). Of the 70 fluids, 10 are pure substances, of which 9 have been published in ISO 817 or ASHRAE 34, while of the 60 mixtures, 40 have publicly know compositions, but only 10 have been published in the ISO 817 or ASHRAE 34 standards, and therefore been included in the RTOC report (UNEP, 2015)[2].

It expected that, after the first introduction of all 70 fluids, testing, development and commercialization will decrease the number of viable candidates. The subsequent, increasing number of experiences from the market will likely further narrow down the number of viable low-GWP candidates in future.

[2] GWPs used here are the ones from the IPCC AR5 report. In the RTOC report (UNEP, 2015) values were used as given in the SAP (2014) (WMO, 2015) report. The issue of GWP values to be used remains an issue that needs to be addressed.

The industry test programs are further described below (and especially in chapter 7). For ease of referencing the names are given here:

- AHRI Low-GWP Alternative Refrigerants Evaluation Program (AREP). This project is divided into two phases: Phase I which is finished and phase II which is ongoing.
- "Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt" (EGYPRA)
- "Promoting low-GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (PRAHA)
- US DoE "Oak Ridge National Laboratory High-Ambient Testing Program for Low-GWP Refrigerants" (ORNL HAT)

The fluids participating in these programmes and the refrigerants proposed under ASHRAE (ASHRAE, 2015), are presented in Table 3-1 for pure fluids and Table 3-2 for blends with publicly known compositions. For ease of reference, key properties for selected commonly used refrigerants are given in Table 3-3 and Table 3-4.

The fluids where the composition is not yet public are (with safety class in brackets):

- ARC-1 (A1) and LPR1A (A2L) for replacing HCFC-123;
- BRB36 (A1) for replacing HFC-134a;
- ARM-32c (A1), D542HT (A1), DR-91 (A1), DR-93 (A1), N-20b (A1) and DR-3 (A2L) for replacing HCFC-22, R-407C;
- ARM-20b (A2L) for replacing HCFC-22, R-404A, R-407C;
- ARM-32b (A1), ARM-35 (A1), D42Yb (A1), D42Yz (A1), ARM-20a (A2L), HDR110 (A2L) and ARM-25a (A2) for replacing R-404A;
- ARM-71a (A2L), DR-55 (A2L) and HPR2A (A2L) for replacing R-410A.

Table 3-1: Pure substances proposed under various test programs and in the ASHRAE 34.

Refrigerant Designation	Proposed to replace (from AREP phase 1)	Safety Class	alternatives Participation in AREP program		High ambient programmes for HCFC-22 and R-410A			Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	GWP 100 Year (IPCC)	GWP 100 Year (RTOC)
			Phase 1	Phase 2	PRAHA	EGYPRA	US DoE								
HFC-32	R-404A, R-410A[×]	A2L	X	X	X	X	X	CH_2F_2	Difluoro-methane (methylene fluoride)	52,0	−52	0,30	0,307	677	704
HC-290	HCFC-22, R-404A, R-407C	A3	X		X	X	X	$CH_3CH_2CH_3$	propane	44,1	−42	0,09	0,038		5
HC-600a	HFC-134a	A3	X					$CH(CH_3)_2$-CH_3	2-methyl-propane (isobutane)	58,1	−12	0,059	0,043		~20
R-717	HCFC-22, R-407C	B2L	X					NH_3	ammonia	17,0	−33	0,000 22	0,116		
R-744	R-404A, R-410A	A1	X					CO_2	carbon dioxide	44,0	−78[◊]	0,072	NF	1	1
HCFC-1233zd(E)	HCFC-123	A1		X				CF_3CH= $CHCl$	trans-1-chloro-3,3,3-trifluoro-1-propene	130,5	18,1	0	NF	1	1
HFC-1234yf	HFC-134a	A2L	X	X				$CF_3CF=CH_2$	2,3,3,3-tetrafluoro-1-propene	114,0	−29,4	0,47	0,289	<1	<1
HFC-1234ze(E)	HFC-134a	A2L	X	X				CF_3CH= CHF	trans-1,3,3,3-tetrafluoro-1-propene	114,0	−19,0	0,28	0,303	<1	<1
HC-1270	HCFC-22, R-407C	A3	X					$CH_3CH=CH_2$	propene (propylene)	42,1	−48	0,001 7	0,046		1,8
HFC-1336mzz (Z)[*]	HCFC-123	A1						$CF_3CH=CH$-CF_3	cis-1,1,1,4,4,4-hexafluoro-2-butene	164,1	33,4	0	NF	2	2

Notes:

[×] HFC-32 was proposed to replace R-404A and R-410A in phase I of the AREP program, but is only proposed to replace R-410A in phase II of same and later projects.

[◊] For CO2 the sublimation temperature is given instead of boiling point. Triple point is −56,6 °C at 5,2 bar.

[*] HFC-1336mzz(Z) is pending official ASHRAE 34 publication.

Table 3-2: Blend refrigerants proposed under various test programs and in the ASHRAE 34.

Refrigerant Designation	Refrigerant development name	Proposed to replace (from AREP phase I)	Safety Class	Participation in AREP program		High ambient programmes for HCFC-22 and R-410A alternatives			Composition	Molecular Weight	Bubble point/dew or Normal boiling point (°C)	GWP 100 Year (IPCC5)	GWP 100 Year (RTOC)
				Phase 1	Phase 2	PRAHA	EGYPRA	US DoE					
—	ARM-41a	HFC-134a	A1	X					R-134a/1234yf/32 (63/31/6)	99,5		860	900
R-513A	XP10	HFC-134a	A1	X	X				R-1234yf/134a (56/44)	108,4	−29,2	570	600
—	N-13a	HFC-134a	A1	X					R-134a/1234ze(E)/1234yf (42/40/18)	108,7		550	570
R-450A	N-13b	HFC-134a	A1	X	X				R-1234ze(E)/134a (58/42)	108,7	–23,4/ –22,8	550	570
—	D-4Y	HFC-134a	A1	X	X				R-1234yf/134a (60/40)	108,9		520	540
—	AC5X	HFC-134a	A1	X	X				R-1234ze(E)/134a/32 (53/40/7)	100,9		570	590
—	ARM-42a	HFC-134a	A2L	X	X				R-1234yf/152a/134a (82/11/7)	104,8		110	110
R-444A	AC5	HFC-134a	A2L	X	X				R-1234ze(E)/32/152a (83/12/5)	96,7	–34,3/ –24,3	89	93
R-445A	AC6		A2L						R-744/134a/1234ze(E) (6/9/85)	103,1	–50,3/ –23,5	120	120
—	R290/R600a	HFC-134a	A3	X					R-600a/290 (60/40)	51,6			14
—	LTR4X	HCFC-22, R-407C	A1	X	X				R-1234ze(E)/32/125/134a (31/28/25/16)	85,1		1 200	1 300
—	N-20	HCFC-22, R-407C	A1	X	X				R-134a/1234ze(E)/1234yf/ 32/125 (31,5/30/13,5/12,5/12,5)	96,7		890	950
—	D52Y	HCFC-22, R-407C	A2L	X	X				R-1234yf/125/32 (60/25/15)	97,8		890	970
—	L-20	HCFC-22, R-407C	A2L	X					R-32/1234ze(E)/152a (45/35/20)	67,8		330	350
—	LTR6A	HCFC-22, R-407C	A2L	X	X				R-1234ze(E)/32/744 (63/30/7)	77,6		200	210
R-444B	L-20a	HCFC-22, R-407C	A2L		X	X	X	X	R-32/1234ze(E)/152a (41,5/48,5/10)	72,8	–44,6/ –34,9	300	310

—	ARM-32a	HCFC-22, R-404A, R-407C	A1	X					R-125/32/134a/1234yf (30/25/25/20)	86,9		1 400	1 600
R-442A		HCFC-22, R-404A, R-407C	A1		X				R-32/125/134a/152a/227ea (31,0/31,0/30,0/3,0/5,0)	81,8	–46,5/ –39,9	1 800	1 900
R-449B*		HCFC-22, R-404A, R-407C	A1		X				R-32/125/1234yf/134a (25,2/24,3/23,2/27,3)	86,4	−46,1/ −40,2	1 300	1 400
R-449A	DR-33 (XP40)	R-404A	A1	X	X				R-32/125/1234yf/134a (24,3/24,7/25,3/25,7)	87,2	–46,0/ –39,9	1 300	1 400
—	N-40a	R-404A	A1	X					R-32/125/134a/1234ze(E)/ 1234yf (25/25/21/20/9)	87		1 200	1 300
—	N-40b	R-404A	A1	X					R-1234yf/32/125/134a (30/25/25/20)	87,1		1 200	1 300
R-452A	DR-34 (XP44)	R-404A	A1		X				R-1234yf/32/125 (30/11/59)	103,5	−47,0/ −43,2	1 900	2 100
R-448A	N-40c	R-404A	A1		X				R-32/125/1234yf/134a/ 1234ze(E) (26,0/26,0/20,0/21,0/7,0)	86,3	–45,9/ –39,8	1 300	1 400
—	R32/R134a	R-404A	A2L	X					R-32/134a (50/50)	68,9		990	1 000
—	ARM-31a	R-404A	A2L	X					R-1234yf/32/134a (51/28/21)	83,9		460	480
—	L-40	R-404A	A2L	X	X				R-32/1234ze(E)/1234yf/ 152a (40/30/20/10)	73,6		290	300
R-454A*	DR-7◊	R-404A	A2L	X	X				R-1234yf/32 (65/35)	80,5	−48,4/ −41,6	240	250
R-454A*	D2Y-65	R-404A	A2L	X	X				R-1234yf/32 (65/35)	80,5	−48,4/ −41,6	240	250
—	ARM-30a	R-404A	A2L	X					R-1234yf/32 (71/29)	84,7		200	200
—	R32/R134a	R-410A	A2L	X					R-32/134a (95/5)	53,3		710	740
—	R32/R152a	R-410A	A2L	X					R-32/152a (95/5)	52,6		650	680
—	DR-5	R-410A	A2L	X					R-32/1234yf (72,5/27,5)	61,2		490	510
—	L-41a	R-410A	A2L	X					R-32/1234yf/1234ze(E) (73/15/12)	61		490	510
—	L-41b	R-410A	A2L	X					R-32/1234ze(E) (73/27)	61		490	510
—	ARM-70a	R-410A	A2L	X					R-32/1234yf/134a (50/40/10)	70,9		470	490
—	HPR1D	R-410A	A2L	X	X				R-32/1234ze(E)/744 (60/34/6)	63		410	420
—	D2Y-60	R-410A	A2L	X	X				R-1234yf/32 (60/40)	77,2		270	280
R-454B*	DR-5A	R-410A	A2L		X	X	X	X	R-32/1234yf (68,9/31,1)	62,6	−50,9/ −50,0	470	490
R-446A	L-41-1	R-410A	A2L		X				R-32/1234ze(E)/600 (68,0/29,0/3,0)	62	–49,4/ –44,0	460	480
R-447A	L-41-2	R-410A	A2L		X	X	X	X	R-32/125/1234ze(E) (68,0/3,5/28,5)	63	–49,3/ –44,2	570	600

notes:
* Indicates refrigerants pending official publication in ASHRAE 34.
◊ DR-7 has changed nominal composition slightly from originally R-1234yf/32 (64/36) to R-1234yf/32 (65/35).

Table 3-3: Currently commonly used pure substances for reference.

Refrigerant Designation	Safety Class	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m^3)	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ppm)	GWP 100 Year (IPCC5)	GWP 100 Year (RTOC)	ODP
HCFC-22	A1	$CHClF_2$	chlorodifluoromethane	86,5	-41	0,21	12	0,21	1 760	1 780	0,034
HCFC-123	B1	$CHCl_2CF_3$	2,2-dichloro-1,1,1-trifluoroethane	152,9	27	0,057	1,3	0,15	79	79	0,01
HFC-134a	A1	CH_2FCF_3	1,1,1,2-tetrafluoroethane	102,0	-26	0,21	14	0,16	1 300	1 360	

Table 3-4: Currently commonly used blend refrigerants for reference.

Refrigerant Designation	Safety Class	Refrigerant Composition (Mass %)	Molecular Weight	Bubble / Dew or Normal Boiling Point (°C)	ATEL/ODL (kg/m3)	GWP 100 Year (IPCC)	GWP 100 Year (RTOC)	ODP
R-404A	A1	R-125/143a/134a (44,0/52,0/4,0)	97,6	-46,6/-45,8	0,52	3 900	4 200	
R-407A	A1	R-32/125/134a (20,0/40,0/40,0)	90,1	-45,2/-38,7	0,31	1 900	2 100	
R-407C	A1	R-32/125/134a (23,0/25,0/52,0)	86,2	-43,8/-36,7	0,29	1 600	1 700	
R-407F	A1	R-32/125/134a (30,0/30,0/40,0)	82,1	-46,1/-39,7	0,32	1 700	1 800	
R-410A	A1	R-32/125 (50,0/50,0)	72,6	-51,6/-51,5	0,42	1 900	2 100	
R-507A	A1	R-125/143a (50,0/50,0)	98,9	-47,1/-47,1	0,53	4 000	4 300	

3.2.1 Data sources for tables 3-1, 3-2, 3-3, and 3-4

In the past, GWP values have been published in various IPCC and WMO reports, starting before 1996. In reporting to the UNFCCC it is not yet clear which values should be used, where there is ongoing discussion on whether to use current GWP or GTP values. It is likely that this issue will not be resolved until 2016 or later, given the emphasis of current UNFCCC talks on preparations for the Paris December Climate COP/MOP.

UNFCCC reporting has been done using the GWP values from the 1996 IPCC Second Assessment (SAR). As of the year 2015 reporting should be based on the values from the IPCC Fourth Assessment (AR4). There is also a trend to refer to the IPCC values from the 2014 Fifth Assessment (AR5) (IPCC, 2014), although it is not clear what this would imply.

There are now updated GWP values from both the IPCC AR5 (IPCC, 2014) report and from the UNEP/WMO report which was published later, at the end of 2014 (WMO, 2014). The UNEP/WMO values were updated from IPCC (2014) taking into account different lifetimes for various HFC chemicals, and resulted overall, in an increase of about 15-30% compared to the IPCC (2014) values. In both the IPCC AR5 and the UNEP/WMO report no GWP values on HFC mixtures (blends) are reported.

In the RTOC report (UNEP, 2014) the deliberate choice was made to use the 2014 UNEP/WMO values.

It was considered desirable to report here on both the GWP values from the IPCC AR5 and the UNEP/WMO and RTOC reports.

The data sources for tables 3-1 through 3-4:

- "GWP (RTOC)" values are taken from the RTOC report (UNEP, 2014) where available; where not available the value is calculated based on the values for pure fluids from the RTOC report (UNEP, 2014).
- "GWP (IPCC5)" values are taken from the IPCC5 report (IPCC, 2014) for pure fluids; for mixtures values are calculated based values for pure fluids from the IPCC5 report (IPCC, 2014).
- For table 3-1 and 3-2, Refrigerant names, safety classes and compositions are taken from the AHRI AREP program where available, and where not available from ASHRAE 34 public review (ASHRAE, 2015).
- All other data in tables 3-1 through 3-4 are taken from the RTOC report (UNEP, 2014).

3. 3 References

AHRI, 2015 — AHRI Low GWP Alternative Refrigerants Evaluation Program, (Low-GWP AREP), Participants Handbook, 2015

ASHRAE 34-2013 — ANSI/ASHRAE, 2015. Standard 34- 2013 with addenda a to n, Designation and Safety Classification of Refrigerants American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, USA

ASHRAE, 2015 — Online Standards Actions & Public Review Drafts, https://osr.ashrae.org/default.aspx (documents only available during the review period)

Cooper, 1988 — Cooper, R. G., The New Product Process: A Decision Guide for Management. Journal of Marketing Management 2:238-255, 1988.

IPCC, 2014 — Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013. Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

ISO 817:2014 — ISO 817: 2014. Refrigerants — Designation and safety classification. International Organization for Standardization (ISO)

UNEP, 2014 — UNEP Nairobi, Ozone Secretariat, 2015. 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Option Committee, 2014 Assessment. ISBN: 978-9966-076-09-0.

WMO, 2014 — Assessment for Decision-makers, Scientific Assessment of Ozone Depletion: 2014. WMO Global Ozone Research and Monitoring Project - Report No. 56, published online September 2014, in print January 2015, ISBN 978-9966-076-00-7.

4 Present status of alternatives for ODS in refrigeration, air conditioning and heat pumps applications

Since the finalization of the XXV/5 Task Force report in October 2014 and the completion of this XXVI/9 Task Force report, the options for replacing ODS and high-GWP refrigerants have not changed. However, new information of these existing options have been obtained through collaboration with Parties and assessments of several additional reports and publications: the 2014 RTOC Assessment report completed the beginning of 2015, several reports from workshops and conferences, and the documents from the "2015 Workshop on Management of Hydrofluorocarbons (HFCs)"[3].

In summary, in the period available for the development of this report the following updates can be highlighted:

- The testing activities of the unsaturated HFCs (HFOs) and blends containing these compounds continue to be carried out in many companies, independent laboratories, and systems manufacturers.
- Special tests programs are being performed with the focus on high ambient conditions (this is described in details in Chapter 7).
- Some refrigerants have now been assigned a refrigerant number and their composition now publicly disclosed (described in Chapter 3).
- New information regarding the main refrigerants applications is presented in Table 4-1 below (updated from Table 3-1 in the XXV-5 Task Force report) at the end of this chapter.
- Regarding the R/AC applications, the main points to be taken into account are:
    - ***Domestic refrigeration****:* no new ODS alternatives emerged. It is predicted that, by 2020, 75% of new production will use HC-600a;
    - ***Commercial refrigeration****:* no new ODS alternatives emerged; hydrocarbons are being used in condensing units for smaller capacities; in supermarket refrigeration systems there is a confirmation of the strong growth of CO_2 systems, and information of the starting of implementation of trans-critical systems in warmer countries using ejector technology; information is available that CO_2 systems costs are decreasing. More information about comparison of cascade systems (the preferred option for these countries) and trans-critical systems with the new developments is expected to come forward in the coming years; distributed systems are gaining market share.
    - ***Transport refrigeration****:* blends containing unsaturated HFCs are considered to play a role for retrofitting and new systems, and non-conventional eutectic system are becoming more applied
    - ***Air conditioners****:* split systems using HFC-32 are being commercialized in Japan and many countries; there is a wide range of blends containing unsaturated HFCs being proposed. Split units using HC-290 have been available in Europe and Australia and are in production in India. In China, HCFC-22 equipment production capacity is being converted to HC-290. HFC-161 is being tested.
    - ***MAC****:* industry is now reporting more testing data on R-445A.

[3] The "Workshop on Management of Hydrofluorocarbons (HFCs)" was convened in accordance with decision XXVI/9 and it was held in Bangkok, 20 and 21 April 2015. The workshop included issues in relation to HFC management, incorporating a focus on high-ambient temperature and safety requirements, as well as energy efficiency. The workshop involved wide participation of technical experts and industries as overview speakers, panellists. The sessions included all the relevant market and industry sectors and sub-sectors and all regions with a specific focus on high-ambient temperature conditions, where relevant. Fact sheets were developed for the refrigeration and air conditioning applications and were presented and discussed in the workshop. The panellists have been drawn from the "technology providers" and "implementers of technologies" groups from around the world, from both non-Article 5 and Article 5 countries.

The following sections briefly describe, for each R/AC sub-sector, a synthesis of the present status of the alternatives for ODS.

4. 1 Domestic appliances

Globally, new refrigerator production conversion from the use of ODS was essentially completed by 2008. HC-600a or HFC-134a continue to be the main choice of refrigerant for new production. No other new refrigerant has matured to become an energy-efficient and cost-competitive alternative. Refrigerant migration from HFC-134a to HC-600a is expected to continue, driven either by local regulations on HFCs or by the desire for reduced global warming impact from potential emissions. Excluding any influence from regulatory interventions, it is still projected that by 2020 about 75% of new refrigerator production will use HC-600a (possibly with a small share by unsaturated HFC refrigerants - HFOs) and the rest will use HFC-134a. HC-600a refrigerators have proved to be a reliable and highly efficient option; flammability issues have been fully addressed. More than 500 million domestic refrigerators using HCs are already operating globally. Certain countries including the US are still using HFC-134a, however, the US market includes products applying HC-600a, and recent regulations allow products applying HC-290.

4. 2 Commercial refrigeration

On a global basis, HCFC-22 continues to represent a large refrigerant bank in commercial refrigeration, and the most widely used HFC is R-404A. Both refrigerants are used at all temperature levels. Over the last decade, HCs --for stand-alone low refrigerant charge systems-- and R-744 (CO_2) --for supermarkets-- have taken significant market share, especially in Europe. In parallel, progress has been made to improve energy efficiency and leak tightness especially for centralized systems. Commercial refrigeration sub-sector is constituted by three groups of equipment that are discussed below.

Stand-alone Equipment: This equipment that is technically comparable to domestic refrigerators, but with refrigerant charge often larger than in domestic refrigeration. For this type of equipment, HFC-134a and R-404A can be expected to be phased-out progressively in developed countries. Lower GWP HFC (HFOs) and HFC blends, hydrocarbons such as HC-290, and R-744 are replacing R-404A and HFC-134a in new stand-alone equipment, and some plug-in units such as bottle coolers and vending machines are using R-744. Minimum energy standards that have been issued or updated in many countries have to be considered in the equipment design for alternative refrigerants

Condensing Units: For new systems, R-404A is still the leading choice, and intermediate blends such as R-407A or R-407F are proposed as immediate options to replace this refrigerant. Global companies are now offering hydrocarbon condensing units for smaller capacities. One can also expect lower GWP HFC and HFC blends and R-744 to grow in acceptance in this application in the future. R-744 is a non-flammable option, where it should be mentioned that capital costs for small condensing units using R-744 are currently quite high.

Supermarket systems: In Article 5 Parties, HCFC-22 is still the dominant refrigerant used in centralised systems. In Europe, new systems have been mainly charged with R-404A; R-744 is now taking a significant market share with improved energy efficiency. Several thousand supermarkets are already using R-744 systems, in both transcritical and cascade configurations. A two-stage system is an option well known from industrial refrigeration. For supermarkets at low to medium ambient temperatures, the so-called “booster system” has been designed to use R-744 at the low and the medium temperature levels. For supermarkets at medium to high ambient temperatures, the cascade system is preferred with R-744 at the low temperature level and R-744 or HFC-134a at the medium temperature level. The efficiency of transcritical systems is very high in cool ambient conditions and new developments allow efficient operation in warmer ambient conditions. In high ambient conditions it is more efficient to use a cascade system. Capital costs were originally higher than those of HFC systems but are decreasing. R-744 systems require enhancements to achieve competitive seasonal efficiency in hot climates.

For centralized systems, considering the amount of refrigerant charge, flammable or toxic refrigerants are not an option inside the supermarket , but small plug-in HC-290 units cooled by a water circuit are used in some types of supermarkets. Non-flammable lower GWP HFCs can be an option for centralized systems.

Distributed systems are also quite common, gaining market share with improved energy efficiency, lower charge levels and lower emission rates. Indirect systems are also popular in order to limit the refrigerant content by more than 50% and to drastically lower refrigerant emission levels. Flammable refrigerants such as HC-290 or ammonia can be used together with a secondary fluid system (such as glycol or pumped R-744. Development trends for ammonia are leading to use of compact heat exchangers, semi-hermetic compressors and systems with a very low charge.

For developing countries, the important issue remains the replacement of HCFC-22, either for retrofit or for new installations. Blends such as R-407A or R-407F as well as lower GWP HFC and HFC blends constitute options offering a significantly lower GWP than R-404A or R-507A. These alternatives often save energy, however, there are also cases know where the efficiency went down. Moderate and low-GWP HFCs, HFC/unsaturated HFCs (HFOs) blends and unsaturated HFCs (HFOs) have been recently introduced, but commercial experience is limited.

4. 3 Industrial systems

The majority of large industrial systems use R-717 as the refrigerant. When R-717 is not acceptable in direct systems, options include R-744 or glycol in secondary systems or HCFCs or HFCs in direct systems. In countries where R-717 has not been the preferred solution, or in market segments with smaller systems, the transition from HCFC-22 is not straightforward. It requires acceptance of higher cost fluorocarbons in systems similar to the types used with HCFC-22 or the adoption of more expensive systems with cheaper refrigerants R-717 or R-744. HFC-1234ze(E) has been demonstrated in large district heating systems (in chillers) as a possible replacement for HFC-134a.

4. 4 Transport refrigeration

For new systems, hydrocarbons offer high energy efficiency, but the safety risks in transport refrigeration applications appear significant and must be mitigated. Evaluation of the safety of HCs in transport refrigeration is underway and market introduction could occur by around 2018. On the other hand, R-744 has been field-tested since 2011. Its non-flammable characteristics make R-744 attractive, but the gap in efficiency at high ambient temperatures and the limited component supply base are limiting market penetration.

HFC blends are likely to play a role as a replacement to R-404A: their GWP is significantly lower than R-404A and performances are relatively close. Candidates include but are not limited to R-407A, R-407F, R-448A, R-449A, R-450A, and R-452A.

One also sees “non-conventional” solutions such as open loop systems or eutectic systems.

4. 5 Air-to-air air conditioners and heat pumps

R-410A is the dominant alternative to HCFC-22 in air-conditioners and is being used in manufacturing in most non-Article 5 and several Article 5 Parties.

A wide range of different low-GWP alternatives are described in the RTOC 2014 Assessment Report. Some of these are already becoming commercially established in certain countries, while others are in an earlier stage of development. There is currently less availability of lower GWP alternatives in

Article 5 Parties, although this is likely to change significantly during the next few years as technologies used in non-Article 5 Parties are made more widely available.

Except for R-744, all of the medium and low GWP alternatives are flammable and should be applied in accordance with appropriate regulations and/or safety standards (under continuous development), considering refrigerant charge amount, risk measures and other special construction requirements. Some safety standards limit the system charge quantity of any refrigerant within occupied spaces.

HC-290 and HC-1270 are mainly considered for systems with smaller charge sizes, whilst the operating pressures and capacities are similar to HCFC-22 and the efficiency is higher than HCFC-22. Split air conditioning systems using HC-290 have been available in Europe and Australia, are in production in India and HCFC-22 equipment production capacity is being converted to HC-290 in China (however, with limited output at present). R-744 is considered to have limited applicability for air conditioning appliances in Article 5 Parties, due to the reduced efficiency when the ambient temperature approaches or exceeds about 30°C. There is continuing research on cycle enhancements and circuit components, which can help improve the energy efficiency under such conditions, although they will impact system costs.

HFC-161 is currently under evaluation for systems with smaller charge sizes only, due to its flammability. The operating pressure and capacity is similar to HCFC-22 and the efficiency is at least as high as HCFC-22, although there is concern in relation to its stability.

HFC-32 is currently on the market for various types of air conditioners and has recently been applied in split units in several countries and some OEMs are also considering it for other types of systems. The operating pressure and capacity are similar to R-410A and its efficiency is similar or better than that of R-410A.

There are various proprietary mixtures targeted for air conditioning applications, which comprise, amongst others, HFC-32, HFC-125, HFC-134a, HFC-152a, HFC-161, HFC-1234yf, HFC-1234ze, HC-600a, HC-600, H-1270 and HC-290. Some mixtures have been assigned R-numbers, such as R-444B, R-446A and R-447A, whilst most are still under development. These mixtures tend to have operating pressures and capacities similar to HCFC-22 or R-410A, with GWPs ranging from 150 to around 1000 and flammability class 1 (for higher GWPs) and class 2L (medium GWPs). Currently, most of these mixtures are not commercially available on a broad scale and adequate technical data is not yet in the public domain. Other low-GWP single component HFCs, such as HFC-1234yf and HFC-152a, are unlikely to be used extensively as a replacement for HCFC-22 in air conditioners principally because of their low volumetric refrigerating capacity.

4. 6 Water heating heat pumps

Refrigerants used are R-410A, HFC-134a, R-407C, HC-290, HC-600a, R-717 and R-744. The majority of new equipment uses R-410A. In some Article 5 Parties, HCFC-22 is being used due to its favourable thermodynamic properties and high efficiency. There are no technical barriers in replacing HCFC-22 by a non-ODS. The technical and process changes related to pressure, lubrication and contamination control are well known. Replacements are commercially available, technically proven and energy efficient. All replacements have a similar or lower environmental impact. R-410A has a slightly higher GWP but the required charge is less than HCFC-22. Replacements such as HFC-32 and other low-GWP HFC blends are under way to become commercially available.

HFC-134a, R-744 and HFC blends R-407C, R-417A and R-410A are commercially available solutions R-410A is most cost effective for small and medium size systems, while for large systems HFC-134a is most efficient. R-407C and R-417A are the easiest alternatives for HCFC-22 from a design point of view, but cannot compete with the other HFC-solutions.

4.7 Chillers

The refrigerants that were used in the transition from ODS refrigerants generally were HFCs with GWPs that are sufficiently high to cause environmental concerns, so a second transition has begun. Major efforts have been launched to propose and test new, lower GWP refrigerants. A number of candidates have been proposed and are in the early stages of testing as possible replacements for higher-GWP HFCs.

The new candidates generally are unsaturated HFCs or blends, which may contain HFCs, HCs, and/or unsaturated HFCs. Options for new equipment include: R-717, R-744, HC-290, HC-1270, HFC-1234ze(E), HCFC-1233zd(E), HFC-1336mzz(Z), HFC-32, R-444B, R-446A, R-447A, and R-450A.

District cooling: district cooling could provide a high efficiency solution that would avoid the installation of multiple pieces of small equipment, addressing some of the difficulties described above. Whilst it was agreed that such systems may be applicable under certain circumstances (e.g. when a major property development was being planned) it is not likely to be a solution for structures where already a majority of small systems have been installed. It is also being pointed out that district cooling may not be applicable in regions with a water shortage.

4.8 Vehicle air conditioning

Currently, all modern MAC systems in cars and other small vehicles use HFC-134a as the refrigerant. In recent years there has been a significant activity in the area of development of new low-GWP refrigerants (<150) as alternatives to HFC-134a. This was stimulated by the 2006 EU MAC Directive that bans the use of refrigerants with a GWP above 150, and by the US EPA (credit for reducing refrigerant-related GHG emissions).

The increasingly rapid evolution of hybrid electric vehicles and electric vehicles with reversible air conditioning and heat pump cycles, which use semi hermetic electrically driven compressors introduces new challenges for any new alternative refrigerant.

At present, no regulations exists that control the use of fluorinated greenhouse gases as refrigerants for MAC systems in buses and trains. It is likely that the choice of refrigerant of passenger car air conditioning systems, as well as developments in the stationary heat pump market, will influence the choice of refrigerant for air conditioning systems in buses and trains.

It looks likely that more than one refrigerant will be used in the coming years for car and light truck air conditioning: HFC-134a will remain largely adopted worldwide, HFC-1234yf will continue expanding in new model cars. At the end of 2014, three million cars were assumed to be on the road using HFC-1234yf. R-744 is expected to be implemented in some regions on a commercial scale by 2017. For large MAC systems using R-744 as an alternate refrigerant, ejector systems should be used to enhance the performance of the system at high ambient temperatures.

All options have GWPs below the 150 threshold and can achieve fuel efficiencies comparable to modern HFC-134a systems. Currently it cannot be forecast whether or not all these refrigerants will see parallel use in the market for a long period of time. It is also unclear whether the bus and train sector will follow these trends.

Due to patent issues, HFC-1234yf is only manufactured by two refrigerant companies. The current cost of this refrigerant is 15 to 20 times that of HFC-134a. A few OEMs and suppliers have investigated hydrocarbons (HC-290, HC-600a) for direct expansion and HFC-152a in a secondary loop. These can provide good thermal performance, but car manufacturers are reluctant to consider them due to flammability concerns.

A few other new refrigerant mixtures for MAC have been developed (e.g. R-445A, GWP=120). Some OEMs and suppliers have conducted extensive testing with R-445A for performance, material compatibility, flammability and risk assessment. However, these systems have not yet been commercialized. For electric vehicles and hybrid vehicles heat pump systems are needed for passenger heating - both R-744 and R-445A have shown good performance in heat pump mode.

Table 4-1: Status of the various refrigerants in R/AC sub-sectors

GWP	0	<1	<1	1	1	2	1 – 5	4	4	89	120	290	300	460
	R-717	HFC-1234yf	HFC-1234ze(E)	R-744	HCFC-1233zd(E)	HFC-1336mzz(Z)	HC-290, HC-1270	HC-600a	HFC-161	R-444A	R-445A	"L-40"	R-444B	R-446A
Domestic refrigeration		F						C						
Commercial refrigeration														
— Stand alone equipment		L	F	C			C	C				F	F	F
— Condensing units		F		L			L	F				F	F	F
— Centralised systems	L	F		C			L					F	F	F
Transport refrigeration		F		C			C					F	F	F
Large size refrigeration	C	F		C			L					F	F	F
Air conds and heat pumps														
— Small self contained		F		L			C		F				F	F
— Mini-split (non-ducted)				L			C		F				F	L
— Multi-split				L									F	L
— Split (ducted)				F			F						F	F
— Ducted split comm. &				F			L						F	F
— Hot water heating HPs	C	F	F	C			C	C				F	F	F
— Space heating HPs	C	F	F	L			C	L				F	F	F
Chillers														
— Positive displacement	C	L	L	C			C					F	F	L
— Centrifugal		L	L		L	F	L							
Mobile air conditioning														
— Cars		C		F			F	F		F	F			
— Public transport		L		F						F	F			

GWP	490	550	570	570	677	1300	1300	1370	1600	1820	1900	1900	2100	3900
	"DR-5"	R-450A	R-447A	R-513A	HFC-32	R-448A	R-449A	HFC-134a	R-407C	R-407F	R-452A	R-410A	R-407A	R-404A
Domestic refrigeration		F		F				C						
Commercial refrigeration														
— Stand alone equipment	F	F	F	F	F	L	F	C	F	F		F	F	C
— Condensing units	F	F	F	F	F	L	F	C	F	F		F	F	C
— Centralised systems	F	F	F	L	F	L	F	C	F	C		F	C	C
Transport refrigeration	F	F	F	F	F	F	F	C	F	F	F	C	F	C
Large size refrigeration	F	F	F	F	F	F	F	F	C	C		C	C	C
Air conds and heat pumps														
— Small self contained	F	F	F	F	L	F	F	C	C	F		C	F	F
— Mini-split (non-ducted)	F	F	L	F	C	F	F	F	C	F		C	F	F
— Multi-split	F	F	L	F	L	F	F	F	C	F		C	F	F
— Split (ducted)	F	F	F	F	L	F	F	F	C	F		C	F	F
— Ducted split comm. & non-	F	F	F	F	L	F	F	C	C	F		C	F	F
— Hot water heating HPs	F	F	F	F	L	F	F	C	C	F		C	F	F
— Space heating HPs	F	F	F	F	L	F	F	C	C	F		C	F	C
Chillers														
— Positive displacement	F	L	L	L	L	F	F	C	C	F		C	F	C
— Centrifugal								C						
Mobile air conditioning														
— Cars		F		F				C						
— Public transport		F		F				C	C			C		

Note: C = Current use on a commercial scale. L = Limited use such as for demonstration trials, niche applications etc. F = Use is potentially feasible, based on fluid characteristics

5 BAU and MIT scenarios for Article 5 and non-Article 5 Parties

5. 1 Overview of updates

- In accordance with Decision XXVI/9, a report has been made available to the meeting of the 36th OEWG, and an update report will be submitted to the Twenty-Seventh Meeting of the Parties, that addresses the information requested by Parties in that decision.
- Considerations for the updates have been submitted in writing and were discussed with Parties during an informal discussion session at OEWG-36, Wednesday lunchtime. TEAP XXVI/9 Task Force members discussed with interested Parties the feasibility of potential updates considering both the update requested within the scope of Decision XXVI/9 as well as the timeline for completing the updated report in early September to meet the deadline for submission of documents to the 27th MOP. At the OEWG-36, considerations for updates to the TEAP Decision XXVI/9 Task Force Final Report (May 2015) were submitted in writing to the OEWG-36 plenary meeting and are part of the meeting report of OEWG-36. The considerations for the updated report are summarized in Annex 1.
- This chapter 5 update to the TEAP Decision XXVI/9 Task Force Final Report incorporates changes to address the following topics related to scenarios:
    - More precise HFC production data for Article 5 and non-Article 5 Parties, to be available to cross-check R/AC calculations up to the years 2014-15;
    - A much better explanation of all assumptions used for the scenario calculations. Furthermore, a clear definition of which low GWP value is to be used in scenarios (if a GWP around 300, then a good analysis why 300 would be the best average);
    - Investigation whether it would be feasible to expand scenarios to the year 2050; and
    - Consideration of which specific sector transitions would need to be considered critical in R/AC in order for HFC reductions to be achieved.

This chapter is organized as follows:

5.1 Overview of updates
5.2 Revision of scenarios
5.3 Method used for calculation
5.4 HFC consumption and production data
5.5 Non-Article 5 scenarios
5.6 Article 5 scenarios

5. 2 Revision of scenarios

In the XXV/5 Task Force report, BAU scenarios were developed for R/AC and foams for non-Article 5 and Article countries. The HFC consumption (demand) for R/AC was estimated to be 5 times larger than for foams in the year 2010, and using a simple extrapolation to 2030, it is expected that, by 2030, R/AC increases exponentially to 95% of the total demand for R/AC and foams.

Mitigation measures were investigated in MIT-1 and MIT-2 scenarios in the XXV/5 Task Force report. Bans on the use of certain high-GWP chemicals were assumed to enter into force in new manufacturing as of 2020.

- In non-Article 5 Parties, the MIT-1 scenario predicts a moderate growth to the year 2030, the MIT-2 scenario a decrease of 40% from 2015 to 2030 in the R/AC sector.
- For Article 5 Parties, the MIT-2 scenario predicts a reduction of about 70%, from 2400 to 800-1000 Mt CO_2-eq. for the same period 2015-2030.

Decision XXVI/9 asks to revise the scenarios in paragraph 1 (c): "Taking into account the uptake of various existing technologies, revise the scenarios for current and future demand elaborated in the October 2014 final report on additional information on alternatives to ozone-depleting substances of the Technology and Economic Assessment Panel's task force on decision XXV/5, and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and stage II of HCFC phase-out management plans".
The Task Force is unaware of significant technical uptake that would require a complete revision of the previous mitigation scenarios. The mitigation scenarios in the XXV/5 Task Force report have already assumed a phase-out date of 2020 for the use of high-GWP substances in the manufacturing for most R/AC sub-sectors, which date is challenging. One option to consider would be a slower phase-in of the manufacturing conversions according to feasibility.

The Task Force has not been able to change the BAU scenarios for the foams sector in both non-Article 5 and Article 5 Parties.

The following scenarios have been calculated, which apply to the R/AC sector only.

a. A BAU scenario: In Article 5 Parties, small downward adjustments were made based on recent (economic) growth percentages expected for the period 2015-2030, in particular related to future growth in larger Article 5 Parties. The change in assumptions had major consequences for the HFC demand in the commercial refrigeration and stationary AC sector.
b. An MIT-3 scenario: This is the same as the MIT-2 scenario described in the XXV/5 report, but with an adjustment of the average GWP for certain replacement refrigerants of 300 for both the commercial refrigeration and the stationary AC sectors.
c. An MIT-4 scenario: This is the same as the MIT-3 scenario, but with the assumption of 2025 for the start of the manufacturing conversion for stationary AC in Article 5 Parties.
d. An MIT-5 scenario: This is the same as the MIT-3 scenario, but with the assumption of a 2025 *completion of* conversion in non-Article 5 Parties of all R/AC sub-sectors and the start of the manufacturing conversion of all R/AC sub-sectors in 2025 in Article 5 Parties.

The MIT scenarios described in the XXV/5 Task Force report assumed that bans for certain refrigerants in R/AC sub-sectors would have immediate effect in 2020, but this is not realistic at all. Therefore in this XXVI/9 report, manufacturing conversion periods have been built in of 3 years for non-Article 5 Parties *before* a ban on certain refrigerants would become effective, and 6 years for Article 5 Parties *after* a control on a refrigerant would become effective. Next to the assumption of 6 years, the length of the manufacturing conversion period has been varied to study the impact on the demand scenario in CO_2-eq. terms.

For Article 5 Parties, manufacturing conversion projects would need preparation to be funded; it would also cost a certain period before conversion projects would have been approved by a funding authority. Finally, experience with CFCs and HCFCs has shown that, the slower the conversion of manufacturing, the longer the servicing tail will be, i.e., the longer servicing of equipment will be required.

In this chapter the scenarios will be given in the following sequence. First the BAU scenario for non-Article 5 Parties will be dealt with, which will be analysed in tonnes and ktonnes CO_2-eq. This is then followed by the MIT-3 and MIT-5 scenarios for non-Article 5 Parties; new manufacturing and servicing analysis is only done in ktonnes CO_2-eq. (not in tonnes). As a next step the Article 5 scenarios are given. Again, first the BAU scenario for Article 5 Parties will be dealt with, which will be analysed in tonnes and ktonnes CO_2-eq. This is then followed by the MIT-3, MIT-4 and MIT-5 scenarios for Article 5 Parties; new manufacturing and servicing analysis is done in tonnes and in ktonnes CO_2-eq.

5.3 Method used for calculation

As requested by parties in comments to the Decision XXVI/9 report, additional information on the method used for calculation is provided in this updated report as below.

A "bottom-up" method has been used to predict the demand for R/AC equipment. The RTOC 2010 Assessment Report (RTOC, 2010) describes the bottom-up method used here. A bottom up method derives the size of banks from information obtained from outside (accountancy reports on trade and exports, if possible, supplemented with a trend analysis). The banks serve to calculate emissions using agreed emission parameters. As a result, the demand (or "consumption") can be calculated, which consists of (1) what is supplied to the existing banks (i.e., to compensate for leakage), and (2) what is added to the bank (i.e., in new equipment that has been charged). In a spreadsheet analysis, this can be seen as one stream of refrigerant into a bank with equipment that has been manufactured over a number of years. In summary, the refrigerant demand or the annual sales of new or virgin refrigerant are equal to the amount of refrigerant introduced into the refrigeration and AC sector in a country (or region) in a given year. It includes all the chemicals used for charging or recharging equipment, whether the charging is carried out in the factory, in the field after installation, or whether it concerns recharging with the appropriate equipment during maintenance operations.

In this type of "bottom-up" approach, one therefore evaluates the consumption of a certain refrigerant based on the numbers of equipment in which the fluid is charged, e.g. refrigerators, stationary air-conditioning equipment, and so on. It requires the establishment of an inventory of the numbers of equipment charged with substances (which then forms the total inventory, or the "bank"), and the knowledge related to their average lifetime, their emission rates, recycling, disposal, and other parameters. The annual emissions are estimated as functions of all these parameters during the equipment lifetime.

The refrigeration and air-conditioning sectors are disaggregated in six sub-sectors in this report. However, due to the diversity of equipment that can be found within the same sector, a more disaggregated level is needed in order to calculate the emission factors and the activity data, such as equipment lifetime, average charge, and refrigerant type. For example, if one considers the commercial refrigeration sector, the emission factor varies widely between the different refrigerating systems that can be found within this sector: the emission factor for standalone equipment is in the range of 1% and, for large centralised systems, it can reach up to 30%. The mass-balance approach shows limitations especially when the recharge frequency is not on annual basis as *for MAC systems*: what enters for the servicing in a given year is not equivalent to what has been emitted. A delay of 5 to 8 years could be observed. In a mature market, where the average charge of the MAC system does not change and emission characteristics are also constant along time, this model could be applied since vehicle characteristics are identical, and the refrigerant stock does not change, which means that what is emitted 8 years ago is equal to what is emitted that year. This is not very realistic due to e.g. the leak tightness improvements observed in MAC systems since the introduction of HFC-134a.

Equations used for the emission-factor approach of the Tier 2 method are the basis of the general calculation method in the program used. Still, some particular issues might appear for each sub-sector, which would require specific input parameters and therefore some modifications to the main calculation algorithm. The method has been adapted to the sub-sectors based on the availability of the activity data and the emission factors. For example, for the commercial centralized systems, chillers, and industrial refrigeration, emission factors are established based on purchase invoices of refrigerants. The amount of refrigerant purchased includes the refrigerant used to replace the losses from leakages and the losses during the system servicing, and therefore both types of emissions are considered within the emission factor, which is then applied to the refrigerant bank. The same methodology is not possible for MAC or stationary air-conditioning systems. Sources of information of emission factors for sectors are often scarce; some studies provide numbers on the initial Leak Flow Rate (LFR) and others give numbers on the LFR of a fleet of vehicles from different vintages.

The calculation method considers that the installed base in operation from the period 1975-1990 will have gradually disappeared in the year 2000, so that estimates for the banks and emissions (from which the demand is calculated) after the year 2000 are based on the amount of equipment that was manufactured after 1990. In this way, choices for certain new refrigerants can be gradually introduced in the total demand (either expressed in tonnes or in CO_2-eq.), consisting of both the new manufacturing (i.e., charging of new equipment) and the servicing demand.

The GWP for low GWP replacement refrigerants has been constructed as follows. In domestic refrigeration the use of isobutane is assumed with a very low GWP. In cases where the replacement refrigerant is known (ammonia, hydrocarbons) the very low GWP factors have been used. In case of commercial refrigeration one can assume the use of carbon dioxide, pure low-GWP refrigerants or refrigerant blends in supermarkets, low GWP hydrocarbons in mass produced units, blends or carbon dioxide in condensing units (where an average GWP of 300 is used). For stationary AC as a whole, an average GWP of 300 has also been used. In MACs, replacement refrigerants are assumed to have negligible GWP.

Table 5-1: Growth rates for high-GWP HFCs in the various R/AC sub-sectors during the periods 2010-2020 and 2020-2030 (a negative growth rate may still imply a positive growth in the number of equipment, but assumes that low-GWP alternatives are increasingly applied in a BAU scenario, and also in MIT scenarios until conversion starts in certain years)

Period	Sub-sector	non-Article 5	Article 5
2010-2020	Domestic refrigeration	-3.9%	5.8%
	Industrial refrigeration	5.1%	1.8%
	Transport refrigeration	0.9%	1.8%
	Commercial refrigeration	-4.4%	1.8%
	Stationary AC	1.2%	1%
	Mobile AC	0.54%	5%
2020-2030	Domestic refrigeration	3%	5.8%
	Industrial refrigeration		3.7%
	Transport refrigeration		4.5%
	Commercial refrigeration		4.5%
	Stationary AC		1%
	Mobile AC		5%

Growth rates for equipment production have been changed compared to the rates used in the XXV/5 report. In this report, the growth rates apply as given in Table 5-1 above.

A number of considerations substantially complicate the calculations. This includes the preference to apply certain alternatives in specific equipment (and often under certain conditions), combined with the fact that the R/AC banks -the amounts present in the equipment- need recharging (i.e., servicing) over the entire lifetime of the equipment. Further details are given in Table 5-2.

In Table 5-2, the percentage ranges given for most sub-sectors are related to equipment in sub-sub-sectors, which are assumed to show different annual leakage percentages (e.g. in transport it would be refrigerated trucks, containers, other types of products, in stationary AC, one can separate between many types of equipment, each with specific leakage rates). Next to a description of the bottom-up method used, (RTOC, 2010) gives estimates for the uncertainties in banks, emissions and demand calculated.

Table 5-2: Lifetime and leakage per year for equipment assumed in the various R/AC sub-sectors for non-Article 5 and Article 5 Parties. The lifetimes and percentages in the two groups of countries vary dependent on the specific country.

Country	Sub-sector	Lifetime (year)	Leakage/year
non-Article 5	Domestic refrigeration	15	1%
	Industrial refrigeration	15-30	15%
	Transport refrigeration	9-30	15-30%
	Commercial refrigeration	15	15-30%
	Stationary AC	10-25	2-10%
	Mobile AC	15-16	10g/y for cars 15% for other
Article 5	Domestic refrigeration	20	2%
	Industrial refrigeration	15-30	15-30%
	Transport refrigeration	9-30	15-30%
	Commercial refrigeration	20	15-40%
	Stationary AC	10-25	2-10%
	Mobile AC	15-20	10g/y for cars 10-20% for other

In Table 5-2, the percentage ranges given for most sub-sectors are related to the equipment in sub-sub-sectors, which are assumed to show different annual leakage percentages (e.g. in transport it would be refrigerated trucks, containers etc.). Next to a description of the bottom-up method used (RTOC, 2010) gives estimates for the uncertainties in banks, emissions and demand calculated.

Depending on the application sector, uncertainties are different either because activity data include different uncertainties or because emission factors may vary significantly from one country to the other. (RTOC, 2010) describes a simple approach that gives a quality index expressed in percentages. For activity data the market, the refrigerant charge and the equipment lifetime are the main elements that define the data quality. For emission factors, fugitive emissions and recovery efficiency at end of life are the two key parameters. Uncertainties on input parameters are based on expert judgements of the different sectors. These values are given in Table 5-3.

Table 5-3: Uncertainties on input parameters for the various R/AC sub-sectors

Uncertainties on input	MAC	Stat AC	Industrial	Transport	Commerc.	Domestic
Equipment market (a)	2.50%	2.50%	10%	12.50%	7.50%	2.50%
Equipment lifetime (b)	7.50%	2.50%	7.50%	2.50%	7.50%	12.50%
Equipment aver. charge (c)	2.50%	12.50%	10%	7.50%	7.50%	2.50%
Emission rate (d)	10.00%	7.50%	10%	7.50%	10%	12.50%
Recovery efficiency (e)	10.00%	7.50%	12.50%	7.50%	12.50%	2.50%

Uncertainties in banks are estimated at 12.5-22.5%, uncertainties in emissions 12.8-37%, specific numbers are dependent on the sub-sector. For the total R/AC sector, the uncertainty range in the demand calculated is estimated at -10/+30%.

The calculation method goes from 1990 until 2030, since it is thought that calculations into a further future would not make much sense, since many unknown variables regarding type of equipment, charge and leakage will determine the demand, emissions and banks calculated. For the scenario calculations reported here, expansion until 2040 or 2050 would certainly be useful to see the long term trends, in particular if conversion processes take a long time. It has therefore been investigated how much work it would cost to adapt the calculation method; this would cost more than 3 weeks and the time and budget required for this information (for this XXVI/9 update report) were simply not available.

Estimates should be cross-checked with reported HFC consumption and production data, specified per refrigerant (or refrigerant blend). However, for non-Article 5 Parties, annual emissions and demand reporting via UNFCCC is not very reliable, and for Article 5 Parties, it is not available on an annual basis, if at all. The following section provides some more detail.

5.4 HFC consumption and production data

If not used for emissive applications, HFCs produced are built up in installed equipment and products and are used for re-charging during maintenance. In reality, the HFC "bank" is growing in equipment, where each type of equipment has a specific lifetime and is characterised by a certain leakage rate. It is thus very difficult to equate emission data with production. However, estimates for global 2012 and 2015 HFC production can be made by combining UNFCCC data, manufacturer's estimates for production capacity as well as global emission data. This is given below.

Data on HFC emissions are reported annually by developed countries, the Annex I Parties under the UNFCCC Kyoto Protocol; these emission data are estimated (calculated) by national agencies. HFC consumption and production data are also reported to the UNFCCC. Even when certain consumption and production data are missing (i.e., data not reported by some countries, or reported as HFCs in general), a reasonable estimate for the production of most HFCs in the Annex I Parties can be made.

However, HFC production data are not reported by developing countries, i.e., the non-Annex I Parties under UNFCCC (apart from perhaps some information in national communications).

Zhang and Wang (2014) published a paper, which gave data for the production of 8 HFCs in China for the period 2005-2009; production shows an increase by a factor four from 50 Mt CO_2-eq. in 2005 to more than 200 Mt CO_2-eq. in 2009. Data were collected from industrial surveys, supplemented with data from other sources. Production for 2009 was given for HFC-125 (18 ktonnes), HFC-134a (60 ktonnes), HFC-143a (5 ktonnes) and HFC-32 (17 ktonnes). It is not clear what the uncertainty in these values is. However, extrapolation towards 2014-2015 is too difficult from the data as given by Zhang and Wang (2014).

Estimates for HFC production in the developing countries are often made by developed country chemical manufacturers (Kuijpers, 2015). Based on global consumption calculations, estimates for HFC production were also made by McCulloch (2015). Furthermore, global emissions data for several HFCs are available from certain literature sources, e.g. from Montzka (2015). Recently, Chinese HFC (and HCFC) production data up to the year 2013 were reported by Kaixiang (2015). Further HFC production estimates from Chinese manufacturers were also obtained through May-July 2015 (Kuijpers, 2015).

This report gives estimates for HFC production of the four main HFCs in Table 5-4 below (based on the 2012 UNFCCC data and a large number of estimates for the production in Article 5 Parties, i.e., mainly China). These HFCs are the ones used in the R/AC sector. It shows a total production of about 475 ktonnes, forecast for the year 2015 for these four main HFCs (about 910 Mt CO_2-eq., if calculated in climate terms). The global production capacity for these HFCs is estimated much higher, at a level of 750 ktonnes (Campbell, 2015).

It needs to be emphasised that the global HFC production (for the four main HFCs) determined in this way is estimated to have a ± 10% uncertainty for the separate HFC chemicals. These production data are reasonably reliable global estimates and can be used in order to check the demand data determined via the bottom-up method used, which are given in the sections below for the R/AC sector. It would then apply to the following HFCs (used in the R/AC sector): HFC-32, -125, -134a and -143a.

Table 5-4: Estimates for global HFC production (for HFC-32, -125, -134a and -143a)

Gg (ktonnes) for HFCs (per year)	(Montzka, 2015) Emissions year 2012	UNFCCC based estimate for non-A5 prod. (2012)	Estimate for non-A5 production (for 2015)	Estimate from various sources A5 production (for 2015)	Estimate global production year 2015 (*)
HFC-32	16 (21**)	≈ 22	23	71	94
HFC-125	41	< 30	31.5	98.5	130
HFC-134a	173	< 100	97	126	223
HFC-143a	21	<10	11	17	28

Note: (*) Global production is equal to non-Article 5 plus Article 5 country (China, minor other) production
Note: (**) Estimate from Rigby (2013)

The production amount of HFC-32 is assumed to be rapidly growing, mainly due to production in Article 5 Parties. The same would apply to HFC-125. HFC-143a production is assumed to be 28 ktonnes in 2015, and cannot be much larger due to the few facilities producing that have been investigated. The HFC-134a amount produced is in the order of 220-230 ktonnes (223 ktonnes determined above), this may be slightly underestimated, amounts could be in the order of 240-250 ktonnes in the period 2015-2017.

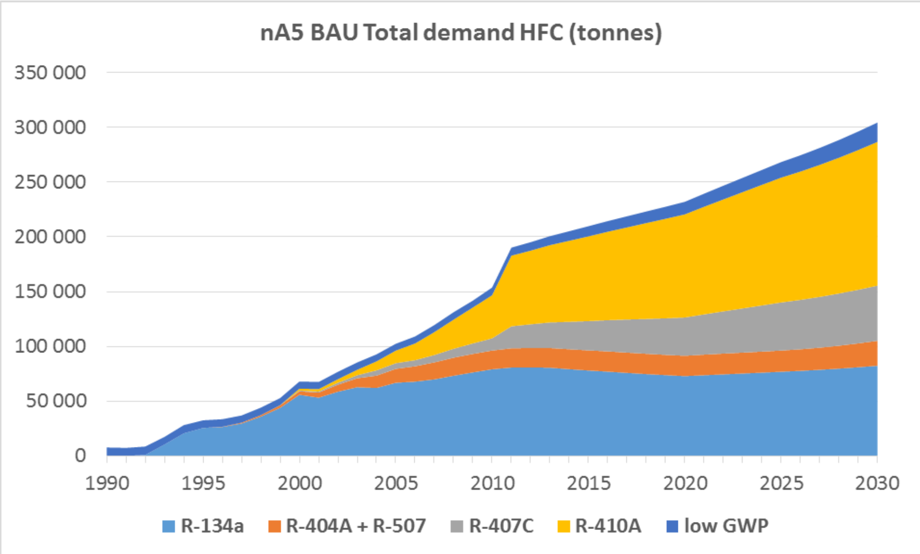
The bottom-up method, of which the numerical results are reported below gives a global result of about 28 ktonnes for HFC-143a, which seems to be consistent. Values for HFC-134a estimated in the R/AC sector are in the order of 170-180 ktonnes, which would be consistent with total estimates for R/AC and other (non R/AC) HFC-134a uses. The production quantity of HFC-32 and HFC-125 together would be in the order of 225 ktonnes in 2015. The bottom up method calculates 250-260 ktonnes for the year 2015, which seems to be too high. This may be due to particular assumptions for the use of R-410A for stationary AC in the bottom-up method, specifically for the rapid conversion from HCFC-22 in 2008-2010. Production might also be slightly underestimated. Differences may be small, however, this needs further investigation, which could not be done with the current calculation procedure and within the timeframe that applied for the Update XXVI/9 Task Force report. For the time being, the best procedure is to analyse the stationary AC sector for the various MIT scenarios on its own merits. Some adjustments downward in future calculations are not expected to change the conclusions for this sub-sector.

5. 5 Non-Article 5 scenarios

5.5.1 BAU scenario

In the figures below the results of the BAU scenario calculations are shown:

- Non-Article 5 BAU scenario with subdivision for refrigerants.
- Non-Article 5 BAU scenario with subdivision for the various R/AC sub-sectors.



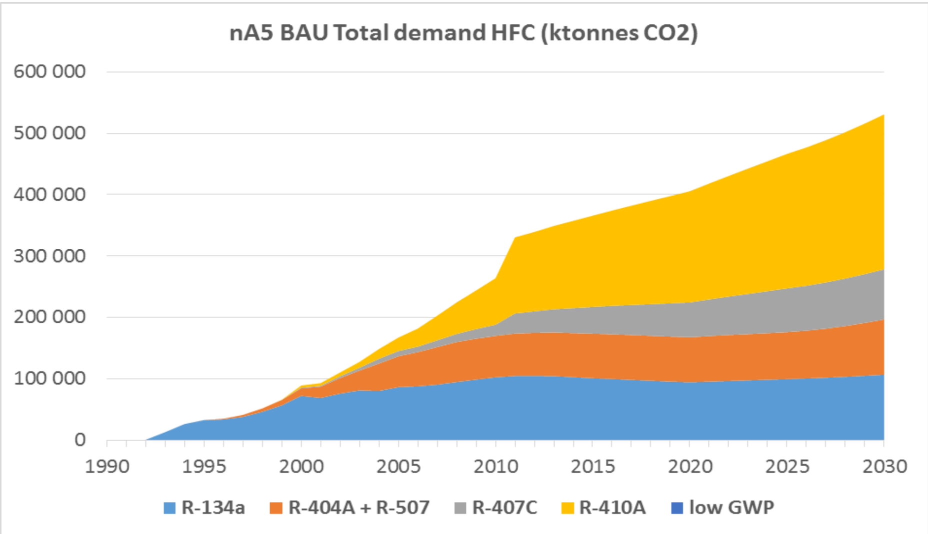
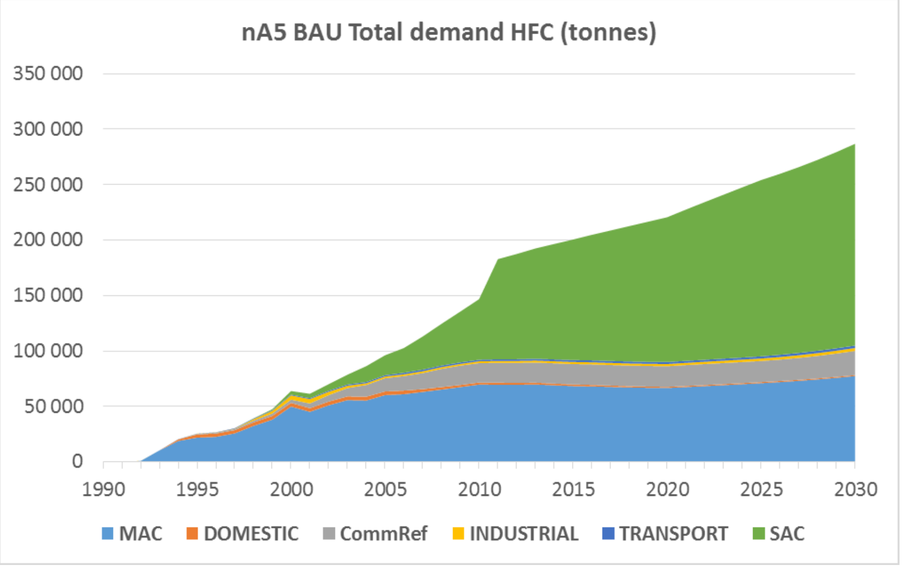


Figure 5-1: Non-Article 5 BAU scenario with subdivision for the various refrigerants or refrigerant blends

Figure 5-1 shows the current and projected future non-Article 5 refrigerant BAU demand, with a subdivision for the commonly used high-GWP refrigerants and low-GWP refrigerants. The demand is given in tonnes and in GWP weighted terms (in CO_2-eq.). Low-GWP refrigerants in the BAU scenario account for about 10% by weight by 2030, but have a very low GWP, since it mainly concerns ammonia, hydrocarbons and some carbon dioxide. Over the period 2010-2030, the importance of R-410A and R-407C for stationary AC becomes quite dominant, with a 30% increase by weight, but a 50% increase over the 2015-2030 period in GWP weighted tonnes. The calculation may be showing a somewhat high demand in 2015 (about 200 ktonnes) due to the increase assumed between 2010 and 2012 (i.e., HCFC conversions); also the demand of 380 Mt CO_2-eq. for the year 2015 seems a bit high.



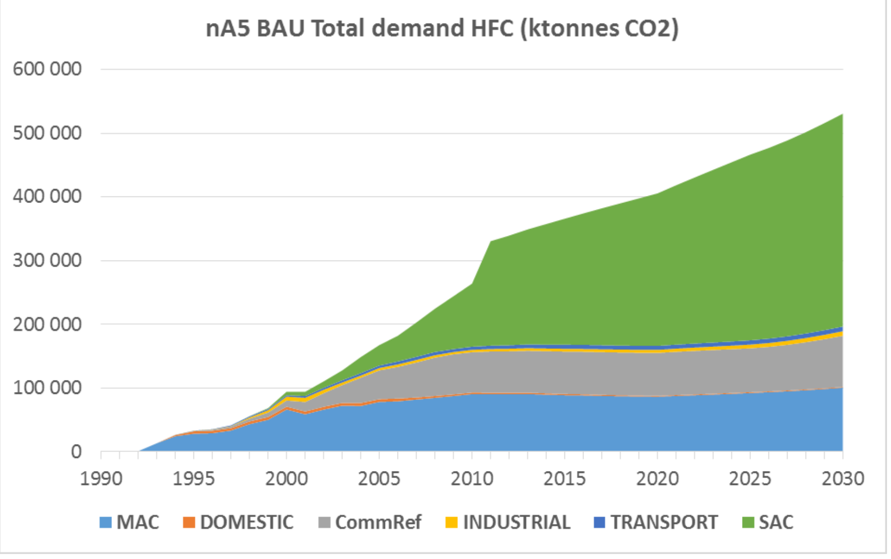


Figure 5-2: Non-Article 5 BAU scenario; subdivision for the various R/AC sub-sectors

Figure 5-2 shows the non-Article 5 refrigerant BAU demand, with a subdivision for the different R/AC sub-sectors (n.b., all graphs start in the year 1990). The demand is given in tonnes and in kt CO_2-eq.). By 2030, stationary AC accounts for almost 70% of the GWP adjusted tonnage (even when using low growth percentages, as given in Table 5-1).

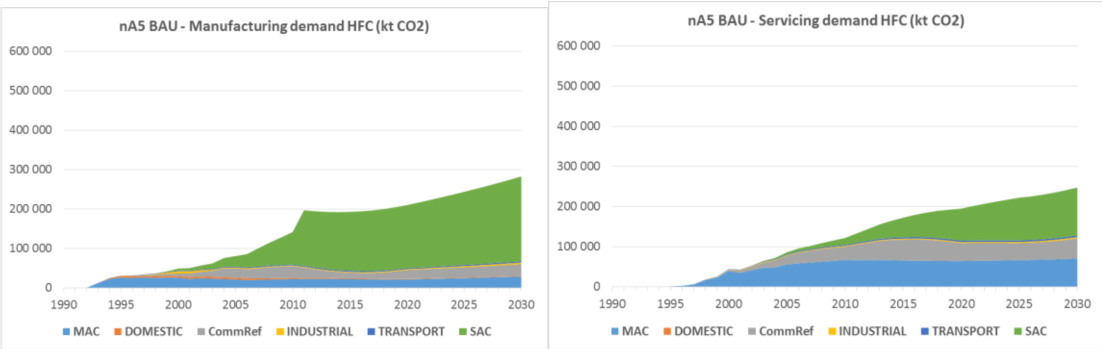


Figure 5-3: New manufacturing and servicing parts of the non-Article 5 BAU scenario with a subdivision for the various R/AC sub-sectors

The above figures, in particular the one for the manufacturing demand needs some explanation. In the bottom-up calculation (which for BAU assumes no HFC measures, but has to include HCFC controls and assumptions on HCFC replacement in Non-Article 5 Parties) the result of an assumption of certain change-overs from HCFCs to HFCs is assumed to be a given in the BAU scenario. Assumptions used for a rapid HCFC-22 transfer to, in particular, R-410A in stationary AC, result in the profile as shown, i.e., a 30% increase in a period of 1-3 years, after which the usual BAU profile starts again. The assumption of the HFC (R-410A) increase (related to the HCFC -22 decrease) may be too high, but that is the main reason why, in these investigations, the estimated demand for stationary AC for 2015-2030 may be high compared to the production capacity that has been realised up to 2015.

5.5.2 MIT-3 scenario

This is an update on the MIT-2 scenario developed for the XXV/5 Report. The following figures are for the MIT-3 scenario, for non-Article 5 Parties, in the various R/AC sub-sectors.

This is the scenario where all sub-sectors are assumed to have converted by the year 2020. The total demand, the new manufacturing and the servicing demand are shown in Figs 5-4, 5-5 and 5-6.

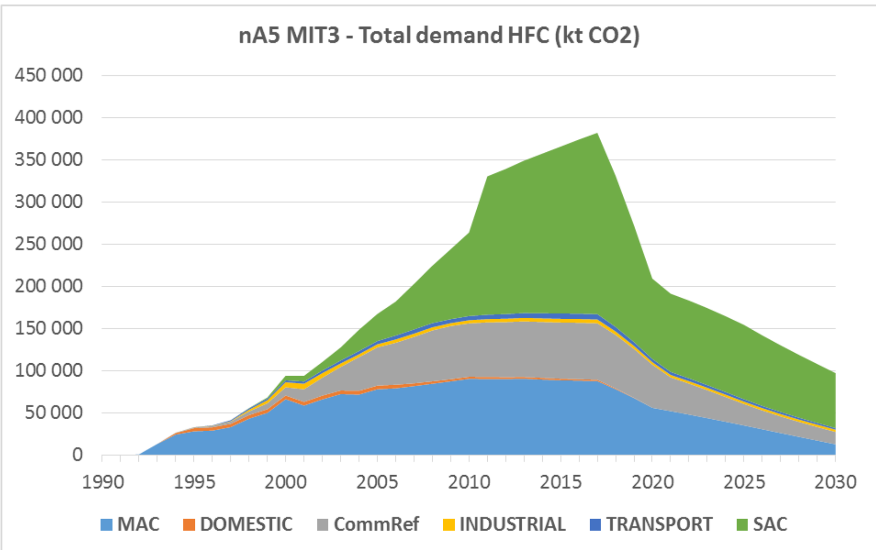


Figure 5-4: Total demand for the Non-Article 5 MIT-3 scenario with a subdivision for the various R/AC sub-sectors

In MIT-3, the conversion in all sub-sectors to replace high-GWP refrigerants with a variety of refrigerants with an average GWP of 300 is assumed to be complete by 2020. Manufacturing capacity is converted in equal portions per year during the period 2017-2020.

Figure 5-4 shows the steep decrease in the years before 2020, after which the curve flattens due to continued servicing needs. Since some high-GWP equipment will have been manufactured until 2020, and has an average 12 year lifetime, supplies of high-GWP refrigerants will continue to be required in decreasing amounts until about 2032.

During 2010-2015, stationary AC and commercial refrigeration demands are assumed to increase quickly (see above). With bans on new manufacturing as of 2020, high-GWP refrigerants in these sector decrease, being replaced by low-GWP refrigerants which will account for 80% of total demand between 2020 and 2030.

This is a large improvement in climate impact, although with GWP of 300, the large refrigerant volumes considered still have a certain climate impact (note: this is a change compared to the MIT-2 scenario in the XXV/5 Task Force report, where a GWP of 600 was chosen), the relative importance of these refrigerants is much lower in the GWP weighted graph. However, this demand still represents a small amount in climate weighted terms.

In Figure 5-5, the new manufacturing demand for the R/AC sub-sectors for high-GWP chemicals is given.

By 2020, the demand for high-GWP refrigerants in new equipment manufacture falls to < 5% of the 2019 peak.

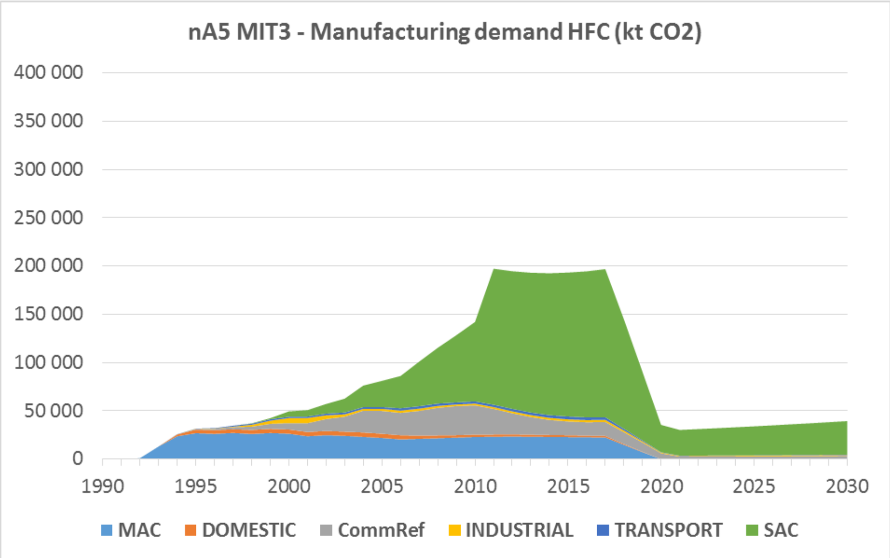


Figure 5-5: Non-Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors (assuming manufacturing conversion over a period of 3 years, 2017-2020).

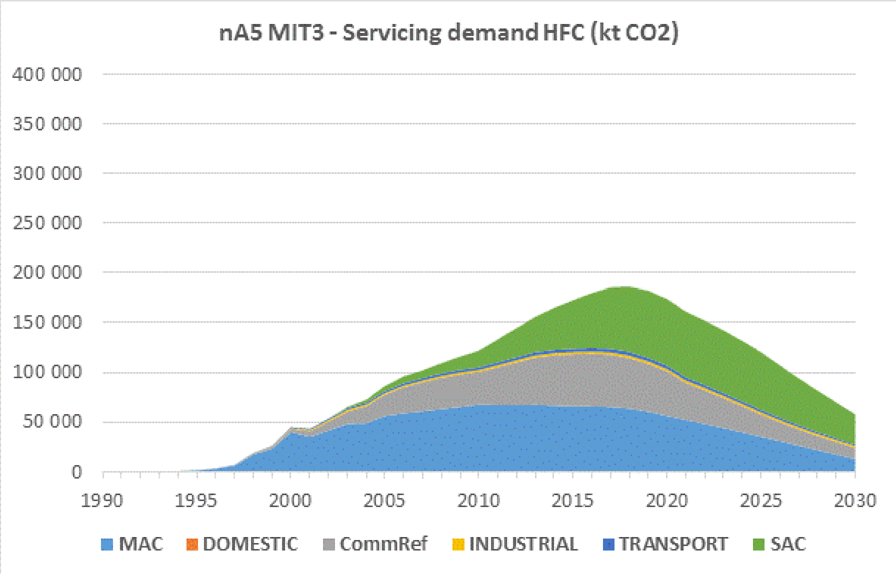


Figure 5-6: Non-Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors (assuming manufacturing conversion over the period 2017-2020)

Figure 5-6 shows the volumes of high-GWP refrigerants that will be needed for servicing the installed equipment in the MIT-3 scenario. This varies between sectors (see table in section above) and decreases rapidly between 2020 and 2030.

For non-Article 5 Parties, the MIT-4 scenario has also been calculated, but is not presented here in graphs, due to a lack of real "insight giving" results with the conversion of stationary air conditioning by 2025. More interesting results can be found in the MIT-5 scenario for a conversion of all R/AC sub-sectors completed by 2025.

5.5.3 MIT-5 scenario

This is the scenario where, for non-Article 5 Parties, all sub-sectors are assumed to have converted by the year 2025. The total demand, the new manufacturing and the servicing demand are shown in Figs 5-7, 5-8 and 5-9.

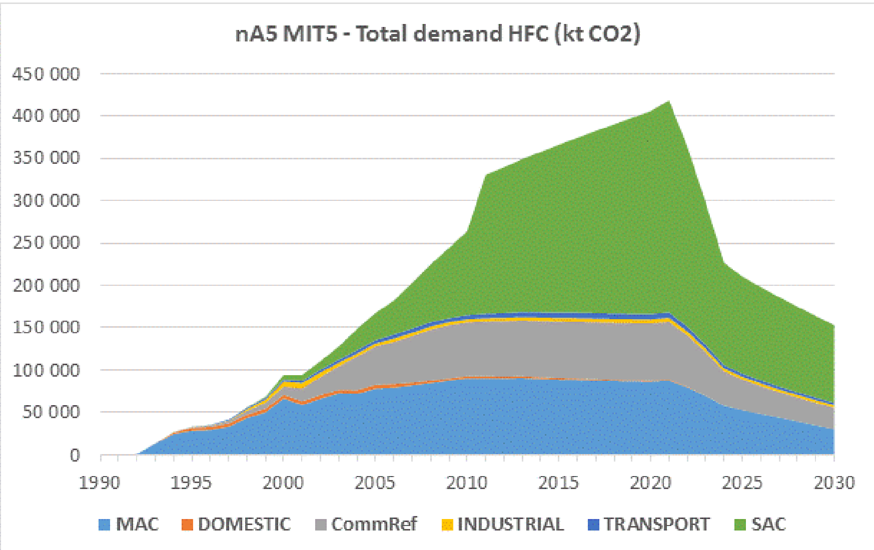


Figure 5-7: Non-Article 5 MIT-5 scenario by R/AC sub-sectors in kt CO_2-eq. (compare Figure 5-4 for MIT-3)

Figure 5-7 includes both manufacturing and servicing, and is similar to Fig 5-5 for MIT-3. MIT-5 parameters are otherwise identical to MIT-2 (apart from the replacement refrigerants with a GWP of 300 that was assumed at 600 before, in the XXV/5 report).

Figure 5-8 shows the same data for HFCs used in new manufacturing only. The sectors are calculated to decline to 30-40,000 ktonnes demand after 2025, mainly due to the remaining demand for certain low-GWP chemicals in the stationary AC sector.

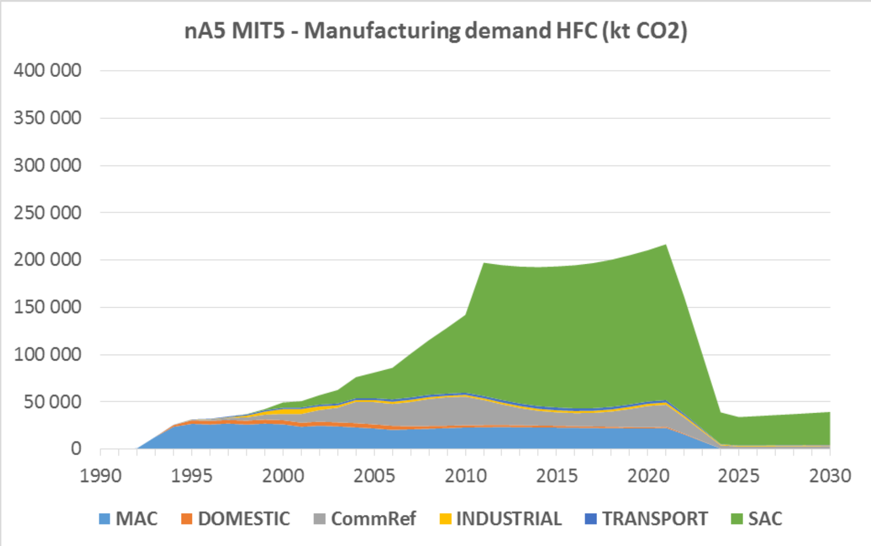


Figure 5-8: Non-Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in GWP weighted terms (compare Fig. 5-5 for MIT-3)

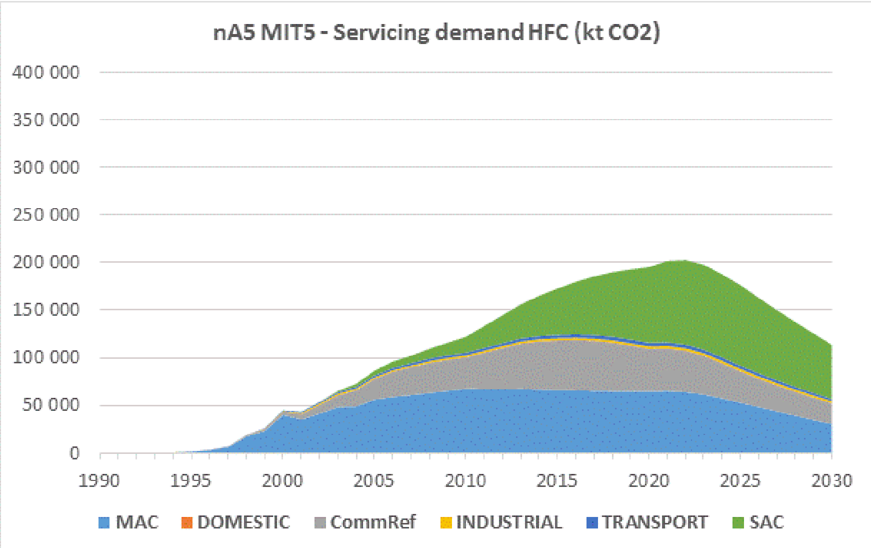


Figure 5-9: Non-Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors in GWP weighted terms (compare Fig. 5-6 for MIT-3)

In 2020, demand for new manufacturing is at about 200 Mt CO_2-eq, and demand for servicing is also at about 200 Mt CO_2-eq, but by 2030, the picture has become different. Servicing demand decreases to somewhat more than 100 Mt CO_2-eq, while new manufacturing demand has already decreased to less than 50 Mt CO_2-eq. This is an issue that needs to borne in mind, i.e., that servicing will be hampering non-Article 5 reductions expressed in Mt CO_2-eq. This is particularly clear in this case, due to the late conversion of the stationary AC sector (assumed to rely on R-410A and to a lesser extent, on R-407C).

5.6 Article 5 scenarios

5.6.1 BAU scenario

Figure 5-10 below shows the Article 5 refrigerant BAU demand, with a subdivision for the different high GWP refrigerants and the low-GWP group, both in tonnes and in GWP weighted terms (in CO_2-eq.). The low-GWP refrigerants applied here are only visible in tonnes and cannot be really seen in these scale when adjusted for GWP, shown in GWP weighted terms. In the 2020-2030 period, the high-GWP refrigerant R-404A, which is used in commercial refrigeration, becomes increasingly important in GWP weighted terms.

The demand calculated for the year 2015 is about 300 ktonnes, a higher value than calculated for the BAU demand in non-Article 5 Parties (210-220 ktonnes, see above). The growth assumed between 2010 and 2015 is mainly based on the economic growth assumed before the year 2015 (see Table 5-1). Total 2015 global demand is assumed to be about 510 ktonnes (for both non-Article 5 and Article 5 regions).

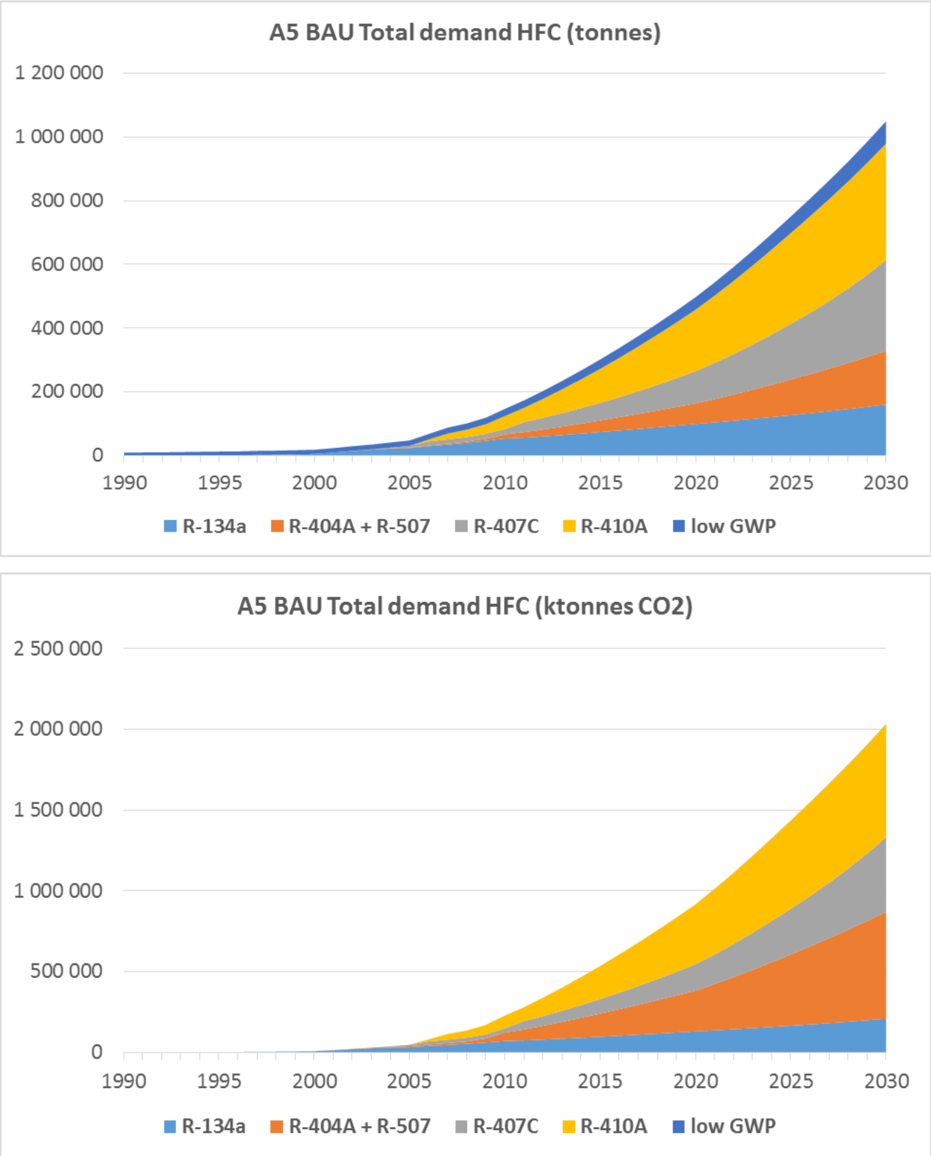
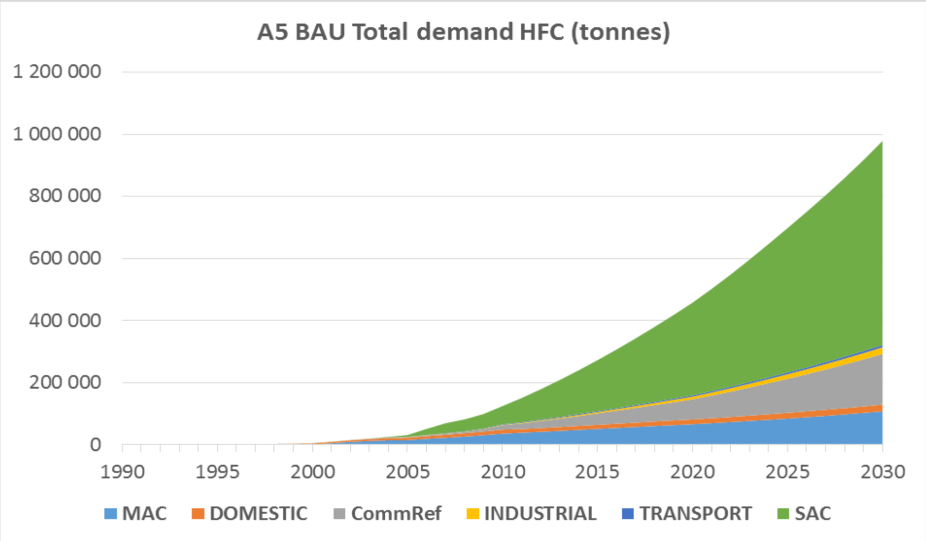


Figure 5-10: Article 5 BAU scenario with a subdivision for the various refrigerants and refrigerant blends in tonnes and ktonnes CO_2-eq.

The combined demand for non-Article 5 and Article 5 Parties of 510 ktonnes (see also the tables in chapter 6) is somewhat higher than the 475 ktonnes estimate for global HFC production in 2015 (about 7% higher). However, this is likely to be caused by differences between production and calculations for stationary AC (see above; for the specific sub-sector the differences between amounts produced and calculated will be larger).

The HFC-134a demand values do not include HFC-134a demand for foams and aerosols including MDIs. When looking at the total calculated demand for HFC-134a for R/AC in 2015 (about 170 ktonnes globally), it leaves about 55,000 ktonnes for other uses, which is thought to be "satisfactory", i.e., covering other sector demands.

Figure 5-11 shows the Article 5 refrigerant BAU demand for the different sub-sectors. The demand is given in tonnes and in GWP weighted terms (in CO_2-eq.). The BAU model predicts that between 2015 and 2030, overall demand increases by a factor of about 3.3. Stationary AC increases substantially, but the commercial refrigeration sub-sector also becomes important in GWP terms, due to the use of the high-GWP R-404A.



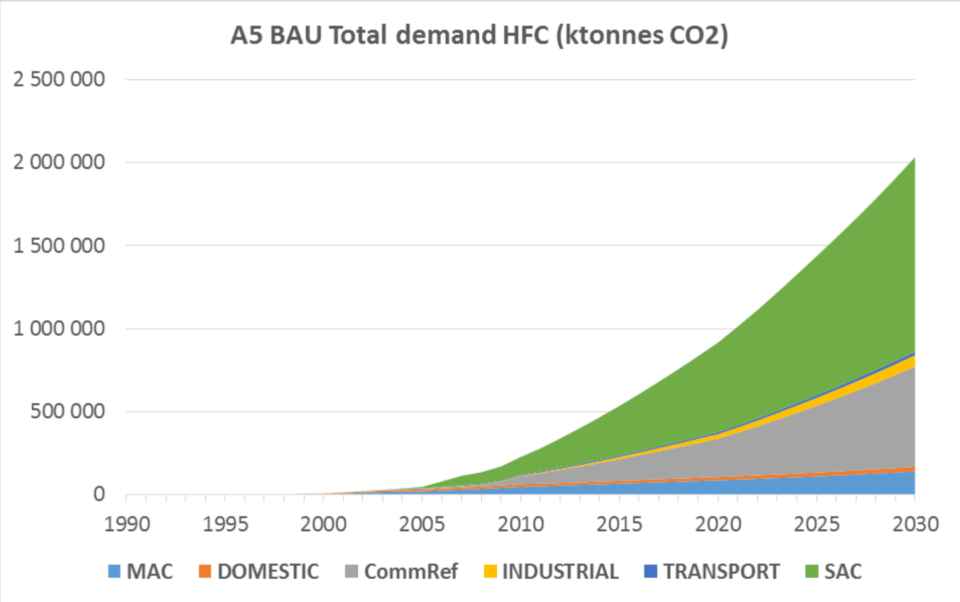


Figure 5-11: Article 5 BAU scenario with a subdivision for the various sub-sectors in tonnes and ktonnes CO_2-eq.

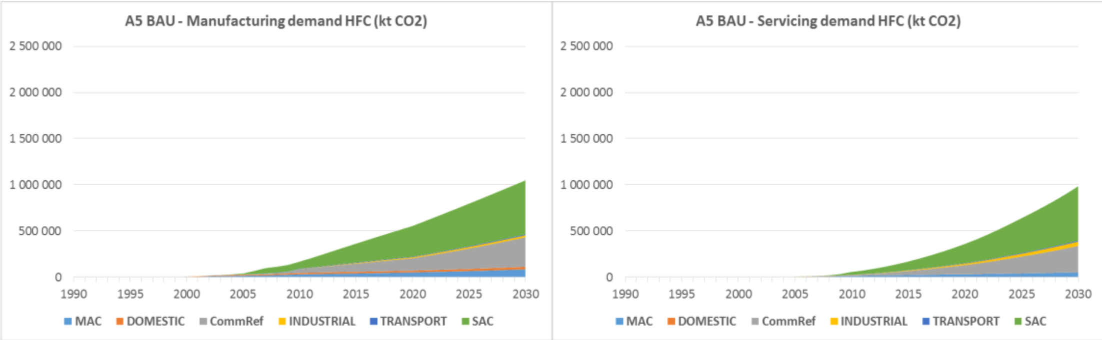


Figure 5-12: Article 5 BAU scenario with new manufacturing and servicing demand for the various sub-sectors (both in ktonnes CO_2-eq.)

Figure 5-12 shows the demand for new manufacturing and for servicing. When manufacturing increases rapidly, the demand for servicing initially lags behind the volumes used for manufacturing. However, after a certain period it catches up, the servicing volumes become comparable to those used in manufacturing as can be seen from these BAU examples (in ktonnes, not in ktonnes CO_2-eq.):

- 2015: new manufacturing 195 ktonnes, servicing 100 ktonnes
- 2020: new manufacturing 300 ktonnes, servicing 200 ktonnes
- 2030: new manufacturing 540 ktonnes, servicing 505 ktonnes

5.6.2 MIT-3 scenario

This is an update on the MIT-2 scenario developed for the XXV/5 Report. In MIT-3, as of 2020, the conversion is assumed to start in all sub-sectors to replace high-GWP refrigerants with a variety of refrigerants, with refrigerant blends having an average GWP of 300. Conversion has been assumed to take 6 years for Article 5 Parties, and in the model, the manufacturing capacity is converted in equal portions per year during the period 2020-2025 (6 years). The following graphs are for the Article 5 MIT-3 scenario, split into in the various R/AC sub-sectors.

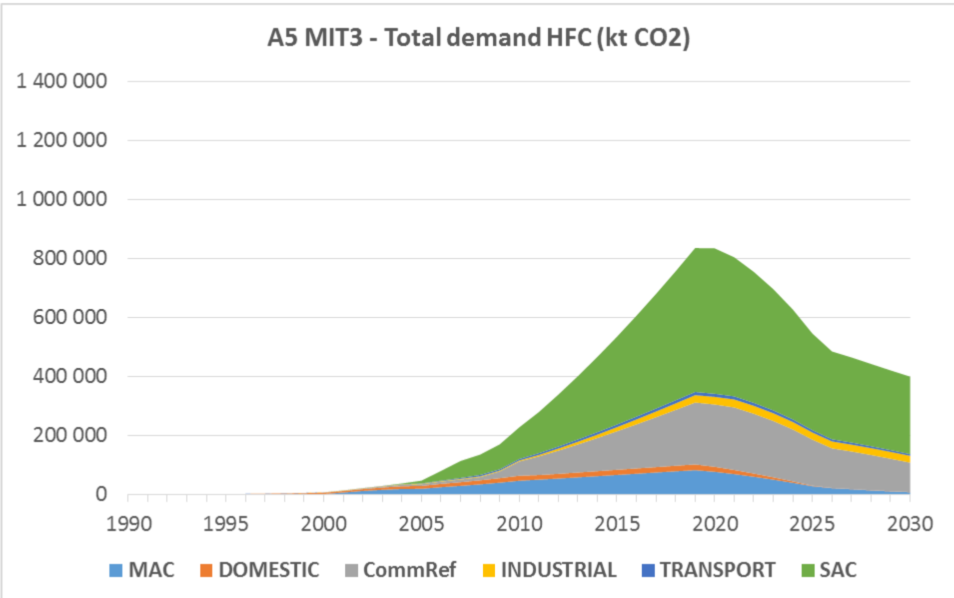


Figure 5-13: Article 5 MIT-3 scenario with the demand for the R/AC sub-sectors, including both new manufacturing and servicing

Figure 5-13 shows the steep decrease in the first 6 years as of 2020, after which the curve flattens due to continued servicing needs only. Since some high-GWP equipment will have been manufactured until 2025, and has an average 12 year lifetime, supplies of high-GWP refrigerants will be continue to be required --in decreasing amounts-- until about 2035-37. During 2010-2015, stationary AC and commercial refrigeration demands increase rapidly. With controls assumed on new manufacturing as of 2020, the high-GWP refrigerant demand in these sector decreases, being replaced by low-GWP refrigerants, which will account for 80% of total demand between 2020 and 2030. This is a large improvement in climate impact, although with this GWP of 300, the large refrigerant volumes considered still have a certain climate impact (note: this is a change compared to the MIT-2 scenario in the XXV/5 Task Force report, where a GWP of 600 was chosen), the relative importance of these refrigerants is now much lower in the GWP weighted graph.

In Figure 5-14, the new manufacturing demand for the R/AC sub-sectors for high-GWP chemicals is given. By 2026, the demand for high-GWP refrigerants in new equipment manufacture falls to <20% of the 2019 peak value (numbers given in the Annex 2).

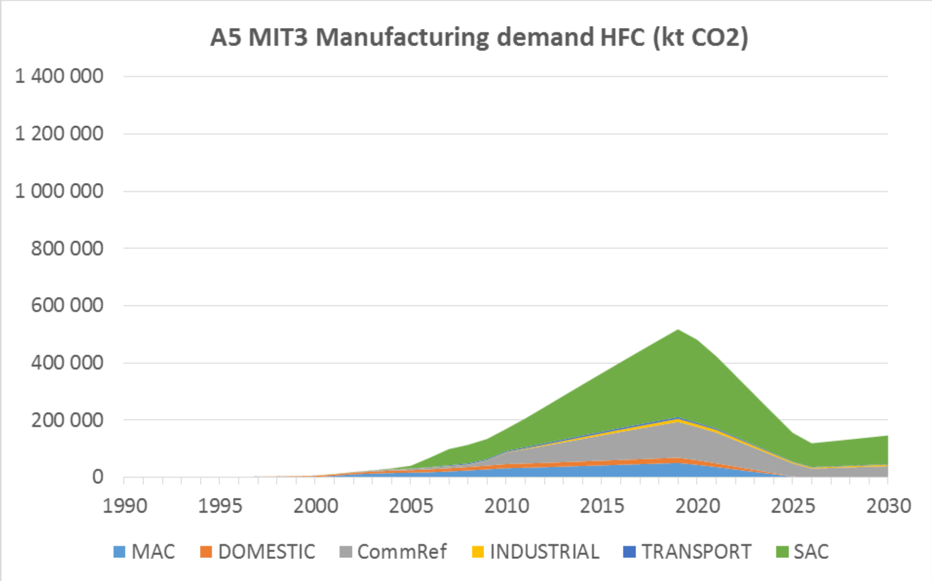


Figure 5-14: Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors (compare Fig. 5-5 for non-Article 5 demand)

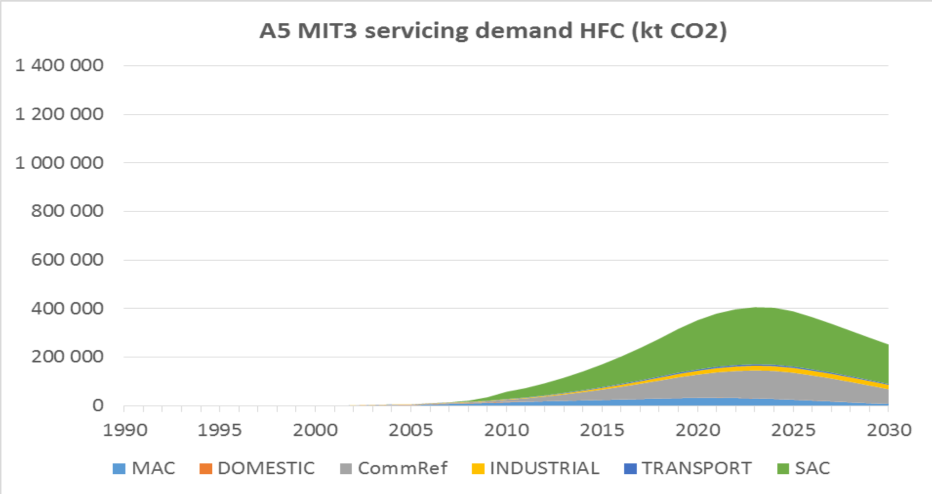


Figure 5-15: Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors (compare Fig. 5-6 for non-Article 5 servicing demand)

Figure 5-15 shows the amounts of high-GWP refrigerants in kt CO_2-eq. that will be needed for servicing the installed equipment. This varies between sectors and according to the speed of the manufacturing transition (the slower the manufacturing transition, the longer the servicing tail).

5.6.3 Impact of manufacturing conversion periods in the MIT-3 scenario

Figure 5-16 shows the demand dependent on the rate of conversion or the length of the conversion period. The six years conversion period in manufacturing for all sub-sectors results in a decrease of approximately 40% by the year 2026, and about 50% by 2030. After 2026, the remaining demand is for servicing, and only declines by about 10% over the following four years (2026-2030).

At the other extreme, a twelve years manufacturing conversion period only leads to a negligible reduction by 2026, and a 25% reduction by 2030. There is a difference of about 350 Mt CO_2-eq. between the 6 and 12 year manufacturing conversion periods after 2025.

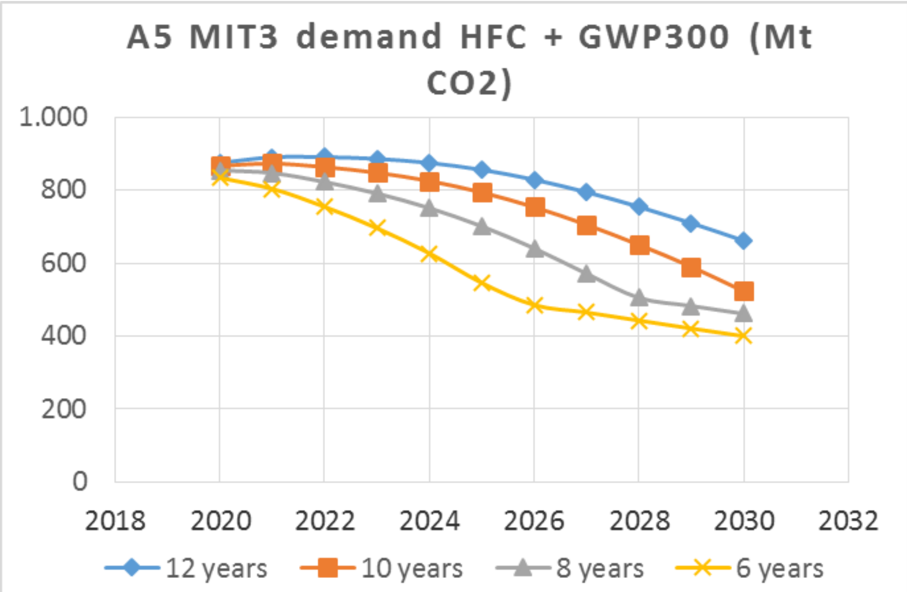


Figure 5-16: Article 5 MIT-3 demand scenario for all R/AC sectors for new manufacturing conversion periods of 6-8-10-12 years

A twelve years conversion period does not yield a lower demand until after 4-5 years after the start of the conversion in the year 2020. The build-up of the servicing demand (from the manufacturing that has not yet been converted) causes this increasing profile in the demand curve (2020-2025). 10 years after the start of the conversion in 2020, a demand reduction of 20-25% can be observed in this case.

In the year 2026, the demand for the 12 years conversion period is almost twice as high as for the six years conversion period, which underscores that a rapid conversion will be very important.

It will be clear that there is a direct relation of the shape of the curves to the conversion period. There are cost implications. A 6 years conversion period would imply twice the costs in the first 6 years after 2020 (2021-2026), compared to the 12 years conversion period, where the same amount will be spread over 12 years (see further in chapter 6).

Of course, there are differences by sector. Domestic refrigeration has a low servicing demand. Figure 5-17 shows the effect of four different periods of manufacturing conversion from the high-GWP HFC-134a to HC-600a (6, 8, 10 and 12 years). The lack of servicing demand means that the graphs go down to zero. However, the time to zero use is delayed by 6 years, with a 6 year conversion timetable versus a 12 year conversion strategy.

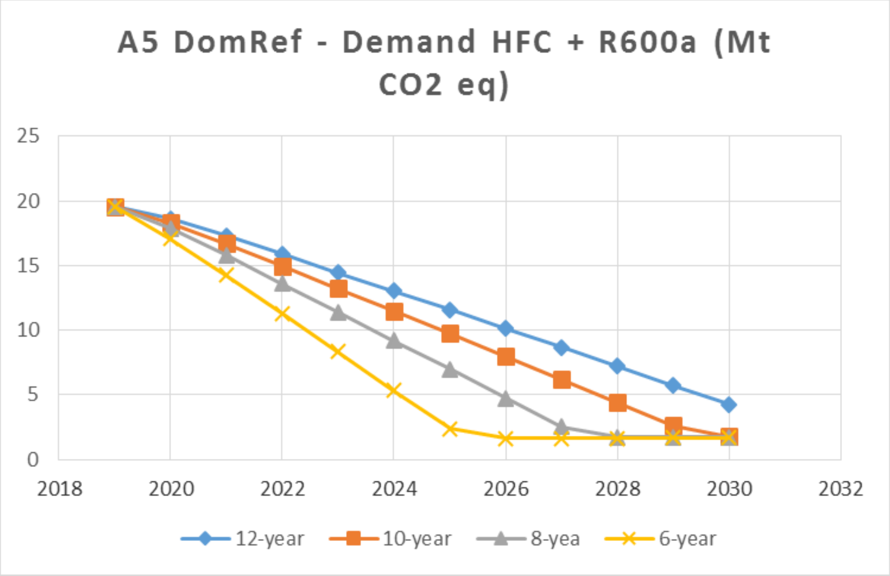


Figure 5-17: Article 5 MIT-3 domestic refrigeration demand scenario for new manufacturing periods of 6-8-10-12 years

5.6.4 MIT-4 scenario

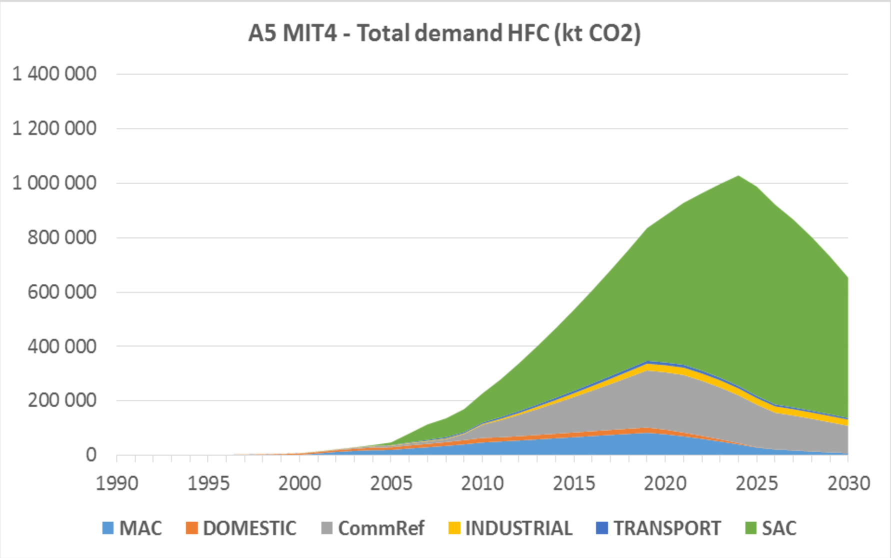


Figure 5-18: Article 5 MIT-4 total demand scenario by R/AC sub-sectors in kt CO_2-eq. (compare Figure 5-13 for MIT-3)

Figure 5-18 includes both manufacturing and servicing, and is the same as Fig 5-13 for MIT-3, except for the stationary AC sub-sector graph (in green), which continues to increase until 2025, before declining. MIT-4 parameters are otherwise identical to MIT-3 (replacement refrigerant blends GWP 300; 6 year manufacturing conversion).

Figure 5-19 also shows the data for HFCs used in new manufacturing only. The various sub-sectors now decline to zero new manufacturing demand at different times.

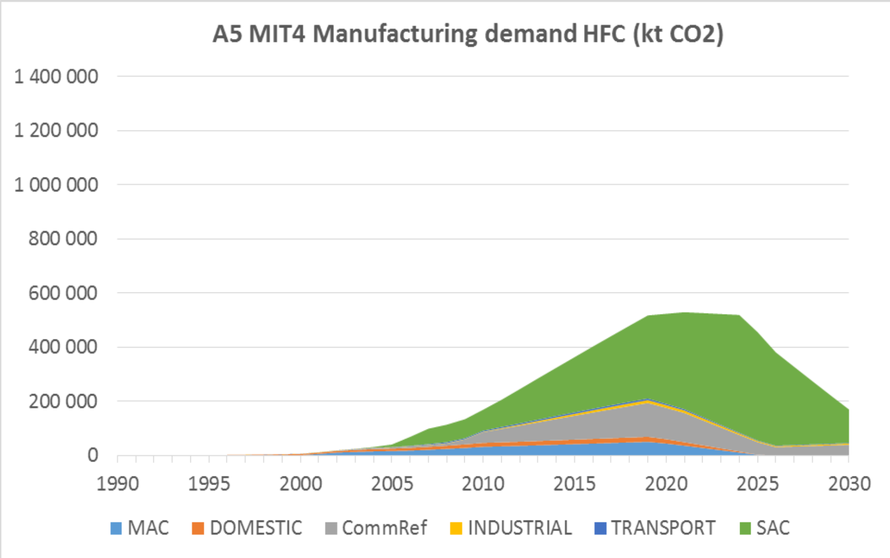


Figure 5-19: Article 5 MIT-4 scenario for new manufacturing demand for the various R/AC sub-sectors in GWP weighted terms (compare Fig. 5-14 for MIT-3)

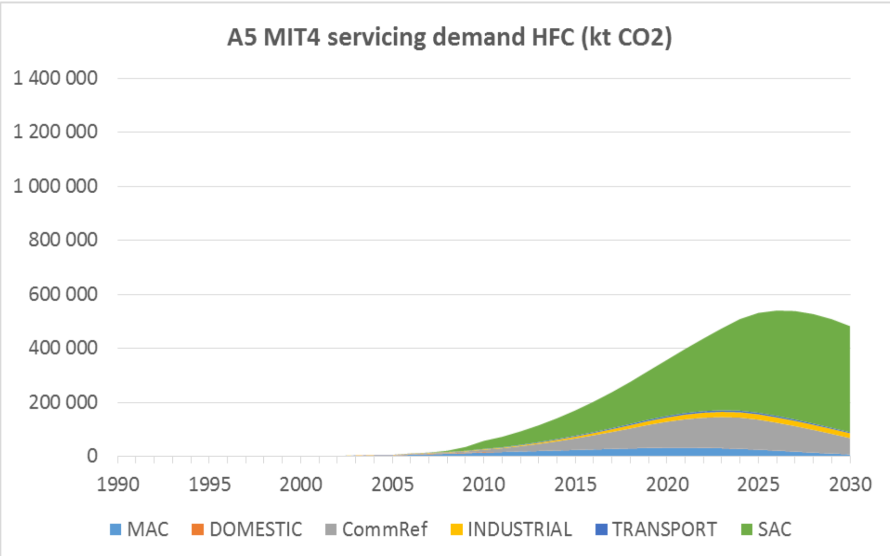


Figure 5-20: Article 5 MIT-4 scenario with the servicing demand for the various sub-sectors (stationary AC starting in 2025, and assuming a conversion of manufacturing over a period of 6 years) (compare Fig. 5-15 for MIT-3)

In 2020-2025, demand for new manufacturing peaks at about 550 Mt CO_2-eq, and demand for servicing is about 300 Mt CO_2-eq, but by 2026, these values are reversed. Servicing demand peaks around 2027, at a high level of about 560 Mt CO_2-eq., due to the late conversion of the stationary AC sector (assumed to rely on the refrigerants R-410A and R-407C).

The above graphs give a good impression of the impact of the stationary AC sector. This scenario is further elaborated upon with numbers in chapter 6, but not to the same degree as scenarios MIT-3 and MIT-5. There the emphasis is on scenario MIT-5 (with a conversion of all sub-sectors as of 2025), which gives a good insight concerning the totals in all sub-sectors when converting late, in 2025.

5.6.5 *Impact of manufacturing conversion periods in the MIT-4 scenario*

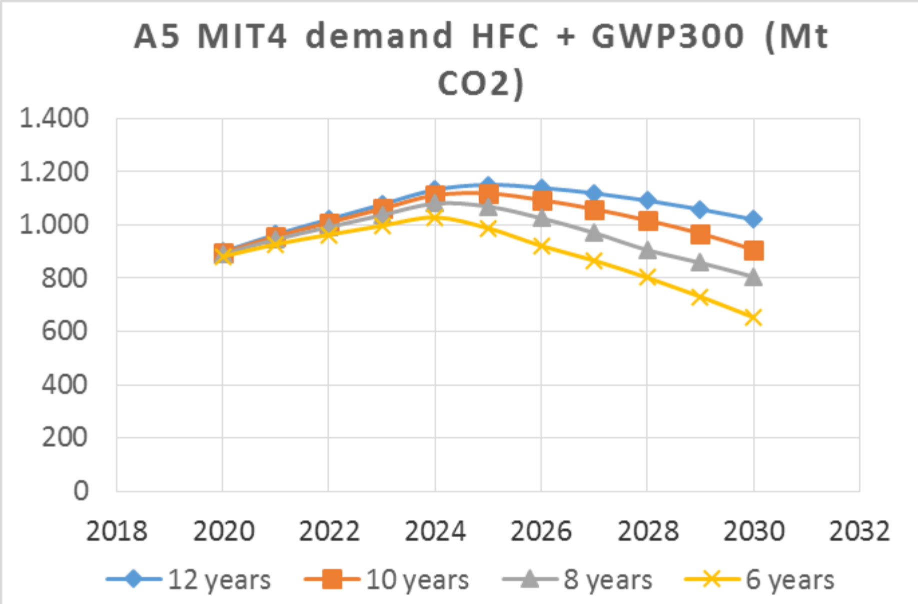


Figure 5-21: Article 5 MIT-4 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years (compare to Figure 5-16 for the MIT-3 scenario)

Impact of the rate of manufacturing conversion: a long period of manufacturing conversion will result in an enhanced and long-lasting demand for high-GWP HFCs for servicing.

Fig. 5-21 gives the 4 curves for the 6, 8, 10 and 12 years manufacturing conversion periods for all refrigeration and AC sub-sectors together. The delayed manufacturing conversion for stationary AC from 2020 to 2025 makes a large difference in the high-GWP demand.

For a 6 year conversion period, the HFC demand is projected for 2030 as:

- MIT-3 (stationary AC conversion starting at 2020) - 410 Mt CO_2-eq
- MIT-4 (stationary AC conversion starting at 2025) - 640 Mt CO_2-eq

The delay of 5 years for stationary AC conversion to 2025 results in a more than 50% increase in annual HFC climate impact by the year 2030.

The MIT-4 scenario has a major adverse climate impact compared to MIT-3. There are cost implications of the MIT-4 scenario. A delay of 5 years for starting SAC conversion, and a 6 year manufacturing conversion period, means that the overall costs have to be considered over a longer period than 6 years (i.e., over 12 years (rather than 6 years)). See further the considerations in chapter 6.

5.6.6 MIT-5 scenario

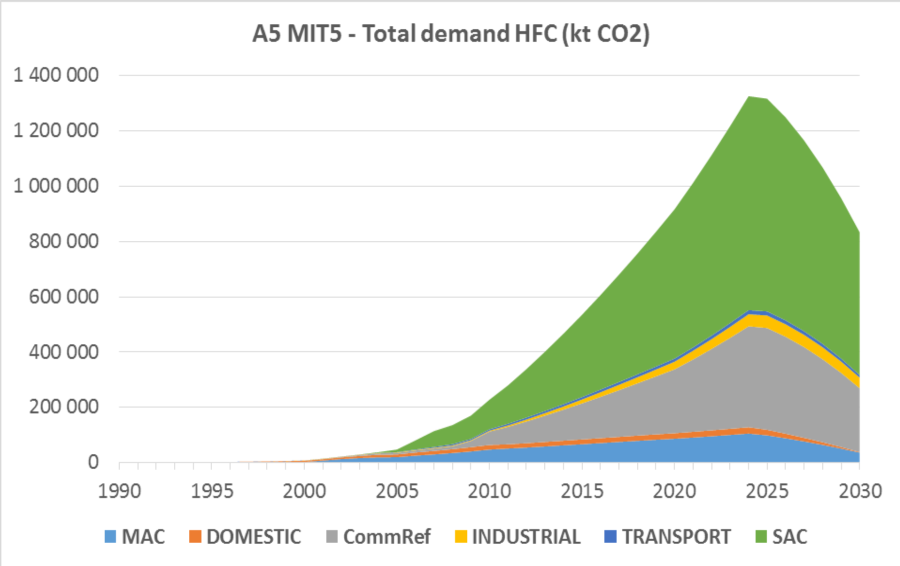


Figure 5-22: Article 5 MIT-5 scenario by R/AC sub-sectors in kt CO_2-eq. (compare Figure 5-13 and 5-18 for MIT-3 and MIT-4)

Figure 5-22 includes both manufacturing and servicing, and is similar to Figs 5-13 and 5-18 for MIT-3 and MIT-4 (replacement refrigerant blends at a GWP of 300; 6 year manufacturing conversion).

Figure 5-23 also shows the same data just for HFCs used in new manufacturing. The sub-sectors decline to zero new manufacturing demand at the same time.

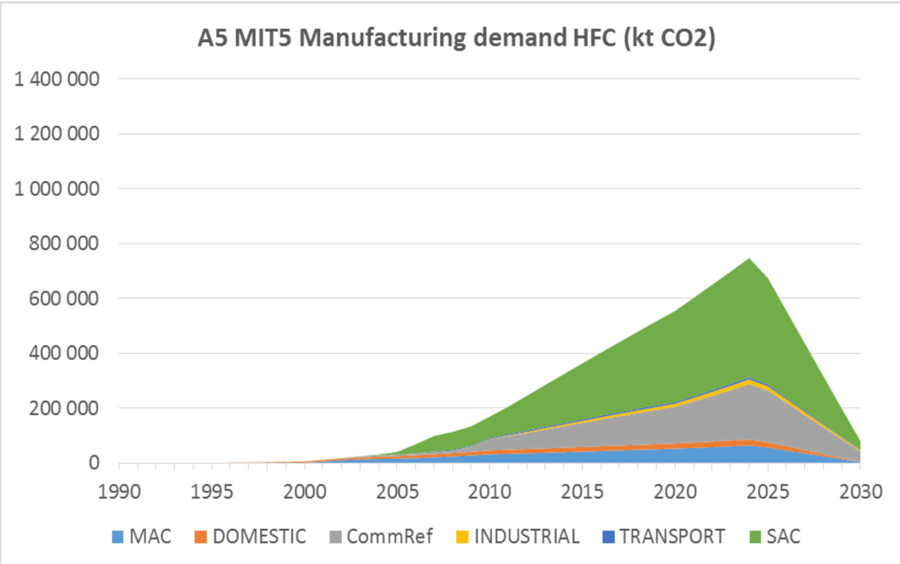


Figure 5-23: Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in GWP weighted terms (manufacturing conversion over a period of 6 years) (compare Figure 5-14 and 5-19 for MIT-3 and MIT-4)

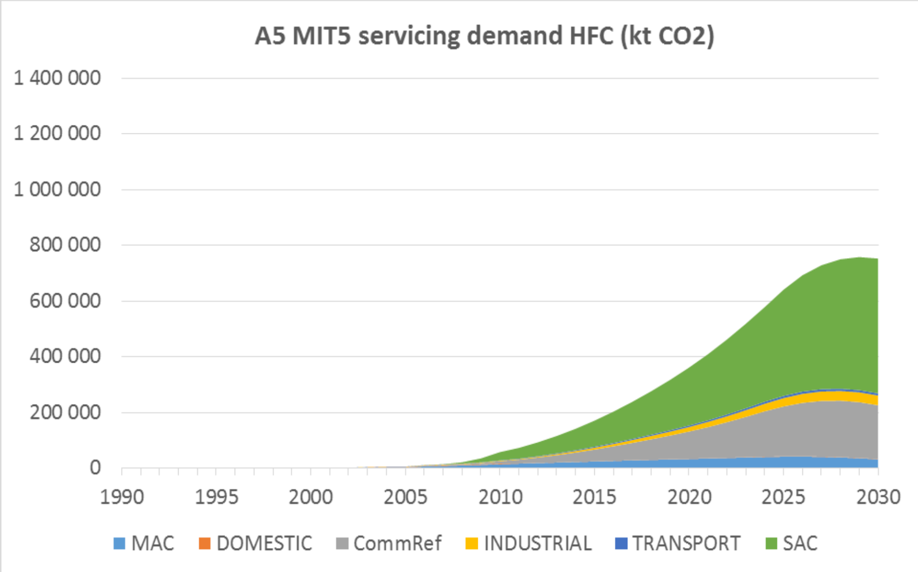


Figure 5-24: Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors (assuming a conversion of manufacturing over a period of 6 years) (compare Figure 5-15 and 5-20 for MIT-3 and MIT-4)

In 2025, demand for new manufacturing peaks at about 760 Mt CO_2-eq, and demand for servicing is about 600 Mt CO_2-eq, but after 2030, manufacturing demand has gone down to about 100 Mt CO_2-eq., while servicing demand is still higher than 700 Mt CO_2-eq., due to the late conversions of all sub-sectors.

5.6.7 Impact of manufacturing conversion periods in the MIT-5 scenario

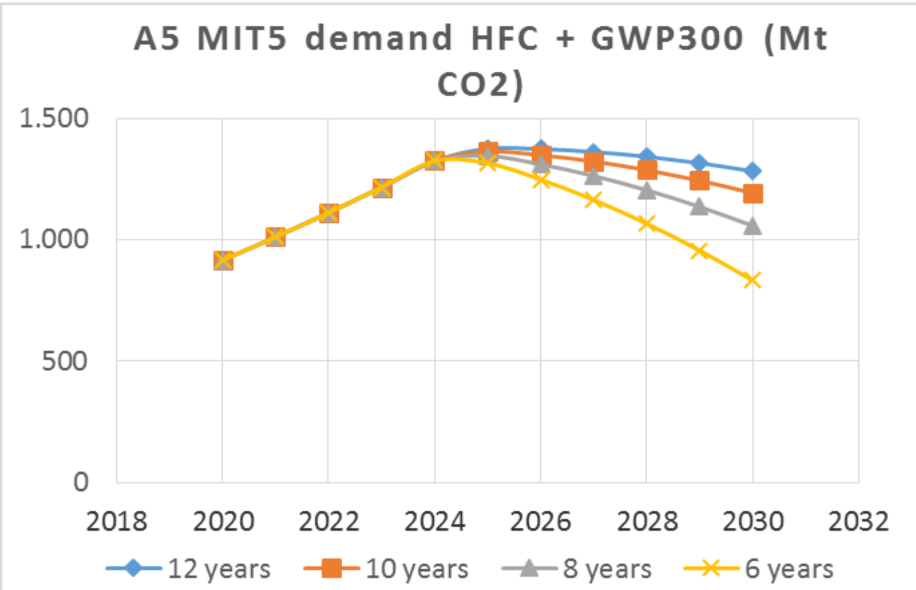


Figure 5-25: Article 5 MIT-5 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years (compare to Figures 5-16 and 5-21 for the MIT-3 and MIT-4 scenarios)

The impact of the rate of manufacturing conversion is: a long period of manufacturing conversion will result in an enhanced and long-lasting demand for high-GWP HFCs for servicing.

Fig. 5-25 gives the 4 curves for the 6, 8, 10 and 12 years manufacturing conversion periods for all refrigeration and AC sub-sectors together. The delayed manufacturing conversion for all sub-sectors as of 2025 makes a large difference. While demand for a 6 year conversion period decreases substantially between 2025 and 2030, a 12 year conversion period only results in a small decrease between 2025 and 2030 (about 100 Mt CO2-eq.).

For a 6 year conversion period HFC demand is projected for 2030 for MIT-3 and MIT-5 as:

- MIT-3 (all conversions starting at 2020) - 410 Mt CO_2-eq
- MIT-5 (all conversions starting at 2025) - 810 Mt CO_2-eq

The delay of 5 years for all sub-sector conversions to 2025 results in roughly a 100% increase in annual weighted climate impact by the year 2030.

The MIT-5 scenario has a major adverse climate impact compared to MIT-3 (and also to some degree to MIT-4). Furthermore, cost implications of the MIT-5 scenario are larger than for MIT-3 and MIT-4. In the case of a 6 year manufacturing conversion period, overall costs will have to be covered over 6 years (expansion to 12 years does not seem desirable given climate impact numbers).

5. 7 BAU – global summary for both foams and R/AC from the XXV/5 report

The XXVI/9 Task Force has not updated the foams BAU scenarios in the 2014 XXV/5 Task Force report because no new information was available . The XXV/5 Task Force report considerations were that it could be important to bring some perspective to the BAU scenarios. In that report it is mentioned that "although comparisons can be made in both actual tonnages and ODP tonnes, the most meaningful from the perspective of this report is to assess the consumption (potential emissions) in climate terms (tonnes CO_2-eq.) ".

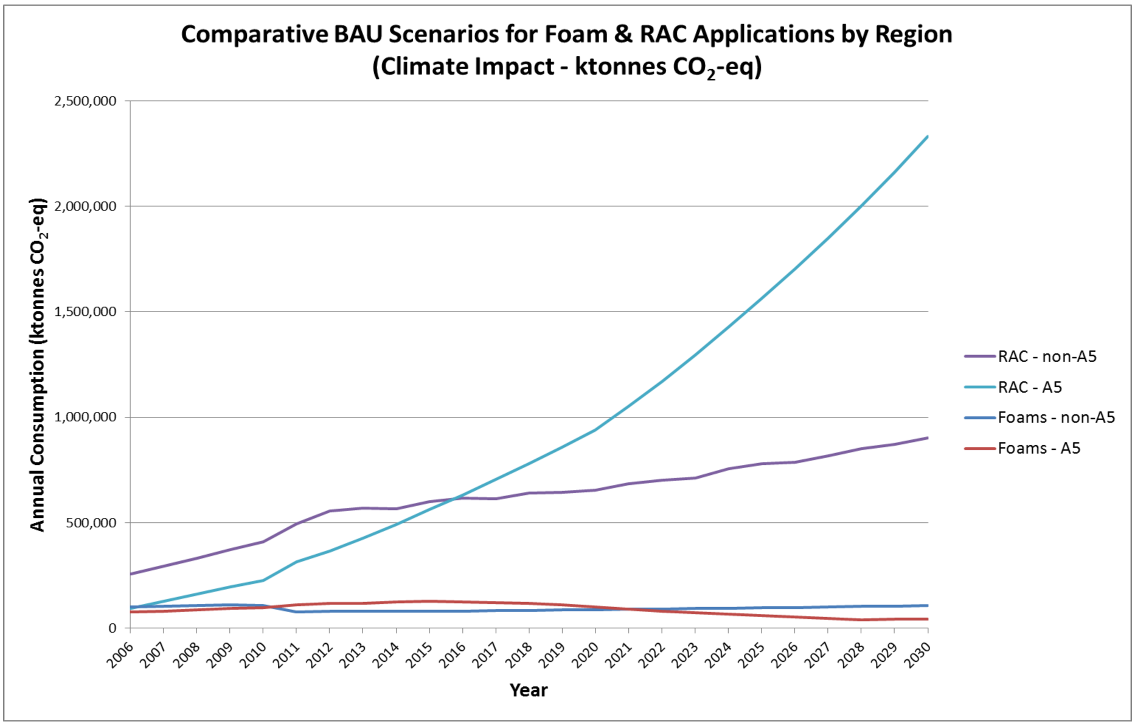


Figure 5-26: Comparative BAU scenarios for foams & R/AC in Article 5 and non-Article 5 regions (source: XXV/5 Task Force report, October 2014)

Figure 5-26 does this and provides an assessment of the actual situation through to 2012 and then projections through to 2030 using the assumptions spelled out in earlier parts of this chapter.

From the XXV/5 Task Force report: "It can be seen that consumption of refrigerants in R/AC applications dwarfs the consumption as taking place in the various foam sub-sectors. It is also evident that the growth in Article 5 Parties, if left unchecked, will have significant climate impact by 2030, especially if emission rates from installed equipment cannot be significantly limited to reduce on-going servicing demand". This important point is shown in the graph from the XXV/5 report, reproduced here as Fig. 5-26.

5.8 References

Campbell, 2015	Campbell, N., Presentation at OORG meeting World Bank, "HFC Production and Demand", May 2015
Kaixian, 2015	Kaixian, W., Presentation at OORG meeting World Bank, "HCFCs/HFCs Production in China", May 2015
Kuijpers, 2015	Kuijpers, L., Private communications from chemical manufacturers, May-July 2015
McCulloch, 2015	Private communications with L. Kuijpers, May 2015
Montzka, 2015	S. A. Montzka, M. McFarland, S. O. Andersen, B. R. Miller, D. W. Fahey, B. D. Hall, L. Hu, C. Siso, and J. W. Elkins, Recent Trends in Global Emissions of Hydrochlorofluorocarbons and Hydrofluorocarbons: Reflecting on the 2007 Adjustments to the Montreal Protocol, J. Phys. Chem., dx.doi.org/10.1021/jp5097376, 2015
Rigby et al., 2013	M. Rigby, R.G. Prinn, S. O'Doherty, B.R. Miller, D. Ivy, J. Muehle, C.M . Hart, P.K. Salameh, T. Arnolds, R.F. Weiss, P.B. Krummel, L.P. Steele, P.J. Fraser, D. Young and .P. Simmonds, "Recent and future trends in synthetic greenhouse gas radiative forcing", Geophysical Research Letters, 10.1002/2013GL059099
RTOC, 2010	UNEP, Refrigeration, AC and Heat Pumps Technical Options Committee, 2010 Assessment Report, ISBN 978-9966-20-002-0
Zhang and Wang, 2014	Zhang, Junjie and Can Wang, "China's Hydrofluorocarbon Challenge", Nature Climate Change, Vol.4, November 2014, pp.943-945

6 Demand, benefits and costs

6.1 Refrigerant demand for BAU and mitigation scenarios

The Decision XXVI/9 mentions "…and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and II of HCFC phase-out management plans". The XXV/5 Task Force report gave a number of tables with current and future refrigerant demand in tables. On the basis of the development of the demand for the various replacements for the various sub-sectors (high-GWP and low-GWP alternatives), total demand in tonnes, as well as in GWP based CO_2-eq. tonnes can be calculated. The tables below give the non-Article 5 and Article 5 updated demand in tonnes and Mt-CO_2 eq. for BAU, MIT-3 and MIT-5 scenarios, with also some data on MIT-4, being an "intermediate".

Table 6-1: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2030 in non-Article 5 Parties (ktonnes)

		2010	2015	2020	2025	2030
nA5 BAU	HFC-134a	79.097	77.977	72.872	76.869	82.356
	R-404A + R-507	17.084	18.376	18.584	19.357	22.780
	R-407C	11.195	26.802	34.942	43.946	50.402
	R-410A	39.385	77.354	94.230	114.001	131.319
	Low GWP	7.011	11.844	13.907	16.802	20.538
	Total	**153.772**	**212.353**	**234.535**	**270.975**	**307.395**

Table 6-2: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2030 in non-Article 5 Parties (kt CO_2 equivalent)

		2010	2015	2020	2025	2030
nA5 BAU	HFC-134a	102.825	101.370	94.733	99.930	107.064
	R-404A + R-507	67.397	72.490	73.312	76.367	89.875
	R-407C	18.135	43.419	56.606	71.193	81.652
	R-410A	75.619	148.520	180.922	218.882	252.133
	Low GWP	8	10	13	19	27
	Total	**263.984**	**365.809**	**405.586**	**466.391**	**530.751**

Tables for total demand, which includes manufacturing and servicing demand for the various R/AC sub-sectors can be found in the Annex 2. Following can be observed for BAU:

- The demand for various HFCs in non-Article 5 Parties is assumed to increase by about 50% in the BAU scenario between 2015 and 2030;
- The growth assumed in stationary AC is the one that is most pronounced (40% growth between 2020 and 2030); this may need further analysis in any future reports.

Table 6-3: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2030 in non-Article 5 Parties (ktonnes)

MIT-3		2010	2015	2020	2025	2030
nA5 3-year conversion 2020	HFC-134a	79.097	77.977	18.758	13.415	7.154
	R-404A + R-507	17.084	18.376	12.882	5.531	2.046
	R-407C	11.195	26.802	13.987	10.417	2.716
	R-410A	39.385	77.354	22.337	15.831	4.127
	Low GWP	7.011	11.844	133.007	189.570	252.410
	Total	**153.772**	**212.353**	**200.971**	**234.764**	**268.453**

Table 6-4: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2030 in non-Article 5 Parties (kt CO_2 equivalent)

MIT-3		2010	2015	2020	2025	2030
nA5 3-year conversion 2020	HFC-134a	102.825	101.370	24.384	17.441	9.301
	R-404A + R-507	67.397	72.490	50.811	21.816	8.072
	R-407C	18.135	43.419	22.660	16.876	4.401
	R-410A	75.619	148.520	42.886	30.396	7.923
	Low GWP	8	10	29.826	43.478	58.396
	Total	**263.984**	**365.809**	**170.568**	**130.007**	**88.093**

The following can be observed for non-Article 5 Parties and the MIT-3 scenario, which results in the conversion of manufacturing by the year 2020.

- The demand for various HFCs in non-Article 5 Parties is assumed to decrease substantially between 2015 and 2030, by more than 70% in climate weighted terms;
- The demand for the stationary AC sub-sector decreases enormously between 2025 and 2030, because virtually all requirements for high-GWP refrigerants disappear, however, the amount of low-GWP refrigerants in climate terms becomes relevant (due to the remaining GWP of 300 assumed for low-GWP refrigerant blends).

Calculations have also been done for a MIT-5 scenario, with all sub-sector conversions starting in 2025. The numbers are not further analysed here, they can be found in the tables in the Annex to the report (Tables A2-1 to A2-3 for tonnes, and tables A2-4 to A2-6 for CO_2 equivalents). With the rapid conversion of new manufacturing by 2025, the new manufacturing demand decreases to small values in the MIT-5 scenario by 2030, similar to the MIT-3 scenario. However, due to the late start, the servicing demand builds up and remains at a much higher level than in the MIT-3 scenario during the period 2025-2030.

Below, a number of tables containing the demand data in tonnes and ktonnes CO_2-eq. for the BAU, MIT-3 and MIT-5 scenarios in Article 5 Parties are given.

Table 6-5: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2030 in Article 5 Parties (tonnes)

		2010	2015	2020	2025	2030
A5 BAU	HFC-134a	54.393	74.524	100.162	127.267	161.107
	R-404A + R-507	13.085	36.404	63.963	111.927	167.690
	R-407C	16.543	55.278	101.216	174.433	285.500
	R-410A	40.975	106.661	192.770	284.682	364.845
	Low GWP	22.430	29.318	39.132	51.975	69.915
	Total	**147.426**	**302.185**	**497.243**	**750.284**	**1.049.057**

Table 6-6: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2030 in Article 5 Parties (kt CO_2 equivalent)

		2010	2015	2020	2025	2030
A5 BAU	HFC-134a	70.712	96.880	130.210	165.447	209.440
	R-404A + R-507	51.584	143.511	252.168	441.229	661.025
	R-407C	26.799	89.550	163.971	282.581	462.511
	R-410A	78.671	204.789	370.118	546.589	700.502
	Low GWP	62	115	203	314	469
	Total	**227.828**	**534.845**	**916.670**	**1.436.160**	**2.033.947**

The following can be observed for the Article 5 Parties and a BAU scenario:

- There are differences in the BAU scenario compared to the XXV/5 report; this is due to small changes in the (BAU) assumptions (see section 5.3);
- The demand for various high-GWP HFCs in Article 5 Parties is (still) calculated to increase by a factor 3-4 in the BAU scenario in climate terms during *2015-2030*;
- The BAU scenario shows a large growth in demand for the high-GWP refrigerants R-404A, R-407C and R-410A, mainly due to the external (economic growth) factors;

Table 6-7: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2030 in Article 5 Parties (tonnes)

MIT-3		2010	2015	2020	2025	2030
A5 6-year conversion 2020	HFC-134a	54.393	74.649	91.265	48.357	39.331
	R-404A + R-507	13.085	36.679	58.259	36.123	12.751
	R-407C	16.543	55.278	92.804	58.029	20.684
	R-410A	40.975	106.661	170.273	65.015	18.972
	Low GWP	22.430	29.318	87.522	562.500	991.332
	Total	**147.426**	**302.585**	**500.123**	**770.024**	**1.083.070**

Table 6-8: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2030 in Article 5 Parties (kt CO_2 equivalent)

MIT-3		2010	2015	2020	2025	2030
A5 6-year conversion 2020	HFC-134a	70.712	96.880	117.959	61.810	49.670
	R-404A + R-507	51.584	143.511	227.693	141.897	50.899
	R-407C	26.799	89.550	150.343	94.007	33.508
	R-410A	78.671	204.789	326.924	124.828	36.425
	Low GWP	62	115	11.394	123.925	230.156
	Total	**227.828**	**534.845**	**834.313**	**546.467**	**400.658**

The following can be observed for the Article 5 Parties, in the case of the MIT-3 scenario:

- There are differences in the MIT-3 scenario compared to the XXV/5 report; this is due to small changes in assumptions for the present MIT-3 scenario;
- The demand for various high-GWP HFCs in Article 5 Parties is estimated to increase by more than 50% between 2015 and 2020 in climate terms, however, decreases again to the 2015 level in the year 2025;
- The most astonishing result is that the demand in climate terms is reduced by only 20-25% in the year 2030, compared to 2015. This is due to the high growth assumed in particular for stationary AC, where, for all sub-sectors together, the use of replacement refrigerant blends with a GWP of 300 (at one million tonnes) is calculated to represent a climate impact of 230 Mt CO_2-eq. in 2030;
- It should be realised that the proposed MIT-3 manufacturing conversion will be very demanding and the assumptions used here are based on the fact that institutional and industrial capacities can completely deal with the conversion in this timeframe.

The MIT-4 scenario assumes a conversion for all sub-sectors starting by 2020, except for the stationary AC sector (by 2025). This is an "intermediate" scenario between MIT-3 and MIT-5. One could have given specific values for the new manufacturing and servicing, however, for the purpose of cost calculations (and the ranges that apply) the focus has been on the two scenarios MIT-3 and MIT-5 here (while still giving overall data for the MIT-4 scenario).

Table 6-9: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-5 scenario) for the period 2010-2030 in Article 5 Parties (tonnes)

MIT-5		2010	2015	2020	2025	2030
A5 6-year conversion 2025	HFC-134a	54.393	74.524	100.162	115.545	60.851
	R-404A + R-507	13.085	36.404	63.963	101.843	54.014
	R-407C	16.543	55.278	101.216	160.942	108.166
	R-410A	40.975	106.661	192.770	254.067	104.162
	Low GWP	22.430	29.318	39.132	117.161	714.856
	Total	**147.426**	**302.185**	**497.243**	**749.558**	**1.042.049**

Table 6-10: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-5 scenario) for the period 2010-2030 in Article 5 Parties (kt CO_2 equivalent)

MIT-5		2010	2015	2020	2025	2030
A5 6-year conversion 2025	HFC-134a	70.712	96.880	130.210	150.208	79.106
	R-404A + R-507	51.584	143.511	252.168	401.490	213.054
	R-407C	26.799	89.550	163.971	260.727	175.229
	R-410A	78.671	204.789	370.118	487.808	199.992
	Low GWP	62	115	203	16.637	166.480
	Total	**227.828**	**534.845**	**916.670**	**1.316.870**	**833.861**

In Tables 6-9 and 6-10 above, the following can be observed for the Article 5 Parties and a MIT-5 scenario:

- As already observed in chapter 5, the MIT-5 scenario represents a much higher climate impact than the MIT-3 scenario. The question remains, for the future, which scenario could or would be the most likely one that Article 5 Parties can follow;
- The demand for various high-GWP HFCs in Article 5 Parties is calculated to increase by about 80% between 2015 and 2020 and by about 140% by 2025, in kt CO_2 eq. (this corresponds to the growth in refrigerant demand in tonnes);
- The above leads to the result that the demand in climate terms will be reduced in the year 2030, but only by a small percentage compared to the year 2020. This is due to the high growth assumed in particular for the stationary AC sub-sector, while, for all sub-sectors together, the remaining use of high-GWP refrigerants plus the use of replacement refrigerant blends with a GWP of 300 (at one million tonnes) is calculated to represent a climate impact of about 830 Mt CO_2-eq. in 2030;
- One may say that the proposed MIT-5 manufacturing conversion is not expected to be demanding and that institutional and industrial capacities should be able to deal with the conversion in this timeframe, if not before. This, of course, assumes the gradual acceptance of alternatives for all sub-sectors before 2025, which seems to be slow compared to the pace of acceptance for many alternatives anticipated at present.

Table 6-10: Refrigerant demand for (refrigerant) ODS alternatives in the BAU, MIT-3, MIT-4 and MIT-5 scenarios for the period 2020-2030 in Article 5 Parties (n.b., in Mt CO_2 equivalent), for all separate years (values for 2020, 2025 and 2030 have been taken from the tables in Annex 2 (for 6 year manufacturing conversion))

In Mt CO2 eq.												
Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
A5 BAU	917	1016	1119	1227	1331	1442	1555	1670	1792	1913	2034	**16016**
A5 MIT-3	834	777	720	662	604	546	481	462	441	421	401	**6349**
A5 MIT-4	882	928	963	997	1029	988	922	866	802	731	653	**9762**
A5 MIT-5	917	1016	1119	1227	1331	1317	1222	1126	1029	931	834	**12069**

Table 6-10 shows the following (rounded) integrated total refrigerant demand for the three scenarios for the period 2020-2030 in Mt CO_2-eq.:

BAU: *16,000 Mt CO_2-eq.*
MIT-3: *6,500 Mt CO_2-eq.*
MIT-4: *9,800 Mt CO_2-eq.*
MIT-5: *12,000 Mt CO_2-eq.*

The MIT-3 reduction from BAU of 9,500 Mt CO_2-eq. represents a saving of 60%. In case of the MIT-4 scenario, with a reduction of about 6200 Mt CO_2-eq., there is a saving of 40% from BAU. The MIT-5 reduction of 4,000 Mt CO_2-eq. represents a saving of 30% from BAU only.

6.2 Article 5 R/AC sub-sector demand for BAU, MIT-3, MIT-4 and MIT-5

Where the Decision XXVI/9 mentions "…and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and stage II of HCFC phase-out management plans", it has been considered useful to put tables in for the demand (in ktonnes) for the various scenarios (BAU, MIT-3, MIT-5) for Article 5 Parties. This has been done for the various sub-sectors and refrigerants in these Parties. Tables show total demand, plus the total demand split up in new manufacturing and servicing; they are given in Annex 2.

In the case of the various sub-sectors, HFC-134a is assumed to be converted in domestic refrigeration and in mobile air conditioning, however not in commercial refrigeration and in stationary air conditioning. New manufacturing using high-GWP refrigerants R-404A and R-507 is assumed to be converted in commercial, industrial and transport refrigeration, whereas new manufacturing using R-407C and R-410A is assumed to be converted in the stationary air-conditioning sub-sector. It will be clear that this applies to both mitigation scenarios MIT-3 and MIT-5. As has been mentioned above, the difference between MIT-3 and MIT-5 is the 5 year later start of conversion in new manufacturing for all R/AC sectors (with MIT-4 being an "intermediate", with only stationary AC converting as of 2025).

Table 6-11: Amounts to be converted in new manufacturing for the MIT-3 scenario (see also Table A2-8)

	Sub-sector	Refrigerant (tonnes)	2020
A5 MIT-3	Domestic	HFC-134a	12238
	Commercial	R-404A + R-507	26172
	Industrial	R-404A + R-507	2132
	Transport	R-404A + R-507	1311
	SAC	R-410A	113983
		R-407C	36495
	MAC	HFC-134a	34293

It is worth noting that the conversion start (5 year later) will cause a substantial increase of the demand for servicing in the period after 2025 - as has already been shown in the graphs in chapter 5. In the case of the MIT-3 scenario, the amounts given for the year 2020 are taken as the amounts in new manufacturing that need to be converted. Table 6-11 shows the amounts for the various sub-sectors of the refrigerants concerned.

In the case of the MIT-5 scenario, the amounts given for the year 2025 are taken as the amounts used for new manufactured equipment that need to be converted for all sub-sectors. Table 6-12 shows the amounts for the various sub-sectors of the refrigerants concerned.

Table 6-12: Amounts to be converted in new manufacturing for the MIT-5 scenario (see also Table A2-8)

	Sub-sector	Refrigerant (tonnes)	2025
A5 MIT-5	Domestic	HFC-134a	14533
	Commercial	R-404A + R-507	44426
	Industrial	R-404A + R-507	4696
	Transport	R-404A + R-507	1402
	SAC	R-410A	150481
		R-407C	58838
	MAC	HFC-134a	43830

The conversion can be done during 6 years (up to 12 years); in principle it does not make a difference which conversion period is used for the amounts to be converted. That also implies that the conversion period, in principle, does not affect total costs for the conversion for Article 5 Parties to be considered. However, the major impact the conversion period will have will be on the servicing amounts to be considered. How this should be addressed is difficult to estimate. On overall climate impact, it will be clear that the faster the conversion will occur, the better. Note that the MIT-4 values are identical to the values for the sub-sectors in Table 6-11, with the exception of the SAC subsector, where the SAC values from Table 6-12 apply.

From the above, it is possible to make a calculation of the high-GWP refrigerant demand in new manufactured equipment and in servicing for the years 2020, 2025 and 2040, for Article 5 Parties (only). Table 6-13 below shows the results. The results for new manufacturing will be the main elements for the cost calculations based upon the demand in the various sub-sectors.

Table 6-13: Demand (amounts in ktonnes and Mt CO_2-eq.) for new manufacture and servicing for high-GWP refrigerants for the BAU, MIT-3 and MIT-5 scenarios for the years 2020, 2025 and 2030

In ktonnes (new manufacturing)				In konnes (servicing)			
A5	2020	2025	2030	A5	2020	2025	2030
BAU	297	415	543	BAU	200	335	506
MIT-3	297	411	539	MIT-3	203	359	544
MIT-5	299	418	547	MIT-5	198	331	495
In Mtonnes CO2-eq.(new manufacturing)				In Mtonnes CO2 eq. (servicing)			
A5	2020	2025	2030	A5	2020	2025	2030
BAU	555	797	1049	BAU	361	639	985
MIT-3	482	157	148	MIT-3	353	389	253
MIT-5	555	690	196	MIT-5	361	663	638

It should be borne in mind that the amounts in tonnes given in Table 6-13 do include the tonnes of low-GWP refrigerants in the various years. For this reason there is no decrease in new manufacturing amounts (in tonnes) as shown, when going from 2020 to 2030.

Table 6-14: Demand of low-GWP refrigerants (in ktonnes) for new manufacture and servicing (total demand) for the various scenarios for the years 2020, 2025 and 2030

ktonnes (A5)	2020	2025	2030
BAU	39	52	70
MIT-3	75	563	990
MIT-5	39	108	714

-- In new manufacturing, it will be clear that the amounts decrease after 2020 in the MIT-3 scenario, with the remainder mainly for HFC-134a demand that is assumed not to be converted in some sub-sectors. The demand increases substantially for the year 2025, if the sub-sectors are not assumed to start to convert until this year (MIT-5).
-- In the servicing sector, the amounts increase in the BAU scenario during 2020-2030, following the usual trend. In the MIT-3 scenario the amounts for servicing increase between 2020 and 2025, because, in this period, there is still (ongoing, but decreasing) manufacturing of high-GWP equipment, which adds refrigerant amounts to the total bank.

In MIT-3, the major change starts to occur after 2025 when new manufacturing has been completely converted and the products that have been manufactured between 2010 and 2015 start to reach their end of life (i.e., the refrigerant bank then decreases substantially). It is clearly shown that the shift of the start of conversion for all sub-sectors to 2025 (following the MIT-5 scenario) has significant effects on the amounts for servicing. The amounts increase from 2020 to 2025 by 50%; the decrease between 2025 and 2030 is only very modest due to the large bank of (mainly stationary AC) high-GWP equipment that still requires servicing. This trend is not expected to really change in the MIT-5 scenario until the period 2035-2040.

6. 3 Conversion costs for the various scenarios

The amounts for conversion can be derived for the various sub-sectors:

- Domestic refrigeration;
- Commercial refrigeration;
- Industrial and transport refrigeration;
- Stationary AC;
- Mobile AC.

The following estimates would apply for new manufacturing conversion costs per kg:

- **Domestic refrigeration**: **US$ 7-9** per kg (based upon MLF experience)
- **Commercial refrigeration** (HFC-134a): **US$ 7-9** per kg (assuming similar operations as for domestic) (although not further considered here)
- **Commercial refrigeration**: **US$ 4-7** per kg (estimate based upon experience in the CFC period and upon the expected 2020 refrigerant cost; it should be borne in mind that current conversions from HCFCs in this sub-sector are done at a maximum of US$ 4.5 per kg (the costs for addressing servicing per kg of refrigerant).
- **Industrial refrigeration**: **US$ 4-7** per kg
- **Transport refrigeration**: **US$ 6-8** per kg
- **Stationary AC**: **US$ 11-13** per kg (estimate based on MLF experience with HCs, combined with expectations for low-GWP refrigerant costs)

- **Mobile AC**: **US$ 4-10** per kg (much related to the expected costs for certain chemical refrigerant alternatives) (by the way, conversion costs are assumed to be higher in the case of phase-in of carbon dioxide equipment).

Taking into account the amounts to be converted in new manufacturing in the MIT-3 scenario in Article 5 Parties (independent from the length of the conversion period), costs can be estimated. It needs to be mentioned that, in certain cases, the parameter of US$/kg of refrigerant used for cost estimates does not represent all costs, and in this case the cost estimates may be underestimated.

Table 6-15: Manufacturing conversion quantities (demand) in 2020 and costs for complete conversion of this new manufacturing to low-GWP refrigerants in all refrigeration and AC sub-sectors (MIT-3, compare Table 6-11)

Sub-sector	**Manufacturing conversion demand (tonnes)**	**Costs (US$ million)**	**Costs (in % of total) (approximate)**
Domestic	12,238	85.7-110.1	4%
Commercial	26,172	104.7-183.2	6%
Industrial-large size	2,132	8.5-14.9	0.5%
Transport	1,311	7.9-10.5	<0.5%
Stat. AC (R-410A)	113,983	1253.8-1481.8	59%
Ibid., (R-407C)	36,495	401.4-474.4	19%
MAC	34,293	137.2-342.9	11%
Total	**226,624**	**1999.2-2617.8**	**100%**

Taking into account the amounts to be converted in manufacturing in the MIT-3 scenario in Article 5 Parties (independent from the length of the conversion period), as given in Table 6-11, as well as in Table 6-15), the costs can be calculated per sub-sector.

The first observation that can be made from Table 6-15 is that for the costs of the conversion of new manufacturing, 78% of the total is estimated to be for stationary air conditioning, 7% for commercial, industrial and transport refrigeration, and 11% for mobile air conditioning. Uncertainty in the conversion costs for stationary air conditioning is therefore the most important factor.

The total cost calculated for manufacturing conversion in Article 5 Parties is in the range US$ 2000-2618 million; the amount can also be given as US$ 2300 ± 310 million. If this would be spread over six years it would mean costs of about US$ 1150 ± 155 million per triennium; this for the next two triennia after 2019, i.e., 2020-2022 and 2023-2025.

If the conversions would be spread over 12 years it would be a cost of about US$ 575 ± 78 million per triennium (a longer period than 12 years would lead to even higher servicing amounts than for a conversion period of 12 years (higher than following any schedules that were considered in chapter 5).

The abovementioned costs would change in the case of the MIT-5 scenario. All the amounts would then be larger for all sub-sectors, since one looks at the year 2025 (see Table 6-16). At that moment in time, the new manufacturing demand is estimated (compare Tables 6-11 and 6-12) to have increased by about 92,000 tonnes, for both R-404A, R-410A and R-407C. Using the cost effectiveness ranges applied above, this would translate into a cost range of US$ 2780-3650 million, or about US$ 3220 ± 430 million. This would mean a huge increase compared to MIT-3 conversion costs, i.e., the costs would be about US$ 920 million higher, i.e., 40% higher than the costs for an MIT-3 conversion.

Table 6-15: Manufacturing conversion quantities (demand) in 2025 and costs for complete conversion of this new manufacturing to low-GWP refrigerants in all refrigeration and AC sub-sectors (MIT-5, compare Table 6-12)

Sub-sector	**Manufacturing conversion demand (tonnes)**	**Costs (US$ million)**	**Costs (in % of total) (approximate)**
Domestic	14,533	101.7-130.8	4%
Commercial	44,426	177.7-311.0	6%
Industrial-large size	4,696	18.8-32.9	0.5%
Transport	1,402	8.4-11.2	<0.5%
Stat. AC (R-410A)	150,481	1655.3-1956.3	57%
Ibid., (R-407C)	58,838	647.2-764.9	22%
MAC	43,830	175.3-438.3	10%
Total	**318,206**	**2784.5-3645.3**	**100%**

On the basis of Tables 6-15 and 6-16 the total costs for the MIT-4 scenario can be calculated. The range is US$ 2640-3380 million, or US$ 3010 ± 370 million.

Table 6-16: Costs involved in new manufacturing conversion and cost ranges derived for the mitigation scenarios MIT-3, MIT-4 and MIT-5

Scenario	**Manufacturing conversion demand (tonnes)**	**Costs (US$ million)**	**Costs (relative to MIT-3)**
MIT-3	226,624	2300 ± 310	-
MIT-4	285,465	3010 ± 370	+31%
MIT-5	318,206	3220 ± 430	+ 40%

It is difficult to make an estimate what the costs for servicing would be. In the case of the MIT-3 scenario, the servicing amounts are in the order of 100-200 ktonnes during 2020-2030. The amounts decrease substantially between 2025 and 2030 (from 198 to less than 100 ktonnes, a 50% decrease) due to the fact that equipment reaches its end of life. Servicing is much higher in the MIT-5 scenario, in particular after 2025 until somewhere in the 2030's.

A reasonable assumption would be that a decrease of 40-60 ktonnes can be addressed via the servicing sector, by improving a wide range of practices including recovery and recycling. If one would use the (historical) number of US$ 4.5 per kg, as for HCFCs under the Montreal Protocol, this amount per kg would translate into costs of US$ 180-270 million. Assuming that this amount would be spread over at least four triennia, it would imply US$ 40-60 million per triennium. It is useful to compare this amount to the amount of US$ 575 million per triennium calculated for a 12 year conversion of high-GWP manufacturing (or the amount of US$ 1150 million per triennium calculated for a 6 year conversion).

In a first instance, servicing amounts, and costs to address servicing will increase when going from MIT-3, to MIT-4 and MIT-5. In the case of MIT-5 they could well be 40-160% larger dependent on which three year period one considers (compare Figs. 5-15 and 5-24); the best estimate would be US$ 100-150 million per triennium.

It should be clear that this cost analysis does not address the costs for any institutional or administrative arrangements to deal with an HFC phasedown. The amount of about US$ 2300 million seems very high, if one would compare the number to the current HCFC phase-out. However, the (HCFC) funding amounts of about US$ 400-500 million committed so far are meant for a 25-35% reduction of HCFC consumption. Manufacturing amounts (foam and R/AC without servicing) were of the same order in 2013 for HCFCs as they are estimated to be for HFCs in the year 2020.

Furthermore, it should also be clear that this is a cost calculation for the conversion of all manufacturing operations situated in Article 5 Parties. It does not take into account aspects such as multinational ownership, which will play a role in (future) funding calculations (once guidelines for this funding will have been developed and agreed). This could decrease possible HFC conversion funding by up to about US$ 500 million, compared to the costs determined above. Not enough data on foreign (multinational) ownership is available to make any further statements here.

Conversion costs for HFCs are estimated at a factor of 1.5-2 higher than current HCFC funding experience. These two aspects together (25-35% addressed so far of HCFC consumption and 1.5-2 times higher costs for HFC conversions, taking into account the amount so far used for HCFC conversions), will lead to a total amount in the range of US$ 2200-2800 million. This is comparable to (and therefore consistent with) the funding range determined for the conversion of HFC new manufacturing in the MIT-3 scenario (and lower than for the MIT-4 and MIT-5 scenarios).

Note: Costs have been determined on the basis of the bottom-up calculations for the R/AC sector in Article 5 Parties. The demand determined for non-Article 5 and Article 5 Parties for the stationary AC sub-sector has been shown to be high (if HFC production estimates are reliable). It needs further investigation how these numbers can be made consistent with (maybe better) estimates for HFC production for the year 2015. This will have to be done in a possible future report describing this type of scenarios.

7 High ambient temperature conditions

7.1 High ambient temperatures and climate zones

High ambient temperature conditions are an important issue for the design of refrigeration and AC systems. As ambient temperature increases, system load increases and capacity decreases. With increasing ambient temperature, the condensing pressure and compressor discharge temperatures also increase, thus leading to possible reliability issues.

While 35°C has been designated as standard ambient, there is no definition currently for what constitutes a High Ambient Temperature (HAT) and consequently a high ambient temperature country (or region). Ambient temperatures are used for cooling load calculation and building envelope design.

A high ambient temperature can be defined as the incidence over a number of hours per year of a certain temperature. If this temperature is set above the standard ambient of 35°C, the question becomes at what incidence will this occurrence be considered to constitute a high ambient condition. HAT countries could then be defined as the countries where a certain percentage of the population lives in areas where the HAT conditions are prevalent.

The industry defines values of ambient dry bulb, dew point, wet bulb temperature, and wind speed corresponding to the various annual percentiles of 0.4%, 1%, 2%, and 5% that are exceeded on average by the indicated percentage of the total number of hours in a year (8,760 hours). These values correspond to 35, 88, 175, and 438 hours per year respectively, for the period of record. The design values occur more frequently than the corresponding nominal percentile in some years and less frequently in others.

Standards define design temperature conditions based on one of the incidences listed above. For example, ASHRAE Standard 90.2 defines the design data at 0.4% condition for Riyadh, KSA as Dry bulb temperature of 111.6°F = 42.22°C and a wet bulb of 65.6°F = 18.67°C. There are arguments for using the 2% or 5% incidence for the definition of HAT in order to preclude areas that experience an unusual period of hot summer temperatures.

There are methods to define climate zones based on meteorological data that has been collected over the years. A **typical meteorological year** (TMY) is a collation of selected weather data for a specific location generated over a period of 15 to 30 years to give a typical average year. The most recent data is TMY 3 for the period 1991-2010. TMY data is frequently used in building simulation in order to assess the expected heating and cooling costs for the design of the building.

One method is to define climate zones ranging “extremely Hot and Humid” to “sub-Arctic/Arctic” based on TMY 3 data. The definition of a zone is based on the criteria of Cooling Degree Days or CDD. This indicator uses daily temperature data from thousands of weather stations to compare the daily average outdoor temperature with a defined baseline temperature for indoor comfort, in this case 65°F (18.3°C). For example, if the average temperature on a particular day is 78°F (26°C), then that day counts as 13 cooling degree days, as a building’s interior would need to be cooled by 13°F to reach 65°F.

In some countries where building codes are not followed and no thermal insulation is used, cooling capacity at high ambient temperatures is a critical issue.

Based on the above, zones were defined in ASHRAE Standard 162-2013 as per Table 7-1, resulting in a mapping of the world as per Figure 7-1.

Table 7-1: An example of zone definitions

Zone Reference	Description		Zone Reference	Description
0A	Extremely Hot Humid		4B	Mixed dry
0B	Extremely Hot Dry		4C	Mixed Marine
1A	Very Hot Humid		5A	Cool Humid
1B	Very Hot Dry		5B	Cool Dry
2A	Hot Humid		5C	Cool Marine
2B	Hot Dry		6A	Cold Humid
3A	Warm Humid		6B	Cold dry
3C	Warm marine		7	Very Cold
4A	Mixed Humid		8	Sub-Artic/Arctic

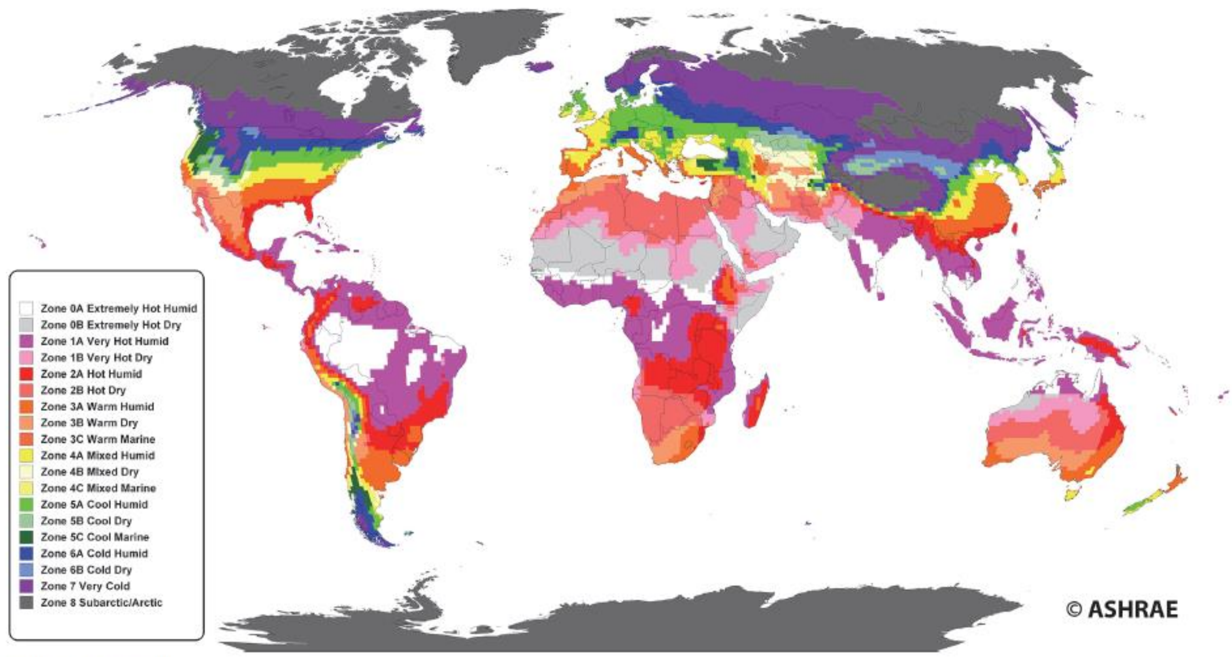


FIGURE C-2 World climate zones map.

Figure 7-1: The world according to the Climate Zones (Table 7-1)

Other examples of climate zone definition based on the Bin Weather method which offers a micro analysis that is more helpful for system design requirements are also available but not included in this update report.

While normally systems are designed for 35°C (T1 in ISO 5151:2010) with appropriate performance (cf. standards requirements) up to 43°C; in some countries, the high ambient temperature condition requires a design at 46°C (T3 in ISO 5151:2010) with appropriate operation up to 52°C.

In high ambient temperature conditions, peak loads can occur at temperatures where the impact of city heat islands, increased roof temperatures and localised sun traps have to be taken into account in the determination of the way of operation at the highest temperatures occurring; these can result in air temperatures exceeding the expected shade temperature Considerations for equipment that will be operated at high ambient temperature conditions must be based on more than the choice of refrigerant but also on overall system design to obtain optimum and reliable performance under those conditions.

7.2 Research related to high ambient temperature conditions

Most of the research and development has traditionally been made at the "standard ambient" of 35°C dry bulb temperature. The performance of units at different ambient temperatures would then be simulated or extrapolated. Countries with high ambient temperatures were faced with the challenges of:

- An unclear global trend about refrigerant alternatives for each category of application particularly those suitable to operate in high-ambient conditions;
- The limited availability of components, mainly compressors, that are suitable for various low-GWP alternatives and designed for high-ambient temperature conditions; and
- The general fact that the behaviour of HVAC systems and their efficiencies (not related to refrigerant choices) has so far not been clearly determined when operated at high ambient temperatures.
- These challenges were accentuated by the absence of national/regional codes/standards that could facilitate the introduction of low-GWP alternatives and deal with flammability (where applicable) and the new energy efficiency rating schemes that were being introduced simultaneously with the phasing out of HCFC systems.

7.2.1 Earlier research

The need for research into alternatives suitable for high ambient became more urgent and some research effort surfaced (Colbourne, 2013), both in modelling and lab research, some done in high ambient temperature regions.

- Earlier modelling by Chin and Spatz (1999) conducting simulations comparing R-410A to HCFC-22 at 52°C ambient showing a 6% drop in capacity and 7% drop COP, respectively for R-410A.
- Domanski and Payne (2002) carried out measurements of a unitary air conditioner to compare HCFC-22 and R-410A, with two different compressors. R-410A indicated a 7-8% reduction in capacity at 52°C and around 14 – 20% drop in COP.
- Devotta et al. (2005a) found a 2-8% drop in capacity and 8-14% increase in COP when a window type HCFC-22 air conditioner was retrofitted with R-407C.
- Tu, Liang, and Zhuang (2011) compared the performance of HFC-32 and R-410A with actual tests carried at 43°C and 48°C ambient. Results showed that the volumetric capacity of HFC-32 increased by 6.96 to 8.87% at standard conditions, and at high ambient, HFC-32 had a 14.95% higher cooling capacity and 6.01% higher EER than R-410A.
- Biswas and Cremaschi (2012) measured the performance of some unassigned mixtures at fairly high ambient temperatures. At about 46°C the fluids "DR-4" and "DR-5" (72.5% HFC-32/27.5% HFC-1234yf) had a COP about 5% higher than R-410A, but had the same COP at 35°C. The capacity of these mixtures was about 2-3% above R-410A for "DR-5" and 15% lower for "DR-4", but there was again negligible difference to the capacity at 35°C.
- Chen (2012) reported a number of tests on split air conditioners using HCFC-22, HC-290, R-410A and HFC-32, with an additional test using HFC-32 where the compressor had an injection circuit in order to help reduce the discharge temperature. The results show that the capacity of R-410A drops by 9% and the COP by 6% relative to HCFC-22 at 52°C. With regards to HC-290, it was found to have a very similar capacity and COP to HCFC- 22 at higher ambient conditions, always within

±1.5%. By using an injection circuit (to reduce excessively high discharge temperature, in excess of 137°C, HFC-32 improved to almost 5% drop in capacity relative to HCFC-22 instead of 10% with no injection. (The injection benefit is in reducing discharge temperature to 115°C instead of 137°Cat high ambient. By comparison, the discharge temperature for both HCFC-22 and R-410A is 110°C.)

- In the high ambient countries, Hamed (2012) also reported on tests with HC-290, HCFC-22, HFC-134a, R-407C and R-410A in an air-to-air (rooftop) air conditioner. The test used the same compressor for HCFC-22, R-407C, and HC-290; 38% bigger capacity compressor for HFC-134a; and an optimized compressor for R-410A. The results gave almost same performance at 50 °C and 52 °C for all refrigerants, except for HC-290 which suffered a loss in capacity by about a 25%. Then and after optimizing the compressor of HC-290, there was an enhancement of both capacity and COP, but still lower than HCFC-22. Other tests with HCFC-22, HFC-32, R-410A, HFC-134a, R-407C and HC-290 for split air conditioner with optimized and dedicated compressors showed a better performance at standard ambient for HFC-32 compared to HC-290 but a higher COP at high ambient for HC-290 over HFC-32. The cooling capacity degradation at high ambient is highest for R-410A.

7.2.2 Collective regional research projects

To shed light into what can be considered as sustainable technologies for high ambient temperature conditions. UNEP and UNIDO launched a project to study and compare refrigerants working in machines specifically built for those refrigerants and operating at high ambient temperatures. The project, "Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (PRAHA) was launched in 2013 with a target completion in 2015. The project is implemented at the regional level in consultation with National Ozone Units of Bahrain, Iraq, Kuwait, Qatar, Oman, Saudi Arabia, and the UAE to ensure incorporating the project outputs within the HPMPs particularly for the preparation of post 2015 policies and action-plans

Building up on PRAHA and the linkage to country phase-out plans, Egypt adopted a similar initiative as part of the HPMP to test refrigerant alternatives for air-conditioning units built in Egypt. The initiative, "Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt" (EGYPRA) proposes to test more blends in different applications. The initiative was launched back in June 2014 and is expected to have the results by early 2016.

Local Original Equipment Manufacturers (OEMs) will build prototypes running with the different refrigerant alternatives and ship other "base units' operating with HCFC and HFC for comparison purposes. Testing will be done at 35, 46, and 50°C ambient temperatures with an "endurance" test at 55°C ambient to ensure no tripping for two hours when units are run at that temperature. The proposed refrigerants are:

- HC-290
- HFC-32
- R-444B (former L-20), replacing HCFC-22
- R-447A (former L-41), replacing R-410A
- DR-3, replacing HCFC-22
- R-454B (former DR-5A), replacing R-410A
- ARM-32, replacing HCFC-22
- ARM-71d, replacing R-410A

In August 2015, at the International Congress on Refrigeration (ICR) in Yokohama, PRAHA project managers gave a glimpse of some of the preliminary findings from 40% of the test results. The main finding is that some of the alternative refrigerants with higher relative volumetric capacity than R-22 show better COP than was theoretically expected. These preliminary results indicate a way forward in the search for efficient low-GWP alternatives for high ambient temperatures especially when coupled with a full system redesign. The results however need to be corroborated with the findings after 100% of the tests have been finalized before they are published in the project report which is expected to be ready by end of 2015.

The work by PRAHA and EGYPRA will facilitate the technology transfer and experience exchange of low-GWP alternatives for air-conditioning applications operating in high-ambient temperature countries. The other indirect objective is to encourage the development of local/regional codes and standards that ease the introduction of alternatives needing special safety or handling considerations, and to ensure that national and regional energy efficiency programs are linked to the adoption of low-GWP long term alternatives PRAHA (2013).

7.2.3 Cooperative international research

AREP (Alternative Refrigerant Evaluation Program), a project launched by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is a cooperative research program to identify suitable alternatives to high GWP refrigerants without prioritizing them.

In the first phase of the project, 21 companies tested 38 refrigerant candidates for replacing HCFC-22 and three other HFCs, R-410A, HFC-134a, and R-404A (Amrane, 2013), in applications varying from air conditioners and heat pumps (both package, split and VRF), chillers (screw and centrifugal), refrigeration (commercial and ice machines), transport, and bus air-conditioning.

Phase II is testing more refrigerants plus doing all tests at high ambient temperature conditions, which phase I did not do.

- AREP and PRAHA signed a joint declaration to set the criteria and conditions for testing and to identify and assist in setting the parameters to be reported, such that, results can be useful to both projects. The declaration includes sharing the results and the outputs for possible comparison. Eltalouny (2014) described the differences between PRAHA and AREP as:
- *AREP is focused on studying refrigerant characteristics, while PRAHA is focused on performance and efficiency comparison;*
- *AREP is based on soft optimization (drop-in) only while PRAHA includes custom built prototypes designed for the new alternatives;*
- *AREP testing is conducted in manufacturers' labs while PRAHA will be tested at one independent 3rd party lab;*
- *PRAHA is focused on high-ambient conditions (T3 (ISO 5151:2010) design conditions) and is linked to local MEPS as reference design and test guides.*

AREP concluded its first phase in 2013 and the second phase began in early 2014. Twenty three entities are members of this second phase, with compressors, air conditioners and heat pumps, rooftop units, chillers and refrigeration products being evaluated. Twenty five refrigerant candidates have been proposed and are shown in the table below:

In Phase I of the AREP some -limited- higher than normal ambient temperature conditions were tested as given the Table 7-2 below.

Table 7-2: Matrix for AREP Phase I low-GWP High Ambient testing

Low-GWP AREP Phase I High Ambient Test Matrix-Completed														
Product	Test companies	High Ambient conditions	Report	Baseline refrigerant	R-1234yf	R32	D2Y60	L-41a	L-40	N-40b	AC5	N-13a	L-20	D-52Y
3.5-ton split system HP	Lennox	115F	AREP Report No. 10	410A	X									
3.5-ton split system HP	Lennox	115F	AREP Report No. 4	410A		X								
3-ton split system HP	Uni. of Maryland	115F	AREP Report No. 20	410A		X	X	X						
3-ton split system HP	Uni. of Maryland	115F	AREP Report No. 32	410A			X							
Ice machine (self-contained)	Manitowoc	110F	AREP Report No. 2	404A					X	X				
Ice machine (split system)	Manitowoc	120F	AREP Report No. 2	404A					X	X				
Bus AC system	ThermoKing	120F	AREP Report No. 12	134a							X	X		
Bus AC system	ThermoKing	120F	AREP Report No. 13	407C									X	X

It was recognized at the end of Phase I that high ambient countries needed additional effort and this was recognized by the tests dedicated to this application as given in Table 7-3.

Table 7-3: Matrix proposed for AREP Phase II low-GWP High Ambient testing

Low-GWP AREP Phase II High Ambient Test Matrix-Porposed												
Product	Test companies	High Ambient condition s	Current Testing Status	Baseline refrigerant	ARM-20b	ARM-71a	DR-5A	HPR2A	L-41-1	L-41-2	N-40c	R-32
10kW water chiller	Armines	115F	in testing	410A		X	X		X	X		
11.3 EER 10-ton rooftop unit	Carrier	125F	in testing	410A			X		X	X		X
14 SEER 3 Ton HP	Carrier	125F	in testing	410A		X	X	X	X	X		
13 SEER 3-ton HP	Danfoss	115F and 125F	in testing	410A			X			X		X
14SEER 3-ton split HP	Goodman	115F and 125F	completed	410A								X
Commercial package unit	Lennox	115F	in testing	410A		X	X	X		X		
split ice machine	Manitowoc	120F	completed	404A	X						X	
4-ton packaged rooftop	Trane	125F	in testing	410A			X					X
Rooftop packaged unit	Zamilac	125F	in testing	410A								X

This second phase of the AREP study is well underway with much of the testing completed and reports being worked on. The progress of the study can be tracked on the AHRI website, where updates are published on a regular basis.

7.2.4 *Additional research – US DoE project*

In response to questions that have been raised by several countries about the performance and efficiency of low-GWP refrigerants in high-ambient temperatures, the U.S. government is establishing a testing program in close cooperation with international equipment manufacturers and refrigerant producers, and government representatives from other countries. The testing program will seek to test the performance of different kinds of air conditioning units that use low-GWP refrigerants in high-ambient temperatures and to show that it is possible to achieve comparable or better performance than existing equipment in terms of energy efficiency and cooling capacity. In particular, the effort will focus on mini splits – and potentially also rooftop units – given their prevalence in high-ambient temperature regions. The testing of mini splits will take place at Oak Ridge National Laboratory (ORNL) and the intended testing of rooftop units will take place at another third-party laboratory, as resources allow.

7.2.5 *Comparison table of the different research projects*

Table 7-4: Comparison of DoE, EGYPRA and PRAHA projects

	Program	US DoE	EGYPRA (UNEP, UNIDO) Egypt	PRAHA (UNEP, UNIDO) high-ambient countries
1	Type of test	Soft optimization tests, comparing with base units: HCFC-22 and R-410A	Individual test prototypes, comparing with base units: HCFC-22 and R-410A	Individual test prototypes, comparing with base units: HCFC-22 and R-410A
2	Number of prototypes	2 commercially available units, soft modified to compare with base refrigerants: HCFC-22 and R-410A	28 prototypes, each specific to one capacity and one refrigerant, compared with the base refrigerants: HCFC-22 and R-410A	18 prototypes, each specific capacity and refrigerant built by two OEMs, compared with base refrigerants: HCFC-22 and R-410A
3	No. Of categories	60 Hz Split unit 18 MBH R22 eq. Split unit 18 MBH R-410A eq.	50Hz Split 12 MBH Split 18 MBh Split 24 MBH Central 120 MBH micro Channel 120 MBH	60 Hz Window 18 MBH Mini Split 24 MBH 50 Hz Ducted 36 MBH Packaged 90 MBH
4	Testing Conditions	ANSI/AHRI Standard 210/240 and ISO 5151 T3 (2010) condition	EOS 4814 and 3795 (ISO 5151), T1, T2, and T3 conditions.	ANSI/AHRI Standard 210/240 and ISO 5151 at T1, T3 and T3+ (50°C) and a continuity test for 2 hours at 52°C
5	Prototypes supplied and Tests performed	ORNL (Oak Ridge National Laboratory), one supplier – soft optimisation in situ	Prototypes built at eight OEMs, test at NREA (Local test laboratory in Egypt)	Prototypes built at seven OEMs, test at Intertek.
6	Refrigerants tested	HFC-32, HC-290 HFOs (>3 types) eq. to HCFC-22 HFOs (> 3 types) eq. to R-410A	HFC-32, HC-290 HFOs (3 Types) eq. to HCFC-22 HFOs (3 Types) eq. to R-410A.	HFC-32, HC-290 HFOs (2 types) eq. to HCFC-22 HFOs (1 type) eq. to R-410A
7	Expected Delivery Dates.	Preliminary report, July 2015 Final Report October 2015	Early 2016	4th quarter of 2015
8	Constraints	To change some components of the two prototypes to accommodate the different refrigerants characteristics, within a "soft optimisation" process	To build new prototypes with dedicated compressors for the selected refrigerants with the condition to meet the same design capacities of the selected models in comparison to the HCFC-22 or R-410A designs	To build new prototypes with dedicated compressors for the selected refrigerants fitting in the same box dimensions as the original design and comparing performance and efficiency to base models with HCFC-22 and R-410A units
9	Other components	N/A	N/A	The project includes other non-testing elements to assess relevant issues of energy efficiency (EE) standards, technology transfer and economics in addition to special reporting on the potential of District Cooling to reduce the use of high-GWP alternatives.

7. 3 Designing for high ambient temperature conditions

It is important to note that any change of refrigerant in an existing design requires careful considerations. Theoretical calculations can give an idea about what is generally to be expected with a change in refrigerant, but specific details on the system design, for instance design and sizing of heat exchanger, will impact how the system capacity and energy efficiency is influenced by a change in refrigerant. For system builders this means that each system design needs to be optimized after the change of refrigerant. This requires an investment similar to what has been spent on optimizing the system for the current refrigerant, and for highly cost optimized systems this investment might be considerable.

In theory, high energy efficiency and safety can be achieved in almost any application with any refrigerant. The challenge is to choose a refrigerant that allows high enough energy efficiency and sufficient safety to be achieved at a cost which is low enough for the system builder to compete with other system builders. The total system cost and total system energy has to be considered, not only the refrigerating circuit cost and energy consumption. Besides cost, installation space and sound levels are other challenge for the system designer that may limit the choice of systems and refrigerant. What constitutes an optimal design is highly dependent on the ambient temperatures. In high ambient conditions there will be a tendency towards larger systems due to the higher heat load, larger heat exchangers compared to the rest of the systems, and refrigerants with low critical point have much lower performance than in colder climates. The higher the energy level the higher the cost and size impact of refrigerants and systems that are not optimal in view of energy efficiency. In most regions with high ambient the water consumption of the system has to be considered carefully which limits in several cases the choice of the system. Based on future tendencies designers have to take more and more care for the efficient use of the available resources. High energy efficient, compact units with low weight and high recyclability will become the future tendency. This will be even more important for larger equipment as needed for high ambient zones.

Another aspect that requires consideration is that attention to safety is important when changing from a non-flammable refrigerant to a flammable refrigerant, for instance avoiding ignition sources and conducting risk assessments. The availability of qualified service personnel will be part of this assessment.

A general rule of thumb is that lowering the GWP increases the flammability or lowers the capacity. It should however be remembered that:

- Safety considerations limit how far flammability can be accepted in a given application. Safety considerations are especially limiting in high ambient where the higher heat load requires higher capacities and larger refrigerant quantities per system. It is possible to increase safety by adding extra features, which increases cost, but also increase the number of applications which can use flammable refrigerants;
- While safety considerations are often focused on the consumer safety, there can also be a significant investment cost in converting production lines, so workers can safely build systems with flammable refrigerants;
- A change of the volumetric capacity of the refrigerant requires changes in the system design. Where the change is large the design changes have large impacts or are not feasible. Lowering the capacity will increase the system size and thereby system cost, which might not yield a competitive solution. Changing from HCFC-22 to HFC-1234yf is such an example, and for centrifugal chiller systems the change from HFC-134a to HCFC-1233zd(E) may also be such an example. Lower capacity may also

lead to higher refrigerant charges and consequently the amount of kgs multiplied by the GWP has to be considered;
- A decrease of the emissions from electricity production may increase the relative importance of refrigerant emissions but energy efficiency will remain an important factor to realise the reduction of emissions form electricity production.

Changes which do not require large investments in R&D will be preferred by most system builders as they minimize the economic risk related to the change. Such changes include:

- Changes from non-flammable to another lower GWP non-flammable refrigerant. Especially for refrigeration, avoiding the use of R-404A but using non-flammable alternatives such as R-407A/F or even lower GWP refrigerants like R-448A, R-449A or R-449B.
- Change to lower flammability substances for smaller systems or systems placed outdoors. For instance for A/C prefer using lower GWP HFC-32, R-447A or R-454B over R-410A, or for chillers prefer using R-454A or HFC(HFO)-1234ze(E) over HFC-134a.
- Changes to higher flammability substances for small systems with a few 100g of refrigerant or systems placed outdoors. For instance using R-600a in place of HFC-134a or using HC-290 in place of R-404A or R-407C.

The design for high ambient temperature conditions needs special care to avoid excessive condensing temperatures and getting close to the critical temperature for each type of refrigerant. Other issues like safety, refrigerant charge quantity, and improving the energy efficiency for both partial and full load have to be taken into consideration.

7.3.1 Heat exchangers

In regions with high ambient temperature conditions, special care in selecting and designing of the heat exchangers must be taken into consideration by using smaller tube diameters of 5 or 7 mm with larger primary and secondary surface areas or by using micro-channel type of heat exchangers to increase heat transfer and to reduce the condensing temperature. A major factor in the design of chilled water systems is the use of brazed plate-type heat exchangers for both condenser, in a water cooled system, and evaporator to increase efficiency and reduce the refrigerant charge. Reducing the refrigerant charge is important to meet safety standards requirements.

7.3.2 Compressor types and availability

Compressor manufacturers offer scroll, reciprocating, and screw compressors for small and medium size units running with low-GWP refrigerants. The trend of using multi compressors is becoming an option for A/C manufacturers in the high ambient countries and compressor manufacturers are now offering compressors with HC-290, HFC-32 and HFC-1234yf with energy efficiency levels that can meet or exceed the new MEPS in the region. These compressors are ATEX (Appareils destinés à être utilisés en ATmosphères EXplosives) certified for flammable refrigerants.

7.3.3 Safety standards

Standards for the new refrigerants (that are mostly flammable), like ISO 5149, EN 378, IEC 60335-2-40 for air conditioners and heat pump systems and IEC 60335-2-89 for commercial refrigeration appliances, are available, although IEC 60335-2-89 need to be adapted to allow larger charges of flammable refrigerants. IEC standards are a de facto legal requirement in several countries as the Certification Body (CB) scheme is the actual requirement for import and sales of products. In some countries, the implementation of old standards in the legislation, for instance building codes or other mandatory safety regulations, blocks the uptake of especially flammable refrigerants.

Updating legislation is a slow process due to the thoroughness needed; this creates a delay in the adaptation of new standards. On top of this, standards, including safety standards, are written by industry participants largely based on general use; this also means that they do not cover specific manufacturer situations. The practice of writing safety standards into legislation as mandatory therefore tends to slow down the up-take of new technology such as flammable refrigerants together with the necessary safety practices.

An implementation strategy used in some countries is to make specific safety standards mandatory, but allow for risk assessments to be used as alternative, often combined with a certification body scheme. In this way newer safety methods can be used since doing a risk assessment is relatively easy when basing the design on published safety standards, besides, even when following a safety standard a risk assessment should always be carried out to ensure safety.

Another important aspect of safety standards is that they only have value if they are followed, and this makes training of system builders and service technicians an important part of implementing safety standards.

7. 4 Energy efficiency and capacity consequences

7.4.1 Energy efficiency for certain cases

In regions with high ambient conditions, legislations which set minimum energy efficiency values on air conditioners are emerging quickly. Most of the countries require third party verification of declared performance. Table 7-5 shows the legislations in force and the upcoming legislations applicable to multi-split, split (ducted) and ducted split commercial and non-split air conditioners.

Table 7-5: Air Conditioners

Country	Number of the standard	Status	Type of requirements	Products in scope	Climate conditions	Test standard to be used
Saudi	SASO 2007/2006	In force	Safety	All	NA	IEC 60335-2-40:1995
	SASO 2663/2014	In force	minimum energy performance values	non-ducted splits and package units < 70000 Btu/h	35°C (T1) and 46°C (T3)	SASO 2681/2007 SASO 2682/2007
	SASO XXXX/2015	Being drafted	minimum energy performance values	all other units	35°C (T1)	ANSI/AHRI 110-2012, ANSI/AHRI 210/240-2008, ANSI/AHRI 340/360-2007, ANSI/AHRI 1230-2010, ANSI/ASHRAE Standard 127-2007, ANSI/ASHRAE/IES 90.1/2010, ANSI/ASHRAE/IES90.1/2013, ISO 15042/2011
United Arab Emirates	UAE.S.5010-1:2011	In force	minimum energy performance values and energy label	residential and commercial single package and non-ducted split type air conditioners	46°C (T3)	ISO 5151:2011
	UAE.S.5010-1:2014	Published (will replace	minimum energy performance	residential single package and	46°C (T3)	ISO 5151:2011

		2011 version)	values and energy label	non-ducted split type air conditioners		
	UAE.S.5010-5: 2014	Published	minimum energy performance values	residential, commercial and industrial ducted split and multiple split-system air-conditioners and heat pumps	46°C (T3)	ISO 13253:2011 ISO 15042:2011
Kuwait		In force	Safety	All	NA	IEC 60335-2-40
		In force	Minimum energy performance values and energy label	Packaged, ducted and non-ducted air conditioners	48°C	AHRI standards

Legislations which set minimum energy efficiency values in high ambient regions also include chillers. The following table shows the legislations in force and the upcoming legislations applicable to chillers.

Table 7-6: Positive displacement chillers

Country	**Number of the standard**	**Status**	**Type of requirements**	**Products in scope**	**Climate conditions**	**Test standard to be used**
Saudi	SASO 2007/2002	In force	Safety	All	NA	
	SASO XXXX/2015	Being drafted	minimum energy performance values	Chillers Absorption chillers	35°C (T1)	ANSI/AHRI 550/590(I-P)-2011, ANSI/ASHRAE/IES 90.1/2010, ANSI/ASHRAE/IES 90.1/2013, ANSI/AHRI 560(I-P)-2000
United Arab Emirates	UAE.S.5010-5: 2014	Published	minimum energy performance values	water-source heat pumps and water-chilling packages	46°C (T1)	AHRI 550/590

7.4.2 Capacity for certain cases and impact on limits of use

In high ambient conditions, the cooling load of a conditioned space can be up to three times that for moderate climates. Therefore larger capacity refrigeration systems may be needed which implies a larger refrigerant charge. In high ambient countries, it is typical to select refrigeration and air conditioning systems for ISO T3 conditions (46°C outdoor temperature) while ISO T1 conditions (35°C outdoor conditions) are used for moderate climates, which also results in larger refrigerant charges in the system. Due to the requirements for charge limitation according to certain safety standards, the possible product portfolio suitable for high ambient conditions is more limited than for average climate conditions when using the same safety standards.

7. 5 How to balance possible consequences

7.5.1 Measures that can improve energy efficiency and capacity

Some factors which can be improve the system Energy Efficiency (EE) and capacity at high ambient conditions:

- Using different types of heat exchangers for both condensers and evaporators: using bigger condensers can improve the EE of the system by reducing the condensing temperature. This is especially true for refrigerants with low critical temperature as the reduction in the condensing temperature will reduce the compressor lift and will also reduce the compressor power consumption. The same positive results can be achieved using micro channel condensers;
- Using high efficiency evaporators (shell and tube or brazed plate). Recently many evaporator manufacturers are reducing the approach temperature between the evaporating temperature and the fluid temperature (air or water) which leads to higher evaporating temperatures in the air conditioning units. This will increase both the cooling capacity and EE;
- Using high efficiency scroll type compressors with compressor speed control (invertor) will increase the partial load efficiency for the whole system. These compressors are now available for low-GWP refrigerants;
- Using special electronic type expansion valves will lead to have higher energy efficiency for the system especially when the system is designed for a wide ambient temperature range for the high ambient countries.

7. 6 Current and near future alternative chemicals for high ambient temperature conditions

7.6.1 Fluorocarbons

Multi-split, Split (ducted) and Ducted split commercial and non-split air conditioners:

- R-407C is chosen as an alternative to HCFC-22 by some manufactures in the Middle East. Whilst many of the proposed blends are seldom used, R-407C has been demonstrated to be an acceptable retrofit refrigerant and has seen widespread use in some regions. This is especially the case in regions with high ambient temperatures as the capacity drop at elevated temperatures is relatively lower than that of R-410A, although there is some loss in capacity and efficiency compared to HCFC-22.
- The use of R-410A is getting more and more popular. Operation at high ambient is achieved by proper selection of heat exchanger. R-410A units use typical invertor driven compressors allowing the equipment to optimize its operation for the different outdoor temperatures. The lower critical temperature results in lower efficiency than HCFC-22 at same condensing temperatures. A larger condenser can resolve this issue, but relative cost increment is inevitable.
- HFC-32 is suitable for regions with high ambient temperatures in most types of split, multi-split and ducted ACs although necessary consideration is needed to provide suitable training for the service sector to handle the lower flammability aspects. First split models were launched in the Middle East in May 2015. The refrigerant properties, including better heat transfer, has resulted in more compact units for the same capacity and efficiency or higher capacity and efficiency for the same size of unit.
- Both R-446A and R-447A have higher critical temperature of around 84°C and 83°C, respectively, compared to 71°C for R-410A. This higher critical temperature enables them to have a higher efficiency at high ambient temperature (Sethi, 2013). The cost

implications should be comparable to those of R-410A, although marginally greater due to the higher refrigerant price at present. Necessary consideration is needed to provide suitable training for the service sector to handle the flammability aspects.

- R-444B has a critical temperature similar to HCFC-22 and thus substantially higher than R-410A, which implies that it should show performance at high ambient temperatures similar to HCFC-22. Preliminary test results indicate that R-444B shows similar capacity and efficiency to HCFC-22 (Sethi et al, 2014). The cost implications should be comparable to that of HCFC-22 although probably greater due to the higher refrigerant price at present. Necessary consideration is needed to provide suitable training for the service sector to handle the flammability aspects.
- As highlighted in TEAP (2013), the use of single component unsaturated HFCs, such as HFC-1234yf and especially HFC-1234ze(E), have not been seriously considered for multi-split and ducted ACs because their volumetric capacity is low , implying bulkier systems and – along with high anticipated refrigerant price –a considerable increase in product cost. Some exceptions may exist for niche situations in systems intended for regions with very high ambient temperatures

Positive displacement chillers:

- Due to its good efficiency at high ambient temperatures, systems with R-444B would have power consumption lower relatively to other options. The direct cost of this refrigerant may be similar to current HFCs such as R-407C. It works well with existing POE lubricants.
- Due to its relative higher critical point compared to other refrigerants, DR-5 performs well at high ambient temperatures. The direct cost of this refrigerant would be slightly high as it contains HFC-1234yf which has an expensive manufacturing cost. It works well with existing POE lubricants. Due to its good efficiency at high ambient temperatures, power consumption would be lower relative to R-410A.
- Due to its relative higher critical point compared to other refrigerants, R-447A performs well at high ambient temperatures and its energy efficiency at high ambient temperatures is better than R-410A. It works well with existing POE lubricants, while the direct cost is similar to R-410A.
- The use of HFC-32 imply that some mitigation device or controls may be necessary for handling the discharge temperature of the compressor especially at high ambient temperatures. Where screw compressors are used this is not an issue as they are generally provided with an oil cooler or liquid injection to maintain the discharge temperature within a reasonable range. The good heat transfer of the refrigerant will show good performance for chillers as the heat transfer depends mainly on the refrigerant heat transfer coefficient (except for flooded type evaporators). HFC-1234ze might also be an interesting option for larger chillers. Besides it is easier to produce large pipes and components for low pressure refrigerants than for high pressure refrigerants.

Centrifugal chillers:

- HCFC-1233zd(E) is an alternative in low pressure centrifugal chillers, and should produce efficiency levels slightly better than HCFC-123, both at moderate and high ambient temperatures. One chiller manufacturer has released a chiller working with HCFC-1233zd(E) chiller, while others are offering HFC-1234ze for centrifugal chillers.

7.6.2 Other refrigerants

Multi-split, Split (ducted) and Ducted split commercial and non-split air conditioners

- The use of R-744 is not suitable for high temperature climates due to the inability or excessive cost necessary to achieve desired efficiencies. There is continuing research on cycle enhancements and circuit components, which can help improve the efficiency under such conditions, although they may be detrimental to system cost.
- In multi-split, split (ducted) and ducted split commercial and non-split air conditioners, both HC-290 and HC-1270 perform well at high ambient. However, due to charge amount limitations, they are not easily applicable and require expert consideration as to suitability of cases. Manufacturers in high ambient countries are experimenting with hydrocarbons in rooftop units (see item 6).

Positive displacement chillers:

- R-717 chillers can and are used in regions with high ambient temperatures, although the very high discharge temperatures need to be accommodated for through inter-stage and oil cooling.
- Due to the low critical temperature, the use of R-744 presents several technical barriers, mainly performance degradation of capacity and efficiency at high ambient temperatures. Although components for high pressure do exist, their use leads in an incremental cost increase. For an ambient temperature of 35°C the efficiency of a basic cycle is about 50-60% of HCFC-22.

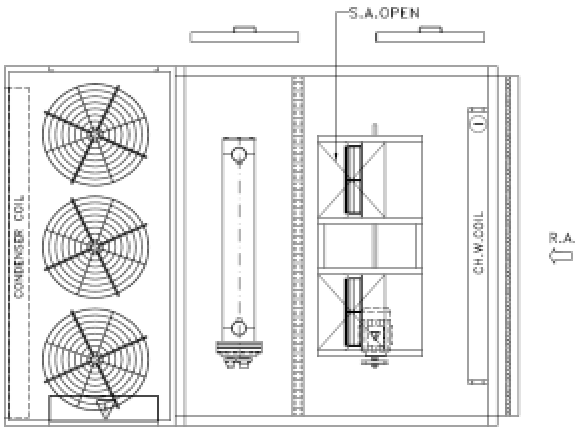


Figure 7-2: Rooftop chilled water packaged unit

Centrifugal chillers:

R-718 (water) chillers are in use in several installations in Europe and are now commercially available in Japan in capacities of up to 350 kW using a special axial type compressor. In principle R-718 chillers should perform well under high ambient temperat ures. R-718 has excellent properties for heat exchange in the liquid phase. Due to its lower molar mass and lower saturation pressure, compression is not so easy. The volumetric rate is 20 times higher than HCFC-123 while the required velocity to compress water 3 times higher than HFCF-123. It cannot operate below zero °C due to freezing. Fouling can have a devastating impact on the performance. The required tightness is extremely high, but difficult to achieve due to the negative pressure even at the high pressure side. Air entering the system can have severe impacts due to corrosion inside the system.

7. 7 Alternative technologies for high ambient temperature conditions

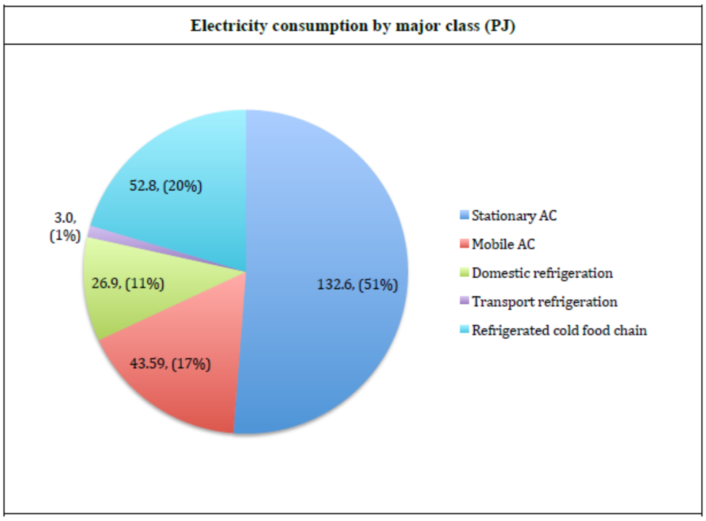
Countries in high ambient areas have been experimenting with small and medium size chilled-water systems for residential and light commercial use meeting the new minimum energy performance requirements (MEPS) regulations for the high ambient Gulf countries. Two such designs are under experimentation:

- A rooftop chilled water packaged unit (see Fig. 7-2) including an air-cooled chiller, a chilled water air handling unit (AHU) and a water pump in one package that is installed outdoors. The system uses multi circuit compressors working with either HC- 290 or HFC-32. The advantages of this system are: A) chilled water is only circulated to AHU to prevent the flammable, and or toxic refrigerant to be in direct contact with the air stream which is circulated to inside the building. By applying this compact design, the refrigerant is totally isolated from the inhabited space in case of a leakage from the heat exchanger coil of the AHU. In a traditional direct expansion (DX) rooftop packaged unit, a leakage will cause the refrigerant to circulate inside the building causing safety concerns from some of the new alternatives being proposed. B) Another advantage is by using multi circuits, the integrated part load efficiency is much higher than a standard traditional rooftop unit using single circuit. Most of the A/C equipment are working 99% of the time partially loaded; consequently, an important factor in evaluating the performance of the A/C system is Integrated Part Load Values (IPLV) values not just efficiency at full load.

- A custom made air cooled outdoor chiller with multi-circuit compressor using HC-290 refrigerant to meet the minimum energy efficiency requirements. The use of multi circuit compressor is to increase the integrated partial load values and to reduce the refrigerant charge to make it possible to use with flammable and or toxic refrigerants.

7. 8 Refrigeration and high ambient temperature conditions

The refrigerated cold food chain, an important consumer of refrigerants, is often overlooked especially in high ambient temperature countries.



Source: Cold Hard Facts (ref. in Australia)

Figure 7-3: Electricity consumption by refrigerant sub-sectors

Typically, the refrigerated cold food chain consumes between 30 and 40 % of a nation's electric power generated for stationary R/AC.

Domestic refrigeration at high ambient temperature conditions

The design considerations associated with high ambient temperatures are those associated with the introduction of HC (HC-600a) and unsaturated HFCs/HFOs (HFC-1234yf and HFC-1234ze) to domestic refrigeration. The RTOC 2014 assessment report estimates that 75% of new domestic refrigeration appliances globally, will use HC-600a by 2020.

Thermodynamically, refrigerators using HC-600a will operate with a better efficiency than using HFC-134a in high ambient temperatures, since its condensing pressures/temperatures are lower. In countries where the charge of refrigerant exceeds 150 grams, because of flammability issues and local standards, HFOs will most likely be the preferred choice. Their thermodynamic properties are close to those of HFC- 134a. HFC-1234yf has a slightly lower COP and HFC-1234ze a lower volumetric capacity, attention must be paid for the safety classification A2L for both. Domestic refrigerators are usually stand-alone self-contained compressors/assemblies located inside the indoor conditioned envelope and therefore not directly affected by the deterioration of capacity and high discharge temperatures associated with high ambient temperature conditions, although the rejected heat load will be an added burden on the space air conditioning load.

Domestic absorption refrigerators design will not be affected by high ambient temperature conditions for the same above reasons, but lower efficiencies are expected. They will still be available for niche markets when noise of is an issue and where electric power supply is unreliable or none existent.

Commercial refrigeration at high ambient temperature conditions.

When commercial stand-alone refrigeration units are installed the in air conditioned envelope the issue is shifted to the air conditioning system of the commercial application.

Refrigeration systems at high ambient conditions have the same issues that air conditioning systems do – as ambient temperature increases, system load increases and capacity decreases. With increasing ambient and condensing temperatures, compressor discharge temperatures also increase thus leading to possible reliability issues. Unlike in air conditioning, refrigeration applications are already subject to high compressor discharge temperatures and use mitigation methods like liquid or vapour injection for the compressors. These methods to control discharge temperature will continue to be required in refrigeration applications with any new alternatives that are being considered.

In non-Article 5 Parties, as HCFC-22 was phased out, refrigeration applications migrated to R-404A, R-507A and HFC-134a in the different types of systems. In the United States, about five years ago, large supermarkets chose R-407A as an alternate to R-404A. At present, R-407A and R-407F are widely used in supermarket systems in the United States. Both of these refrigerants will work as alternates to HCFC-22 as high ambient countries consider phasing out HCFC-22. HFC-134a is an option in small close-coupled systems as well as the medium temperature refrigerant in a cascaded supermarket system. Cascade refrigeration systems can also be an option for high ambient countries where CO_2 is used as the low temperature refrigerant and rejects heat to a medium temperature system like one that uses HFC-134a as the refrigerant.

There are other lower GWP options in refrigeration that are soon to be introduced in the United States and Europe that can be future options for high ambient countries. Some of these are R-448A, R-449A and R449B which are all replacements for R-407A, R-407F, R-404A, and R-507A; R-450A and R-513A which are replacements for HFC-134a. While these refrigerants are non-flammable A1, there are mildly flammable refrigerants that are also in the process of being released for production – HDR110, DR3 and ARM20a, etc. These less than 150 GWP refrigerants and the HFOs are more suited for self-contained, factory charged applications and other small charge systems in supermarket and cold room applications.

In the hydrocarbon category of refrigerants, HC-290 is the one that is most commonly used in low charge commercial refrigeration systems in Europe. Larger systems use secondary coolants that exchange heat with the HC-290 which is typically located in a machine room where access is controlled. Both small self-contained refrigeration systems and these larger secondary HC-290 systems are options for high ambient countries in refrigeration. Similar to air conditioning, the standards, codes and technician training and certification are not well developed for flammable refrigerants and that has to be a consideration in the choice being made.

In absorption refrigeration applications, an absorption chiller and CO_2 cascade are trialled, for supermarkets. In this case, the concept is to base the system around a combined heat and power (CHP) plant for a self-contained system, but waste heat or solar energy could be used with the absorption chiller. The refrigeration system uses CO_2 as a secondary (volatile) refrigerant for the medium temperature (MT) cabinets and direct expansion (DX) for the low temperature (LT) cabinets. In designing the system, this maximises the system efficiency as the compressor power for MT refrigeration, which is the predominant load in a supermarket, is replaced by a much lower pump power to pump the liquid refrigerant to the refrigerated cabinets.

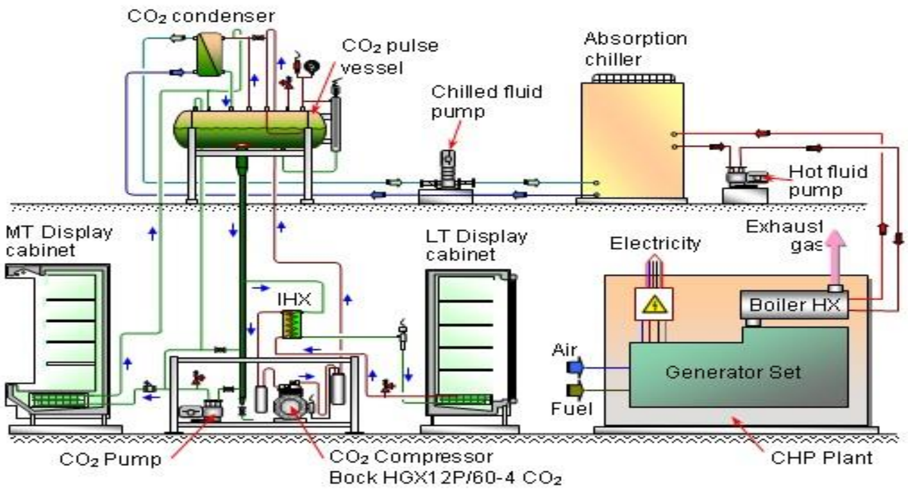


Figure 7-4: A commercial refrigeration system using reject heat and absorption refrigeration (*Source: http://dea.brunel.ac.uk/rdco2/press-en.htm)*

Industrial refrigeration in high ambient temperature conditions

R-717 is an important refrigerant for high ambient temperature industrial applications. CO_2 cascaded systems are also being introduced. Because a trans-critical CO_2 solution it is not adapted to a high ambient temperature climate, only cascade systems are possible. When outdoor temperature is higher than 25°C ($T_{condensation}$ > 31°C) the efficiency of trans-critical CO_2 quickly deteriorates. For instance, at 38°C ambient temperature, the efficiency of a basic cycle is lower from 40 to 50 % than that of R-404A.

In food processing, ammonia is already largely used; the cascade architecture, with CO_2 at the low temperature (from -35°C to -50°C) and ammonia at the medium temperature (-20°C to -10°C), allows ammonia charge limitation. This means the facilities are safer, there is a limited risk of ammonia leaking in the premises. Manufacturers of refrigeration systems have developed solutions based on a cascade sequence between HFC-134a and CO_2 refrigeration cycles, mainly for installation in high ambient temperature countries where outdoor temperatures are too high to allow a simple trans-critical CO_2 refrigeration cycle.

Solar refrigeration cascade with CO_2

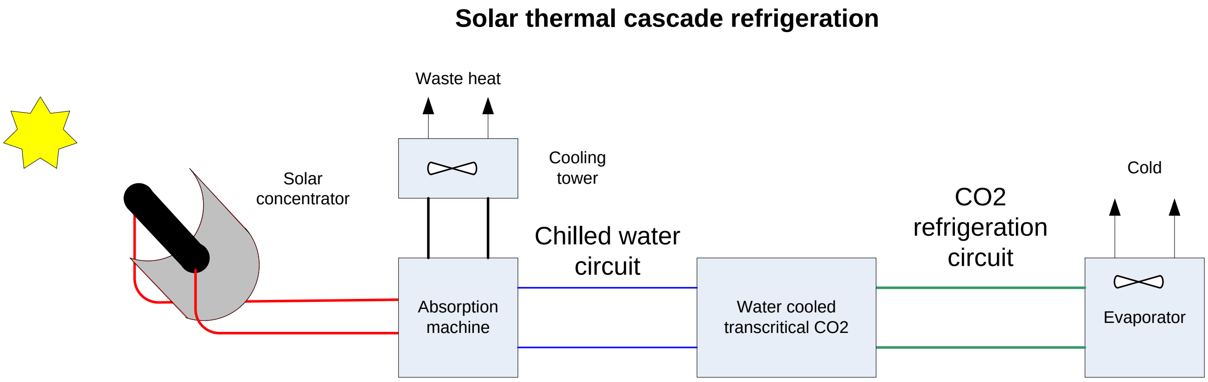


Figure 7-5: Solar thermal cascade refrigeration cascaded with CO_2 circuit

Cascaded solar-fired absorption units are being considered in high ambient temperatures conditions, cascaded with a CO_2 refrigeration circuit. An HFO mechanical vapour compression system can also be used instead of the CO_2 system. Both systems require additional testing.

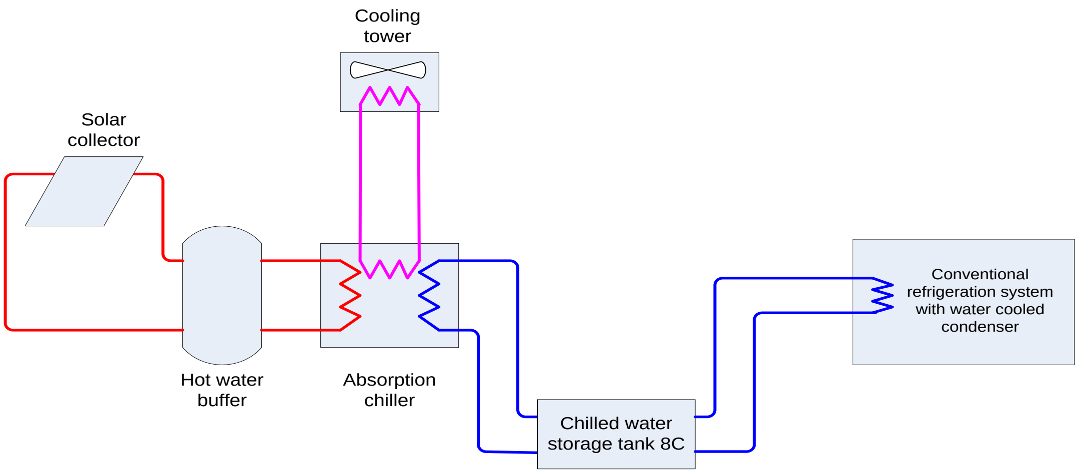


Figure 7-6: Solar thermal cascade refrigeration cascaded with vapour compression circuit

7. 9 References

Amrane, 2013 — Amrane, K. Overview of AHRI Research on Low-GWP Refrigerants. Webinar Aug 2013

Biswas and Cremaschi, 2012 — Biswas, A and Cremschi, L. Performance and Capacity Comparison of Two New LGWP Refrigerants Alternatives to R410A in Residential Air Conditioning Applications. Proc. 2012 International Refrigeration and Air Conditioning Conference at Purdue, USA.

Chen, 2012 — Chen, Z.H., Research on Rotary Compressors Based on R-290 Technology. Proc. UNEP conference on technologies for high ambient conditions, Dubai, 2012.

Chin and Spatz, 1999	Chin, L., Spatz, M.W., Issues Relating to the Adoption of R-410A in Air Conditioning Systems, 20th International Congress of Refrigeration, IIR/IIF, Sidney, Australia.
Colbourne, 2013	Colbourne, C., HC-290 as an Alternative Refrigerant for Split Air Conditioning Systems in High Ambient Temperatures. Papiernicka 2013
Devotta et al, 2005a	Devotta, S., Padalkar, A.S., Sane, N. K., 2005a. Performance assessment of HCFC-22 window air conditioner retrofitted with R-407C. Applied Thermal Engineering, Vol. 25, Issue 17–18, 2937–2949.
Domanski and Payne, 2002	Domanski, P.A., Payne, W., Properties and cycle performance of refrigerant blends operating near and above the refrigerant critical point. Task 2: Air conditioner system study, Final report. ARTI-21CR/605-50010-01-P.2., 2002
Eltalouny, 2014	Eltalouny, A., Challenges in Identifying Low-GWP Refrigerants for High Ambient Temperature Climates. International Conference on Efficient Building Design, October 2014, Beirut, Lebanon.
Hamed, 2012	Hamed, S., “Using HC and HFC refrigerants in rooftop package units Which refrigerant is the future?”, Proc. UNEP conference on technologies for high ambient conditions, Dubai, 2012.
ISO 5151:2010.	Non-ducted air conditioners and heat pumps -- Testing and rating for performance. International Organization for Standardization (ISO).
PRAHA 2013.	PRAHA project document, 2015
Sethi, 2013	Sethi, A., Low GWP Replacements for R-410A in Air Conditioning Applications., Proc. 2013 ASHRAE Summer Meeting, Denver, CO, USA.
Tu et al., 2011	Tu, X. et al., Study of R-32 Refrigerant for Residential Air-Conditioning Applications, International Conference on Refrigeration, Prague 2011.
UNEP, 2014.	2014 Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee Assessment Report, edition published 2015

8 Information on alternatives to ODS in the fire protection sector

8.1 Introduction

This section addresses the halon alternative requirements of Decision XXVI/9: Response to the report by the Technology and Economics Assessment Panel on information on alternatives to ozone-depleting substances. The Halons Technical Options Committee (HTOC) has provided these responses at the request of the Task Force addressing the Decision.

The production and consumption of halons used in fire protection ceased in non-Article 5 Parties on January 1, 1994 and ceased world-wide prior to January 1, 2010. The production and consumption of HCFCs for use in fire protection continues. Ozone depleting substances (ODS) used as fire extinguishants possess unique efficacy and safety properties that serve as a basis of fire protection systems where the application of water (by hose stream or sprinkler heads), dry chemical agents, or aqueous salt solutions is problematic. This is especially true in high-value commercial electronics environments and in military systems, to name only two of many applications where non-gaseous systems had many serious technical disadvantages.

Development of alternatives to ODS fire extinguishing agents, beginning in the late 1980s, has progressed steadily and is now relatively mature. Interest still remains, however, in development of new alternatives that offer further advancements in efficacy, safety, and environmental characteristics.

8. 2 Alternatives for fixed fire protection systems

The proven alternatives to ODS for total flooding fire protection using fixed systems remain unchanged from those fully described in HTOC Technical Note #1, which was updated during the HTOC 2014 Assessment process and is available on the Ozone Secretariat website. These agents are as follows.

a) Halocarbon agents:
   FK-5-1-12
   HFC-23
   HFC-125
   HFC-227ea
b) Inert Gas agents
   IG-01
   IG-100
   IG-55
   IG-541
c) Carbon dioxide (for use in unoccupied areas only)
d) Water Mist technologies
e) Inert Gas generators
f) Fine solid particles

Although the above alternatives are available in both Article 5 and non-Article 5 Parties, their use pattern depends on the hazard threat to be protected against as well as local regulations and relative costs. High ambient temperature and high urban density have not been shown to affect the use patterns of these agents but extremely low ambient temperatures such as those found in arctic regions or the outside of aircraft at high altitude do. Extremely low temperatures pose significant challenges for currently commercialised alternatives seeking to replace halon in these environments. They are also challenged by other constraints in civil aviation, such as space and weight limitations because all the alternatives require more agent to suppress a fire than the halon being replaced.

Other halocarbon agents are in the early stages of testing and development. However, due to the lengthy process of testing, approval and market acceptance of new fire protection equipment types and agents, it is not anticipated that these agents can have any appreciable impact in the near-term. Phosphorous tribromide (PBr_3) has been commercialised for use as a fire extinguishant in one small aircraft engine application but it is not being considered for any other application at this time owing to its toxicity and corrosiveness.

8.3 Alternatives for portable fire protection systems

The proven alternatives to ODS for local application fire protection using portable systems remain unchanged from those fully described in the HTOC Technical Note #1, which was updated during the HTOC 2014 Assessment process and is available on the Ozone Secretariat website. These alternatives are as follows:

a) Halocarbon agents
   HFC-236fa
   HFC-227ea
   FK-5-1-12
b) Carbon dioxide
c) Dry chemical
d) Straight stream water
e) Fine water spray
f) Aqueous salt solutions
g) Aqueous film-forming foam

High ambient temperatures and high urban densities have not been shown to affect the use patterns of these agents.

Two chemicals are at an advanced stage of testing and development and may be commercialised as fire extinguishing agents in the future. It is not anticipated that high ambient temperatures or high urban densities will affect market uptake of these agents. These new chemicals are as follows.

h) FK-6-1-14
i) 2-Bromo-3,3,3-trifluoropropene

   Note, civil aviation is trying to meet the International Civil Aviation Organisation's (ICAO) 31st December 2016 deadline for the replacement of halon handheld portable extinguishers using 2-Bromo-3,3,3-trifluoropropene. The required regulatory process for commercialisation / manufacturing in Europe (*Registration, Evaluation, Authorisation and Restriction of Chemicals* - REACH registration) has been completed but in the United States the required listing as acceptable under the Significant New Alternatives Policy (SNAP) program and approval under the Toxic Substances Control Act (TSCA) is not yet completed. If successful, from a performance and environmental perspective, this agent will likely be the most effective replacement for halon 1211 applications. However, according to its manufacturer, the agent is anticipated to be at least double the cost of other clean agent alternatives, and will require stabilisers to maintain the material in long-term storage. For these reasons, the agent is only likely to fill the needs of niche applications where its lower weight and superior fire protection performance justify the higher cost.

For local, non-portable, applications such as the protection of floating roof tank rim seals, CF_3I (iodotrifluoromethane) has re-emerged as an acceptable alternative for halon 1211 or halon 2402.

Although the above alternatives are available in both Article 5 and non-Article 5 Parties, their use pattern depends on the hazard threat to be protected against as well as local regulations and relative costs. Of concern are reports of the introduction of some clean agent portable extinguishers in some Article 5 Parties that are not rated by internationally recognised testing laboratories.

8. 4 Revised scenarios for current and future demand

The principle chemical alternatives to ODS are HFCs and a fluoroketone. As was the case reported in the TEAP response to Decision XXV/5, the production of these agents for use in fire extinguishing systems and portable fire extinguishers is performed by very few manufacturers, all of whom treat the information on their historical, present and projected production and costs as proprietary. Without a clear understanding of these production levels and costs there is no basis on which to create scenarios to assess economic costs and implications and any potential environmental benefits of avoiding high-GWP alternatives to ODS. Making such an assessment with no factual data may in fact provide results that are misleading.

On a relative scale, the manufacturers provided the following trends on usage and growth of their agents.

A) HFCs

The split of HFC sales for fire protection between Article 5 and non-Article 5 Parties is approximately 70:30.

Sector Growth: HFC Sales for fire protection according to one manufacturer are:

- US: flat
- Middle East: growing
- Asia Pacific: growing
- Latin America: flat
- Europe: flat

B) Fluoroketone

The split of fluoroketone sales for fire protection between Article 5 and non-Article 5 Parties is approximately 50:50.

Sector Growth: Fluoroketone sales for fire protection according to the manufacturer are: Sales continue to grow substantially in Europe, the Middle East, Africa, North America and South East Asia. In addition, sales are increasing in Latin America.

It should be noted that all of the alternative systems have their own special characteristics, such as effectiveness, cost, weight, space and environmental properties to name a few. Energy efficiency is not a key consideration between alternatives, however system cost is one of the most important considerations in system selection. In cases where space and weight are not limiting factors, there is recent, but limited, information that in some parts of the world inert gas systems can be cost competitive with halocarbon systems, a heretofore unanticipated situation. The HTOC is continuing its investigation into this development, which may provide additional clarity on market penetration options for low environmental impact agents in the future.

9 Information on alternatives to ODS in medical uses

9.1 Metered Dose Inhalers

Inhaled therapy is essential for the treatment of asthma and chronic obstructive pulmonary disease (COPD). There are two main types of inhalers for the delivery of respiratory drugs: the Metered Dose Inhaler (MDI) and the Dry Powder Inhaler (DPI). The choice of the most suitable inhaler is a complex decision taken between doctor and patient.

CFC-propelled MDIs were historically the inhaled delivery device of choice. They have been replaced as follows:

- HFC MDIs: the CFC propellant in MDIs has been gradually replaced with HFCs (HFC-134a and to a lesser extent HFC-227ea), and there are now HFC MDI alternatives available to cover all key classes of drugs used in the treatment of asthma and COPD. Approximately 690 million HFC MDIs (with an average 15g HFC/MDI) are currently manufactured annually worldwide, using about 10,300 tonnes of HFCs and accounting for a relatively small proportion of global HFC usage.
- Dry Powder Inhalers (DPIs): do not require a propellant, are a not-in-kind alternative to MDIs. DPIs fall into two categories: single-dose DPIs, which have been in use for more than 60 years, and multi-dose DPIs, which have been in use for more than 20 years. There are two main types of multi-dose DPI, reservoir and multi-unit dose devices. New drugs continue to be developed in the DPI format, sometimes exclusively.
- Nebulisers: are used to inhale drug solutions and account for about 10 per cent or less of the market on a dose basis.
- Propellant-free aqueous mist inhalers have been recently launched by one company.
- Emerging alternatives are in the earlier stages of development, commercialization or marketing, such as iso-butane propelled MDIs. These include applications for systemic delivery of drugs by the inhaled route.

9.1.1 Technical and economic assessment of alternatives to CFC MDIs

An assessment was presented of the technical and economic feasibility, and the potential limitations, of the two main alternatives to CFC-propelled MDIs, HFC MDIs and DPIs, in the previous TEAP XXV/5 Task Force Report October 2014, which remains current and relevant. The criteria established in Decision XXVI/9 are similar to those for Decision XXV/5, and a further analysis is not considered necessary here. More recently published information on the range of alternatives is also available elsewhere[4]. A summary of conclusions follows.

There are now HFC MDI and DPI alternatives available for all key classes of drugs used in the treatment of asthma and COPD. HFC MDIs and DPIs have been subjected to extensive regulatory assessments for safety, efficacy and quality. Clinical evidence also indicates that MDIs and DPIs are equally effective for the treatment of asthma and COPD for patients who use both devices correctly.

DPIs are technically and economically feasible alternatives that could minimise the use of HFC MDIs. New drugs are mainly being developed as DPIs. Nebulisers and emerging technologies may also be technically feasible alternatives for avoiding the use of some HFC

[4] *2014 Assessment Report of the UNEP Medical Technical Options Committee, 2014, pp.7-38.*

MDIs. The exception is for salbutamol; currently salbutamol HFC MDIs account for the large majority of HFC use in inhalers, and are significantly less expensive per dose than multi-dose DPIs, making them an essential and affordable therapy. At present, it is not yet technically or economically feasible to avoid HFC MDIs completely because there are economic impediments in switching from HFC MDIs to multi-dose DPIs for salbutamol, and because a minority of patients (10-20 per cent or less), notably the very young and very old, cannot use available alternatives to HFC MDIs. Healthcare professionals continue to consider that a range of therapeutic options is important. Any consideration of policy measures to control HFCs should carefully assess patient health implications with the goals of ensuring patient health and maintaining a range of therapeutic options. Each country has its own unique and complex makeup in terms of availability of medicines, overarching health care systems, and patient preferences. Nevertheless, DPIs may play an increasing role over the next decade.

9.1.2 Current and future demand for ODS alternatives

The combined patient prevalence of asthma and COPD worldwide is 600 million, and rising; the acceptance and use of inhalers are also increasing. These two factors combined mean that the overall numbers of inhalers used worldwide are also increasing, especially in Article 5 Parties.

The current and future demand for ODS alternatives has been presented in the recent TEAP XXV/5 Task Force Report October 2014 and 2014 Assessment Report of the Medical Technical Options Committee[5]. Since the June XXVI/9 Task Force Report, HFC manufacturing industry data have been reviewed and revised to take account of recent industry developments and to make predictions for an additional five years, to the year 2030. A detailed presentation of findings can be made in 2016. A summary of conclusions follows.

The International Pharmaceutical Aerosol Consortium (IPAC)[6] provided IMS Health[7] market data of global inhaler usage from 2007-2012[8]. Worldwide usage of CFC MDIs is declining, and is less than either DPI or HFC MDI usage, based on dose equivalence. Meanwhile there has been an increased overall use of inhalers due to the increased use of both MDIs and DPIs. The data show an increase in the total consumption of all MDIs during the period 2007-2012 (2.1 per cent per annum), and an increase in the consumption of DPIs (3.0 per cent per annum). In 2012, CFC MDIs accounted for about 16 per cent of all inhaled medication globally, based on dose equivalence, HFC MDIs for about 43 per cent, DPIs about 32 per cent, and nebulised solutions about 8 per cent. Based on IMS Health market data, approximately 300 million DPIs are manufactured annually worldwide.

Based on HFC manufacturing industry estimates[9], approximately 690 million HFC based MDIs (with an average 15g/MDI)[10] are currently manufactured annually worldwide, using an

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[5] *2014 Assessment Report of the UNEP Medical Technical Options Committee*, *2014, pp.21-24, 36-38.*

[6] The International Pharmaceutical Aerosol Consortium is a group of companies (Astrazeneca, Boehringer Ingelheim, Chiesi Farmaceutici, Glaxosmithkline, Teva) that manufacture medicines for the treatment of respiratory illnesses, such as asthma and COPD.

[7] IMS Health is a respected company that has been gathering and analyzing pharmaceutical market data for decades. IMS Health; IMS MIDAS granted IPAC permission to submit this data to MTOC/TEAP.

[8] While data on trends is available until 2012, substantial changes have been taking place from 2013 onwards, with CFC MDI phase-out almost completed worldwide.

[9] T.J. Noakes, Mexichem Fluor, United Kingdom, personal communications, 2015. HFC consumption data derived from this HFC industry source differs from that derived from IMS Health market data. For the purposes of this report, the “top-down” HFCindustry data has been used to derive HFC consumption.

estimated 10,300 tonnes of HFCs in 2015. HFC-134a makes up the major proportion of MDI manufacture (~9,500 tonnes in 2015), with HFC-227ea accounting for about 7 per cent (~760 tonnes in 2015). This corresponds to direct emissions with a climate impact of approximately 15 million tonnes CO_2- equivalent, which is about 3 per cent of global GWP-weighted emissions of HFCs used as ODS replacements in 2014[11]. HFC emissions from MDIs are estimated as about 0.03 per cent of annual global greenhouse gas emissions[12].

Under a business as usual model, global HFC demand in MDI manufacture (HFCs -134a and -227ea) has been estimated by industry for the period from 2015 to 2030 (see Figure 9-1). It is worthwhile noting that accuracy is likely to decline beyond about 2020. This modelling does not allow, other than in the flattening of demand for HFC-227ea due to the European Union F-gas regulations[13], for any other regulatory impact. Neither does it allow for the on-going trend towards smaller metering chambers[14], which may have a net effect of a 25-30 per cent reduction in future HFC demand. Nevertheless, based on these predictions, global HFC demand for MDI manufacture is estimated to increase annually by 5 per cent over the period. This is higher annual growth than previously predicted, and reflects a recent surge in developing country market growth. It is worth noting that this short term surge may result in an over-estimation of consumption when extrapolated out to 2030.

[10] This compares with industry data indicating sales of 750 million cans in 2015, which might imply that MDI charge size is smaller than 15 grams as previously thought.

[11] *Assessment for Decision-Makers: Scientific Assessment of Ozone Depletion: 2014*, World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 56, Geneva, Switzerland, 2014. Global GWP-weighted emissions of HFCs used as ODS replacements (0.5 Gt CO_2-equivalent) specifically exclude HFC-23 emissions. These emissions are currently growing at a rate of about 7% per year and are projected to continue to grow.

[12] WRI, CAIT 2.0. 2014. Climate Analysis Indicators Tool: WRI's Climate Data Explorer. Washington, DC: World Resources Institute. http://cait2.wri.org. Accessed February 2014. Total greenhouse gas emissions (~43 $GtCO_2$-equivalent in 2011) exclude land use change and forestry. Total HFC consumption in MDIs was estimated based on data from T.J. Noakes for 2011, and used as a surrogate for emissions. GWP-weighted HFC emissions from MDIs in 2011 are estimated as 0.011 $GtCO_2$-equivalent.

[13] The European Union F-gas regulations prescribe, *inter alia*, reductions in HFCs permitted on the market in the European Union from 2015 onwards. Reductions will apply to MDIs until 2018 onwards, after which MDIs are currently exempted from on-going HFC reductions.

[14] Some companies have reduced the size of the metering values on the canisters (to ~25 or 30µl) from an historically larger size (50-65µl) to deliver the same dose, allowing a reduction in the amount of propellant used per can and per dose. Many companies have also reduced the number of doses in each inhaler (from 200 to 120), which reduces the amount of propellant used per can. Both of these changes will increase the number of inhalers made per tonne of HFCs.

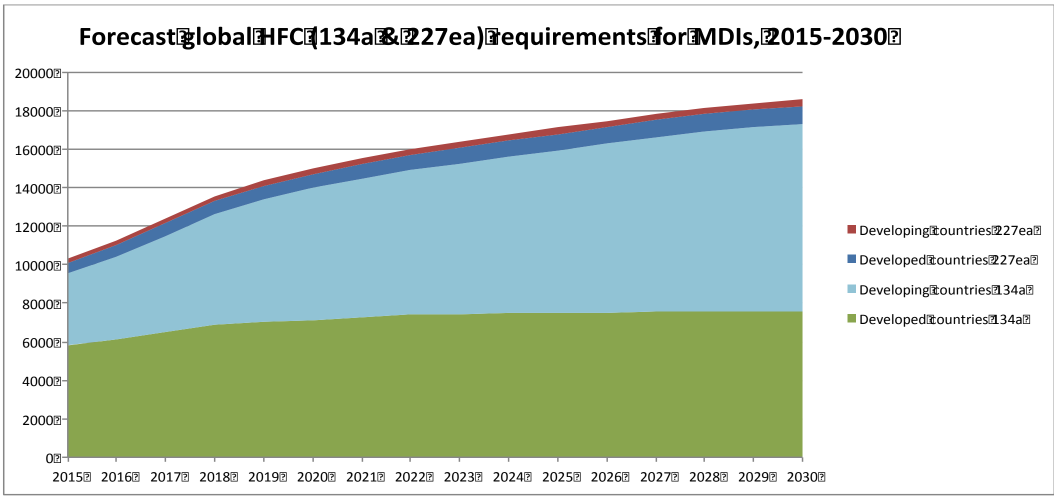

Figure 9-1: Forecast global HFC (134a and 227ea) requirements for MDIs, 2015-2030

HFC-134a accounts for about 93 per cent of total global demand for MDI manufacture over the period, with annual growth of 5 per cent. Under a business as usual model, HFC-227ea demand accounts for about 7 per cent of HFC demand for MDI manufacture over the period, with annual growth of 4 per cent. However, it is possible that, in reality, the manufacture of HFC-227ea for use in MDIs may become non-viable as industrial use declines. HFC-227ea MDIs are unlikely to expand significantly due to expected increasing HFC-227ea prices and uncertainty in the long-term viability of the industrial HFC-227ea business as a result of HFC regulations.

Under a business as usual model, for the period 2015 to 2030, the total cumulative HFC consumption in MDI manufacture is estimated as 249,000 tonnes (232,000 tonnes HFC-134a; 17,000 tonnes HFC- 227ea), corresponding to direct emissions with a climate impact of approximately 360 million tonnes CO_2-equivalent, which would be significantly less than the climate impact of CFC MDIs had they not been replaced.

9.1.3 Costs and benefits of avoiding high-GWP alternatives

Projected HFC emissions, and associated environmental impacts, could be avoided under a hypothetical mitigation scenario where the MDI sector was required to phase down its HFC emissions. However, in the short to medium term, this would have adverse health and economic implications for patients, pharmaceutical companies, and countries.

Early in the CFC MDI transition to ODS-free alternatives, healthcare professionals, Price, Valovirta and Fischer[15], observed that measures potentially affecting patient use of HFC MDIs should be carefully considered, especially if measures were imposed while the transition of patients from CFC MDIs was still in progress. They also noted the importance of maintaining a choice of inhaler devices in providing effective treatment. Regulatory authorities appear to be proceeding cautiously with controls for HFCs with regard to MDIs. Recent amendments to the European Union's F-Gas Regulations exclude MDIs from mandated HFC reductions from 1st January 2018 onwards.

DPIs are technically and economically feasible alternatives that are already avoiding the use of some high-GWP HFC MDIs by meeting demand for a significant proportion of inhaled therapy. Nebulisers and other emerging technologies may also be technically and

[15] D. Price, E. Valovirta, and J. Fischer, The Importance of preserving choice in inhalation therapy: the CFC transition and beyond, *Journal of Drug Assessment* 2004; 7: 45-61.

economically feasible alternatives for avoiding some use of HFC MDIs, both now and in the future. The exception is for salbutamol; salbutamol HFC MDIs are currently an essential and affordable therapy. It is not yet technically or economically feasible to avoid HFC MDIs completely in this sector because, currently:

- HFC MDIs are less expensive than multi-dose DPIs for salbutamol;
- 10-20 per cent, or probably less, of patients cannot use available alternatives to HFC MDIs;
- The role for traditional nebulisers in replacing MDI use is limited, mainly because of convenience and portability.

Therefore, the main challenges are the current availability of affordable alternatives to salbutamol HFC MDIs, and treating patients with low inspiratory flow and for acute attacks, for which, currently, MDIs with a spacer and nebulisers may be the only suitable devices. Some argue that there may be more opportunities associated with the replacement of HFC MDIs containing preventer medicines such as corticosteroids, where there is little difference in cost between DPIs and HFC MDIs. Others disagree, contending that some therapies, particularly corticosteroids, have been shown to be more effective when delivered as ultrafine HFC MDI aerosols than DPI aerosols. However, some other experts do not believe that the ultrafine HFC MDIs have gained a clinically significant advantage. Despite these differences, MTOC experts have agreed that a range of therapeutic options is important because some devices, and/or drug products, are more effective for some patients.[16]

The availability of affordable alternatives to salbutamol HFC MDIs varies from country to country. In Article 5 Parties, single-dose DPIs are relatively affordable and available for the short-acting bronchodilator salbutamol, as well as other inhaled therapies such as beclomethasone. Patients buy the re-usable inhaler device once and generally that device will last for up to 24 months, and buy the medicines (capsules) for the inhaler as needed. Single-dose DPIs have the advantage that they permit low-income patients to afford a limited number of individual dose units of their medication, where they might otherwise be unable to afford the expense of buying MDIs or multi-dose DPIs, which often contain 100 or more doses per unit. However, this purchasing behavior has the potential to undermine compliance for products that are required on a daily basis (e.g. corticosteroids or combination therapies). In India and Bangladesh, doctors prefer single-dose DPIs for the majority of their economically challenged patients. In India, for example, single-dose DPIs account for more than 50 per cent of inhaled therapy, and DPIs generally for about half of the market value [17]. While affordable based on the monetary outlay needed to acquire a limited number of doses, the use of single-dose DPIs for daily use medications may not be as cost effective over the long term as MDIs or multi-dose DPIs when considered as cost-per-dose.

In non-Article 5 Parties, multi-dose salbutamol DPIs are more commonly used than single-dose salbutamol DPIs, with the former generally more expensive than salbutamol HFC MDIs. Despite this, in some markets, multi-dose salbutamol DPIs are used in preference to MDIs e.g. Sweden, where a proactive campaign successfully promoted this technology.

The profitability of DPIs is lower than MDIs for pharmaceutical companies (which was also a barrier in the transition from CFC MDIs to HFC MDIs, where profitability of the latter was relatively lower for pharmaceutical companies). Patents also protect DPI device technologies, so any company wanting to manufacture DPIs must either in-license the technology or

[16] *2014 Report of the UNEP Medical Technical Options Committee*, 2014 Assessment Report.

[17] D Waite, *Comparison of OIP Experiences in Different Markets*. IPAC-RS Respiratory Conference, March 18-20, 2014.

undertake its own research and development. Consequently, the current economics for patients and pharmaceutical companies are an impediment in switching from HFC MDIs to multi-dose DPIs, especially for salbutamol.

The hypothetical cost of switching MDIs to DPIs has been estimated previously. Multi-dose salbutamol DPIs are generally more expensive than salbutamol HFC MDIs, in part because many of these MDIs are off patent. MDIs containing salbutamol constitute about 50 per cent of all MDIs, or about 315 million HFC MDIs. Switching these to an equivalent salbutamol DPI would incur significant costs to health care systems. In 2000, the cost effectiveness of a gradual switch from MDIs to DPIs in the European Union was estimated at the time to cost more than €500/tonne of CO_2 equivalent saved, greater than a range of low cost opportunities to reduce greenhouse gas emissions in other sectors, such as energy efficiency measures [18]. An accelerated transition[19] was estimated to be even less cost effective at more than €710/tonne of CO_2 equivalent saved. In 2005, the hypothetical cost of a complete shift from HFC MDIs to multi-dose DPIs was estimated as US$ 150-300 per tonne of CO_2-equivalent, assuming a minimal twofold increase in price, with an estimated emission reduction of about 10 Mt CO_2-equivalent per year by 2015[20]. In 2015, a salbutamol DPI, where commercially available, is roughly estimated as 2 times the cost of a salbutamol MDI on a per dose basis. In about ten years, by about 2025, when patents expire, or even despite patent protection, there is likely to be more competition and more widespread DPI manufacture, such as in Article 5 Parties like China, and more affordable DPIs. These factors are likely to improve the cost effectiveness of DPIs compared with HFC MDIs.

In transitioning patients from MDIs to DPIs, or to other non-MDI devices, there are costs and implications associated with patient re-training, such as physician visits, marketing by pharmaceutical companies, and guidance provided by healthcare agencies and patient advocacy groups. Costs are borne by patients, pharmaceutical companies, government and/or private health insurance. These may not be significant additional costs where there is on-going patient education, rather than with one-off or intermittent advice, regarding the use of inhalers. Patient and physician preferences and resistance to switching medication, when current medication is already effective, is likely to be a potential barrier to change.

Some countries completed their manufacturing transitions from CFC MDIs to CFC-free alternatives before 2010 (including Australia, Canada, Croatia, Cuba, Hungary, Japan, Poland, Ukraine), while other countries completed in 2010 or later (including Argentina, Bangladesh, Egypt, European Union, India, Iran, Mexico, United States, Venezuela). China, Pakistan and Russia are in the final stages of manufacturing transitions, with China likely to be the last country to complete its manufacturing transition in 2015-2016.

Development costs for pharmaceutical companies for the transition of MDIs from CFCs to HFCs have been in excess of US$1 billion, with investment still continuing. The return on investments depends on the size of the investment, and the potential within the market to make profit with inhaler sales. The length of time to recover investments will vary for each company and for each product. In general, a favourable return on investment is already likely to have been achieved by large multinational pharmaceutical companies, especially in non-Article 5 Parties. However, smaller companies, especially in Article 5 Parties and in other

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[18] *Study on the Use of HFCs for Metered Dose Inhalers in the European Union*, September 2000, undertaken by Enviros March for the International Pharmaceutical Aerosol Consortium (IPAC).

[19] A gradual transition was assumed to be 8-12 years, and an accelerated transition, 5-8 years. Transition was taken to 80 percent DPI market share, assumed to be the maximum technically feasible at that stage.

[20] *IPCC/TEAP Special Report on Safeguarding the Ozone and the Global Climate System*, 2005.

countries that only recently transitioned, may take longer to achieve a positive return on investment. Recovery of investment may also take longer in markets with price controls or other market regulations. While it is possible some instances of transition from CFC to HFC technology may never achieve a positive return on investment, more broadly, a phase-down of HFCs in the MDI sector would have adverse economic impacts for companies where a favourable return on investment is possible, but not yet achieved.

9. 2 Other medical aerosols

Aerosols, in general, are used in a wide range of different applications. The term aerosol product describes a product *pressurized* with a propellant that expels its contents from a canister through a nozzle. Propellants include compressed gases (nitrogen, nitrous oxide, carbon dioxide), or liquefied gases, which are a liquid inside the pressurized container; these liquefied gas propellants include CFCs, hydrochlorofluorocarbons (HCFC-22) and HFCs (-134a, -152a), HFO-1234ze, hydrocarbons, dimethyl ether (DME). Some aerosol products also contain solvents, including CFCs, HCFCs, HFCs (-43-10mee, -365mfc, -245fa), hydrofluoroethers, aliphatic (e.g. heptane, hexane) and aromatic solvents, chlorinated solvents, esters, ethers, alcohols, ketones, and low-GWP fluorinated chemicals. There are also "not-in-kind" (NIK) technologies that compete with aerosol products to perform the same or similar functions, including trigger sprays, finger pumps, squeeze bottles, roll-on liquid products (e.g. for deodorants), and non-sprayed products (e.g. for polishes and lubricating oils). Aerosols are often preferred for ease of use.

Aerosols can be divided into three main categories:

- Consumer aerosols, including cleaning products, tyre inflators, personal care products, spray paints, pesticides, novelty aerosols, food products;
- Technical aerosols, including lubricant sprays, dusters, contact cleaners, safety horns, degreasers, mould release agents; and
- Medical aerosols**,** including MDIs that are the major medical application for aerosol products. There are also medical aerosols that deliver treatment for other medical purposes e.g., nasal and topical aerosol sprays. These "other medical aerosols" are used to deliver topical medication mostly onto the skin, but also to the mouth, and other body cavities.

Medical aerosols, excluding MDIs, are estimated as a small percentage (1-2 per cent) of total aerosol production in terms of units, with approximately 250-300 million cans per year. These medical aerosols include a wide range of uses from simple numbing of pain, nasal inhalation, to the dosage of corticosteroids for the treatment of colitis. In general, HFC-134a has been used for applications where there is a risk of the propellant inadvertently being inhaled.

Since 1978, when the aerosol market was the dominant source of all ODS emissions, CFCs used in aerosols as propellants and as solvents have gradually been phased out in response to concerns about ozone depletion. MDIs will be the last category to be phased out in 2015-2016. When the Montreal Protocol identified essential uses of CFCs, allowing for exemptions from CFC production phase-out schedules, it differentiated oral inhalation into the lungs (MDIs) from other medical aerosols, for which CFCs were considered non-essential. Small quantities of CFCs[21] and HCFCs are reportedly still used for other medical aerosol products such as topical anaesthetic sprays and coolants to numb pain respectively.

[21] For example, Cetacaine spray, for numbing the airways, still contains CFCs. http://www.cetacaine.com/dental/about/prescribing-information , accessed March 2015.

HCFC use is estimated as about 200 ODP tonnes[22] or less worldwide (HCFC-22 and HCFC-141b), with the majority used in China.

Technically and economically feasible alternatives to ozone-depleting propellants and solvents (CFCs and HCFCs) are available for all other medical aerosols. Most aerosols, including other medical aerosols, replaced CFC propellants with hydrocarbons and DME propellants. HFCs are used where a non-flammable or safe to inhale propellant is needed, or where emissions of volatile organic compounds (VOCs), such as hydrocarbons and DME, are controlled owing to concerns about air quality.

In 2010, the total amount of HFCs used for *all* aerosol products was estimated as 54 million tonnes CO_2-equivalent, or 5 per cent of total GWP-weighted HFC consumption.[23] Medical aerosols, including MDIs, are estimated to account for about one quarter of GWP-weighted HFC consumption in all aerosol production. Medical aerosols, predominantly MDIs, use about 11,000 metric tonnes per year of mainly HFC-134a and also HFC-227ea (about 16 million tonnes CO_2 equivalent). It is estimated that less than 10 per cent of other medical aerosols (excluding MDIs) use HFC propellants, or less than 1,000 tonnes per year. The majority are for nasal inhalation, throat topical medication, and nitroglycerin sublingual application. "Not-in-kind" alternatives include hand-pumped aqueous sprays, drops and creams. However, aerosol products are often favoured due to their ease of use.

9.2.1 Alternatives to ODS-containing medical aerosols (excluding MDIs) and their assessment using criteria

An assessment follows of the technical and economic feasibility of the various alternatives to ODS-containing medical aerosol propellants (excluding MDIs) (Table 9-1). An assessment of aerosol solvent alternatives is described in the Chapter on Aerosols. Not all of the criteria established in Decision XXVI/9 are relevant to an assessment of medical aerosols. In particular, energy efficiency and easy to service and maintain are not relevant in an assessment of the suitability of other medical aerosols. An assessment of "easy to use" was undertaken rather than an assessment of "easy to service and maintain", as ease of use is an important consideration that affects the choice of technology in medical applications. An assessment of "*safe to use in areas of high urban densities considering flammability and toxicity issues, including where possible risk characterisation"*, has been broadened to assess safety in production and in use, which are both relevant issues for medical aerosols.

Aerosol production developed differently in each country due to, *inter alia*, the respective regulations for fire protection and occupational safety; VOC controls; and the availability from suppliers of ODS, HCFCs or HFCs for aerosol production. The availability and number of different medical aerosol products varies within countries and regions, and is closely related to the development of the local aerosol industries. Hence, the alternative technologies assessed below are not necessarily interchangeable because of regional or local differences, and, in the space available, are crudely assessed against each criterion on their own merit, unless otherwise specified.

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[22] Updated data compared with recently published 100 ODP tonnes estimated by MTOC in its 2014 Assessment Report, based on new estimates from industry in China.

[23] US EPA, *Transitioning to Low-GWP Alternatives in Non-Medical Aerosols*, EPA 430-F-13-013, April 2013.

Alternatives to CFC-containing aerosols	**Products**	Commercially available	Technically proven	Environmentally sound	Economically viable and cost effective	Safety in production and use	Easy to use
			Propellants				
HCFC-141b HCFC-22	Topical coolants to numb pain	◆ (green)	◆ (green)	◆ (orange)[1]	◆ (green)	◆ (green)	◆ (green)
HFC-134a	Metered dose corticosteroid spray, throat/mouth topical sprays (disinfectants, anti-inflammatories, anaesthetics), anaesthetic, analgesic, calamine sprays for minor blunt injuries or itches, nitroglycerin sublingual sprays	◆ (green)	◆ (green)	◆ (orange)[1]	◆ (orange)[2]	◆ (green)	◆ (green)
HFC-152a	Sprays for diaper rash for babies, nitroglycerin sublingual sprays, sunscreen sprays.	◆ (green)	◆ (green)	◆ (orange)	◆ (green)	◆ (orange)[3]	◆ (green)
Blends of: Propane n-Butane iso-Butane	Anaesthetic, analgesic, calamine sprays for minor blunt injuries or itches; cut or wound sprays; sprays to prevent bedsores; foot sprays and other anti-fungal products; vaginal hygiene sprays, rectal foams for treatment of colitis; foams for scalp hair loss; sunscreen sprays.	◆ (green)	◆ (green)	◆ (orange)[3]	◆ (green)	◆ (orange)[2]	◆ (green)
Dimethyl ether (DME)	Anaesthetic, analgesic, calamine sprays for minor blunt injuries or itches; anti-fungal products; sunscreen sprays.	◆ (green)	◆ (green)	◆ (orange)[4]	◆ (green)	◆ (orange)[3]	◆ (green)
Carbon dioxide	Anaesthetic, analgesic, calamine sprays for minor blunt injuries or itches	◆ (green)	◆ (green)[5]	◆ (green)	◆ (green)	◆ (green)	◆ (green)
Nitrogen	Throat/mouth topical sprays (disinfectants, anti-inflammatories, anaesthetics), sterile saline solutions	◆ (green)	◆ (green)[5]	◆ (green)	◆ (green)	◆ (green)	◆ (green)

Table 9-1: Technical and economic assessment of alternatives to CFC-propelled medical aerosols (excluding MDIs) [24]

[24] Medical aerosols (excluding MDIs) cover a wide range of uses from simple numbing of pain to the dosage of corticosteroids for the treatment of colitis. Some traditional Chinese medicines may also be administered using aerosol products. Therefore, it is difficult to make an all-inclusive list of medical

Alternatives to CFC-containing aerosols	Products	Commercially available	Technically proven	Environmentally sound	Economically viable and cost effective	Safety in production and use	Easy to use
"Not-in-kind" Alternatives							
Pump sprays	Variety of medical applications	◆	◆	◆	◆	◆	◆[6]
Drops		◆	◆	◆	◆	◆	◆[6]
Creams		◆	◆	◆	◆	◆	◆[6]

Table 9-1: (cont.): Technical and economic assessment of alternatives to CFC-propelled medical aerosols (excluding MDIs)

Legend: Column 1 lists sterilisation methods, and Columns 2-7 indicate the qualitative assessment of each method according to each criterion, using the following indicators:

◆ Yes or More acceptable; ◆ Not always or Less acceptable; ◆ No or Unacceptable.

1. The use of CFCs, HCFCs and high-GWP HFCs for production of medical aerosols (excluding MDIs) can be restricted by government or actively discouraged by suppliers in many non-Article 5 Parties. CFCs, HCFCs and HFC-134a are non-flammable propellants. CFCs and HFCs are used when flammability and/or toxicity are a consideration.

2. HFCs -134a and -227ea are expensive compared with hydrocarbons, and hence are only used when their safety properties are necessary for the specific product (non-flammability, very low toxicity), and the benefits outweigh the increased cost.

3. Hydrocarbons and DME are highly flammable propellants. HFC-152a has low to moderate flammability, and is often used alone or in blends with hydrocarbons to lower their flammability. HFC-152a can also be blended with HFC-134a propellant to produce a propellant with lower GWP and lower flammability. Flammable propellants require special equipment, training and handling in production, and special precautions in use.

4. Hydrocarbons and oxygenated hydrocarbons are volatile organic compounds (VOCs) that contribute to photochemical smog generation in areas of high urban density. In some jurisdictions, strict VOC controls (e.g. in California) can have an impact on the choice of propellant, where hydrocarbons are avoided, although medical aerosols have been largely exempted from these requirements.

5. Carbon dioxide and nitrogen are gaseous propellants, not liquefied propellants, and as such are technically suitable for some but not all aerosol product applications.

6. Aqueous sprays and drops are well-established "not-in-kind" alternatives to nasal aerosol products. Aqueous formulations in general and other "not-in-kind" alternatives, such as creams, are used in many medical applications. "Not-in-kind" alternatives can sometimes be less convenient to use. Aerosols can be favoured due to their ease of use.

Commercially available— Technically and economically feasible alternatives to ozone-depleting propellants (CFCs and hydrochlorofluorocarbons (HCFCs)) are available for all other medical aerosols. Other medical aerosol products were reformulated to use CFC-free propellants, mainly hydrocarbons (butane, propane, isobutane, dimethyl ether (DME)), but also HCFCs and HFCs in specific applications. "Not-in-kind" alternatives, including hand-pumped aqueous sprays, drops and creams, are also used for medical applications where CFC propellants might have been used previously. Many external factors affect the selection of a given propellant or alternative, including regulatory approval of products, industry codes of

products that are not oral inhalers, but the following table presents the most common applications of this group of products.

conduct, Volatile Organic Compounds controls, supplier controls of HCFCs and HFC-134a, ease of use, and propellant properties, such as flammability or safety for certain uses.

Regulatory controls for HFC alternatives used as aerosol propellants and solvents are increasingly limiting and/or prohibiting their use where other suitable alternatives are available. Recent regulatory developments affecting HFC use in aerosol products are summarised in the Chapter on Aerosols.

Technically proven— Extensive respiratory toxicological studies were conducted for HFC-134a (IPACT-1) and HFC-227ea (IPACT-2) for their use as propellants in inhaled medications (MDIs) to prove their acceptability as replacements for CFC propellants. Any other propellant intended for inhalation medical use would presumably require similar toxicological evaluation. The Task Force is unaware of toxicology studies having been undertaken for HFC-152a for inhalation use and therefore its safety has not been proven for use in respiratory medications. It is not clear whether the reported use of HFC-152a as a propellant in nitroglycerin sublingual sprays would require the same rigour of toxicological evaluation as would use in a chronic respiratory medication. One company in Argentina, Pablo Cassara, is undertaking research and development to use iso-butane as the propellant, planning to launch a salbutamol MDI in 2016. Previous studies have reported toxicological concerns for iso-butane used in combination with a beta-agonist [25]. However, many medical aerosols are used for topical application where respiratory safety is not a requirement.

Propane or iso-butane (and their blends) tend to cause an "oily" or slightly stinging taste, and so are not favoured for nasal or oral use. Most other pressurised medical aerosol products tend to use propane/butane mixtures or DME and compressed gases to a lesser extent. Medical aerosol products for use on or near the nose or mouth, and also on babies, where flammability and safety are of importance, tend to use HFCs or nitrogen. For treatments where there is a significant risk of inhalation into the respiratory tract, HFCs are preferred, where safety has been proven for HFCs -134a and -227ea.

In most countries, there are no regulatory requirements for the use of *specific* propellants for medical aerosols. However, a change in propellant for products approved for a medical use (like the nasal MDIs) would necessitate a new development programme and regulatory approval. In the United States, some products, while regulated by FDA, may not require prior approval following the over-the-counter (OTC) monograph system (also known as “grandfather clause” for products with a long time of use), provided they do not change propellant. In Japan, the Japanese pharmacopoeia codex for additives, and other official compendia limit propellants for medical aerosols. If a pharmaceutical company uses a new propellant in an aerosol product, necessary toxicity data on both propellant and the aerosol product are required for registration. All aerosols in the European Union are regulated, especially with regard to flammability, under the Aerosol Dispensers Directive 75/324/EEC and subsequent amendments.

Environmentally sound— Aerosols are a totally emissive use, and so the propellant and solvent can have a direct environmental impact. In some countries, CFCs and HCFCs are prohibited for use in the manufacture of aerosol products. In the United States, and other countries, where use of CFCs from pre-1996 stockpiles is not prohibited, some products are still filled with CFCs; these are being phased out, with final revisions to US regulations underway to address remaining products.

In Article 5 Parties, where the use of HCFCs in aerosols is not prohibited, HCFC-141b is used in medical aerosols to numb pain, using its cooling effect as it evaporates, despite the

[25] Final report of the Safety Assessment of isobutane, isopentane, n-butane, and propane. *Int. J. Toxicology*, 1; 4: 127-142, 1982.

fact that the same result can be achieved with hydrocarbon blends. In addition to HCFC-141b, HCFC-22 is also used in China. Other than in Article 5 Parties, it is unlikely that HCFCs are used in medical aerosols elsewhere in any significant quantities. For example, in the United States, sale and distribution of aerosols using HCFCs was banned in 1994 with few exceptions.

HFC-134a, which is the major HFC propellant used in medical applications, has a high GWP (GWP 1360). In some medical aerosol applications, HFC-152a is used because it has a lower GWP (GWP 148) than HFC-134a and lower flammability than hydrocarbons. HFC-152a can also be blended with HFC-134a propellant to produce a propellant with lower GWP and lower flammability. When considering direct climate impacts, the climate-friendly alternative propellants include hydrocarbons and their blends, DME, carbon dioxide and nitrogen, and "not-in-kind" alternatives.

In areas with high urban densities, photochemical smog generation can be a major environmental and health problem. Hydrocarbons and oxygenated hydrocarbons, such as DME, are volatile organic compounds (VOCs) that contribute to photochemical smog generation. In some jurisdictions, strict VOC controls (e.g. in California) can have an impact on the choice of propellant, where hydrocarbons are avoided, although medical aerosols have been largely exempted from these requirements.

Economically viable and cost effective— Hydrocarbons and their blends are the most affordable propellant for aerosol products. HFCs are more expensive, and are therefore used by manufacturers for specific applications where a propellant with low flammability and proven safety is needed.

Safety in production and use— The flammability of hydrocarbons, DME, HFC-152a and their flammable blends makes safety a priority in the production and use of medical aerosols containing these ingredients. Flammable propellants and solvents require special equipment, training and handling in aerosol production, and special precautions in aerosol use.

Easy to use— Pressurised aerosols, using propellants, are sometimes considered more convenient products to use than "not-in-kind" alternatives such as aqueous sprays, drops and creams. Flammable propellants and solvents require safety precautions in the use of aerosol products to ensure safety.

9.2.2 Current and future demand for ODS alternatives

Non-MDI medical aerosols are estimated to represent around 1 per cent globally of all aerosol products, with production of approximately 250-300 million cans per year. This estimate has been derived using data from the North American Consumer Specialty Products Association (CSPA) and the British Aerosol Manufacturers Association (BAMA) that excludes MDIs. When compared with the estimated 690 million HFC MDIs, and estimated HFC consumption, MDIs are likely to be the major medical application for aerosol products[26].

Other medical aerosols use about 200 ODP tonnes HCFCs or less worldwide (HCFC-22 and HCFC-141b), with the majority in China.

In 2010, the total GWP-weighted HFC consumption for *all* aerosol products was estimated as 54 million tonnes CO_2-equivalent, or 5 per cent of total GWP-weighted HFC consumption [27].

[26] *2014 Assessment Report of the UNEP Medical Technical Options Committee, 2014.*

[27] U.S. Environmental Protection Agency, EPA 430-F-13-013, www.epa.gov, April 2013.

A quarter of this GWP-weighted amount was estimated to be used for medical aerosols (including MDIs)[28]. Medical aerosols, mainly MDIs, are estimated to use about 11,000 metric tonnes HFCs, or about 16 million tonnes CO_2-equivalent. Less than an estimated 10 per cent of non-MDI medical aerosols use HFC propellants, close to 25-30 million cans per year, with less than 1,000 tonnes per year. The aerosol industry in the United States considers HFC use to be flat or declining [29]. Global production of HFC-containing aerosols is likely to be growing very slowly, if at all, and this is not likely to change in the near future. Nevertheless, there may be individual countries where production is growing.

Medical aerosol products are common in China where production has been growing rapidly. For other medical aerosols, production was between 120-130 million units in 2014, with some HFC propellants (300-400 tonnes), and also DME, carbon dioxide and HCFCs (2,300 tonnes HCFC-22 and 600 tonnes HCFC-141b, which is used as a blend with HCFC-22) [30]. The number of non-MDI medical aerosols is relatively large when compared with the total 1.5 billion aerosols produced in China in 2013.

9.2.3 Costs and benefits of avoiding high-GWP alternatives

The majority of HFCs used for other medical aerosols is for nasal inhalation, throat topical medication, and nitroglycerin sublingual application. HFC use is often limited by the market itself, either owing to cost, safety or regulatory reasons, or to applications where VOC controls might limit hydrocarbon use, or where a propellant with low flammability and/or proven safety is needed. Nevertheless, there could be significant environment benefits in selecting more low-GWP and climate-friendly alternatives and by avoiding high-GWP propellants and solvents. In many cases, HFC propellants and solvents can be substituted with low-GWP options. Suitable alternatives to avoid using HFC propellants include nitrogen or "not-in-kind" metered pump sprays. Registration of new HFC-free formulations would be costly and would require time. In the absence of flammability and safety risks, the only reason for not using hydrocarbons would be if the formulation did not work with these propellants. It is worth noting that the Montreal Protocol did not authorise these uses as essential when it considered similar CFC-containing aerosols, except MDIs.

It is difficult to quantify the costs of conversion of high-GWP HFC-containing aerosol products to low-GWP and "not-in-kind" alternatives. Costs may include reformulation, redesign, production re-engineering, safety, training and education, product testing, and consumer information, and will depend on the application, the market and its regulatory environment.

9. 3 Sterilants

There is a range of commercially available sterilization methods including: heat (moist heat or dry heat), ionizing radiation (such as gamma electron beam, x-ray radiation), alkylating processes (such as ethylene oxide (EO), formaldehyde) and oxidative processes (including hydrogen peroxide gas, gas plasma systems, liquid or gaseous peracetic acid, and ozone).

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[28] This market breakdown of GWP-weighted HFC consumption updates information provided in the 2014 Assessment, *2014 Report of the UNEP Medical Technical Options Committee*, which was originally based on data contained in U.S. Environmental Protection Agency, EPA 430-F-13-013, www.epa.gov, April 2013. Further work is underway to re-evaluate global HFC consumption in aerosols, and may become available next year.

[29] Market Characterization of the U.S. Aerosols Industry. ICF International May 2014 for the Stratospheric Protection Division, Office of Air and Radiation, US EPA.

[30] Updated data compared with recently published tonnages estimated by MTOC in its 2014 Assessment Report, based on new estimates from industry in China.

Further sterilization methods based on these and other chemicals are now available or are under investigation for commercialization.

Sterilization using humidified EO under controlled cycle conditions is used to treat heat and moisture sensitive medical devices, which are packaged in breathable materials that maintain sterility once the product is removed from the sterilization chamber. EO can be used as a sterilant either alone or diluted with other gases (e.g. CFC-12, HCFCs -124 and -22, HFC-134a, CO_2) to make non-flammable mixtures.

Total global use of CFCs for sterilisation is believed to be zero. Estimated global use of HCFCs in sterilization is less than 500-700 metric tonnes, which amounts to less than 25 ODP tonnes worldwide. EO/HCFC use in Article 5 Parties is estimated to be less than 200-400 tonnes. The use of HFCs for sterilisation is believed to be rare, and globally almost non-existent.

9.3.1 Alternatives to ODS sterilants and their assessment using criteria

An analysis was presented of the technical and economic feasibility, and the potential limitations, of the various alternatives to ODS-consuming sterilants in the previous TEAP XXV/5 Task Force Report October 2014, which remains current and relevant. The criteria established in Decision XXVI/9 are similar to those for Decision XXV/5, and a further analysis is not considered necessary here. More information on alternative sterilants is also available elsewhere [31].

9.3.2 Current and future demand for ODS alternatives

The future demands for sterilization technology are likely to rise with increasing demands for healthcare, economic development, aging populations and increases in chronic conditions. Methods for sterilization of medical devices have developed differently in each country, meaning that the availability of alternatives varies in different countries. Considering the range of sterilization methods in routine application in healthcare and industrial facilities, the use of EO/CFC and EO/HCFC sterilants are no longer required and can be phased out. Existing capital equipment using EO/HCFC or, in very rare cases, EO/HFC sterilants could remain in use if a source of gas could be secured for perhaps the next ten years. However, there is no technical or economic reason for EO/HCFC or EO/HFC sterilants to be in used in non-Article 5 Parties beyond 2020, and in Article 5 Parties beyond 2030 or possibly earlier.

9.3.3 Costs and benefits of avoiding high-GWP alternatives

Due to the wide variety of technically and economically feasible alternatives available in sterilisation, and the almost non-existent use of high-GWP alternatives, there are very few implications for the sterilisation sector in avoiding high-GWP alternatives to ODS.

[31] (1) *2014 Report of the UNEP Medical Technical Options Committee*, 2014 Assessment Report, pp.49-54; (2) US Centers for Disease Control and Prevention, Healthcare Infection Control Practices Advisory Committee, *Guideline for Disinfection and Sterilization in Healthcare Facilities*, 2008, US CDC http://www.cdc.gov/hicpac/Disinfection_Sterilization/13_0Sterilization.html; (3) G. McDonnell, *Antisepsis, Disinfection and sterilization: Types, Action and Resistance*, 2007, ASM press, Washington DC.

10 Information on alternatives to ODS in non-medical aerosols

10.1 Introduction

Aerosols are used in a wide range of different applications. The term aerosol product describes a product *pressurized* with a propellant that expels its contents from a canister through a nozzle. Propellants include compressed gases (nitrogen, nitrous oxide, carbon dioxide), or liquefied gases, which are a liquid inside the pressurized container; these liquefied gas propellants include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) (-134a, -152a), HFO-1234ze, hydrocarbons, and dimethyl ether (DME). Some aerosol products also contain solvents, including CFCs, HCFCs, HFCs, hydrofluoroethers, aliphatic and aromatic solvents, chlorinated solvents, esters, ethers, alcohols, ketones, and low-GWP fluorinated chemicals.

Aerosols can be divided into three main categories:

- Consumer aerosols, including cleaning products, tyre inflators, personal care products, spray paints, pesticides, novelty aerosols, food products;
- Technical aerosols, including lubricant sprays, dusters, contact cleaners, safety horns, degreasers, mould release agents; and
- Medical aerosols**,** including MDIs that are the major medical application for aerosol products. There are also medical aerosols that deliver treatment for other medical purposes e.g., nasal and topical aerosol sprays. These "other medical aerosols" are used to deliver topical medication mostly onto the skin, but also to the mouth, and other body cavities.

In the late 1970s, the aerosols sector was the major source of all ODS emissions (about 75 per cent). CFCs used in aerosols as propellants and as solvents have gradually been phased out in response to concerns about ozone depletion, predominantly migrating to non-fluorocarbon alternatives. Small quantities of HCFCs (and possibly a very small quantity of CFCs) are reportedly still used. HCFC use is estimated as about 200 ODP tonnes[32] or less worldwide (HCFC-22 and HCFC-141b) for medical aerosols, with the majority used in China. Consumer and technical aerosols are estimated to use another 100 ODP tonnes of HCFCs -22, -141b, and -225ca/cb.

Technically and economically feasible alternatives to ozone-depleting propellants and solvents (CFCs and HCFCs) are available for aerosol products. A significant proportion of aerosol propellants have migrated to hydrocarbons and DME, which dominate in the consumer aerosol market. Hydrocarbons and DME are highly flammable propellants. They are also used in technical aerosols where flammable propellants can be used safely. Hydrocarbons and oxygenated hydrocarbons are volatile organic compounds (VOCs) that contribute to photochemical smog generation, which is of concern in areas of high urban density. In some jurisdictions, strict VOC controls (e.g. in California) can have an impact on the choice of propellant, where hydrocarbons are avoided.

A smaller proportion migrated to HFC propellants where:

- Emissions of VOCs, such as hydrocarbons and DME, are controlled;
- A non-flammable propellant is needed; and/or
- A propellant is necessary that is safe to inhale, such as HFC-134a.

[32] Updated data compared with recently published 100 ODP tonnes estimated by MTOC in its 2014 Assessment Report, based on new estimates from industry in China.

CFC and HCFC solvents (CFC-113, methyl chloroform, HCFC-141b) used in aerosols have migrated to hydrofluorocarbons (HFC -43-10mee, -365mfc, -245fa), hydrofluoroethers (HFEs), aliphatic and aromatic solvents, chlorinated solvents, oxygenated organic chemicals, and low-GWP fluorinated chemicals, e.g. hydrofluoroolefin (HFO) HCFC-1233zd(E).

There are also “not-in-kind” (NIK) technologies that compete with aerosol products to perform the same or similar functions, including trigger sprays, finger pumps, squeeze bottles, roll-on liquid products (e.g. for deodorants), and non-sprayed products (e.g. for polishes and lubricating oils). Aerosols are often preferred for ease of use.

Total aerosol production is estimated at 14 billion cans per year. In 2010, the total GWP-weighted amount of HFCs used in aerosol production was estimated as 54 million tonnes CO_2-equivalent, or 5 per cent of total GWP-weighted HFC consumption.[33] Consumer and technical aerosols are estimated to account for about three-quarters of GWP-weighted HFC consumption in aerosol production, and medical aerosols, including MDIs, for the remaining quarter.[34]

Medical aerosols, predominantly MDIs, use about 11,000 metric tonnes per year of mainly HFCs -134a, and also HFC-227ea (about 16 million tonnes CO_2 equivalent). Medical aerosols, excluding MDIs, are estimated as a small percentage (1-2 per cent) of total aerosol production in terms of units, with approximately 250-300 million cans per year. It is estimated that less than 10 per cent of medical aerosols (excluding MDIs) use HFC propellants, or less than 1,000 tonnes per year. MDIs and other medical aerosols are assessed further in the Chapter on Medical Uses.

10. 2 Alternatives to CFC-containing aerosols (non-medical) and their assessment using criteria

Table 10-1 summarises a range of alternatives to CFC-containing non-medical aerosols, their ODP, GWP, flammability, and the types of aerosols where they are commonly used and/or under what conditions. The list is not inclusive of the full range of available alternatives.

[33] US EPA, *Transitioning to Low-GWP Alternatives in Non-Medical Aerosols*, EPA 430-F-13-013, April 2013.

[34] This updates information provided in MTOC’s 2014 Assessment report. Further work is underway to re-evaluate global HFC consumption in aerosols, and may become available next year.

Alternatives to CFC-containing aerosols	ODP	GWP	Flammability	Comments
Propellants				
HCFC-22	0.055	1760	Non-flammable at atmospheric temperature and pressure	Recommendations for exposure limits.
HFC-125	0	3170	Non-flammable	-
HFC-134a	0	1300	Non-flammable	Approved for use in asthma inhalers. Very low acute inhalation toxicity.
HFC-152a	0	138	Flammable, less so than HCs (LEL 3.9 % volume in air)	Not approved for inhaled medical aerosols. Low acute inhalation toxicity. Recommendations for exposure limits.
HFC-227ea	0	3350	Non-flammable	Approved for use in asthma inhalers. Very low acute inhalation toxicity. Due to cost and high GWP, probably used exclusively in MDIs.
HFO-1234ze (E)	0	<1	Non-flammable. Exhibits flame limits at elevated temperatures.	Used as replacement for aerosols (e.g. novelty) previously using higher GWP HFC propellants. Recommendations for exposure limits.
Hydrocarbons and blends (propane, n-butane, iso-butane)	0	≤4	High flammability (iso-butane, LEL 1.8 % volume in air)	Recommendations for exposure limits.
Dimethyl ether (DME)	0	1	Highly flammable	-
Compressed gases - CO_2 - N_2 - Air - N_2O	 0 0 0 0.017	 1 0 - 265	Non-flammable	 Recommendations for exposure limits. - - Recommendations for exposure limits.
"Not-in-kind", e.g., - Pump sprays - Liquids - Roll-on liquids/sticks	 0 0 0	 0 0 0	Non-flammable where liquid dispensed is non-flammable	Indirect life cycle climate impacts

Alternatives to CFC-containing aerosols	ODP	GWP	Flammability	Comments
		Solvents		
HCFC-141b	0.11	782	Non-flammable	Recommendations for exposure limits.
Blends of HCFC-225ca/ HCFC-225cb	0.025 0.033	127 525	Non-flammable	Recommendations for exposure limits.
HCFO-1233zd(E)	~0	1	Non-flammable	Recommendations for exposure limits.
HFC-43-10mee	0	1650	Non-flammable	Recommendations for exposure limits.
HFC-365mfc	0	804	Flammable	Recommendations for exposure limits.
HFC-245fa	0	858	Non-flammable	Recommendations for exposure limits.
Hydrofluoroethers HFE-449s1 (HFE-7100) HFE-569sf2 (HFE-7200)	 0 0	 421 57	 Non-flammable Non-flammable	 None. Recommendations for exposure limits.
Aliphatic and aromatic solvents (e.g. Hexane, Heptane)	0	≤3	Highly flammable	Recommendations for exposure limits.
Chlorinated solvents e.g. Trichloroethylene Perchloroethylene Methylene chloride	 ~0 ~0 ~0	 140 Low 9	 Non-flammable Non-flammable Non-flammable (combustible at high temperature)	Recommendations for exposure limits.
Oxygenated organic compounds (e.g. Esters, Ethers, Alcohols, Ketones)	0	<20	Flammable	Check any recommendations for exposure limits.
Water-based formulations	0	0	Non-flammable	Indirect life cycle climate impacts
"Not-in-kind" (see above)	0	0	Non-flammable where liquid dispensed is non-flammable	Indirect life cycle climate impacts

Table 10-1: Alternatives to CFC-containing non-medical aerosols

An assessment follows of the technical and economic feasibility of the various alternatives to ODS-containing non-medical aerosols. Not all of the criteria established in Decision XXVI/9 are relevant to an assessment of non-medical aerosols. In particular, energy efficiency and easy to service and maintain are not relevant in an assessment of the suitability of aerosols. An assessment of "easy to use" was undertaken rather than an assessment of "easy to service and maintain", as ease of use is an important consideration that affects the choice of technology in medical applications. An assessment of "*safe to use in areas of high urban densities considering flammability and toxicity issues, including where possible risk characterisation*" has been broadened to assess safety in production and in use, which are both relevant issues for aerosols.

Aerosol production has developed differently in each country due to, *inter alia*, the respective regulations for fire protection and occupational safety; VOC controls; and the availability from suppliers of ODS, HCFCs or HFCs for aerosol production. The availability and number of different aerosol products varies within countries and regions, and is closely related to the development of the local aerosol industries. Hence, alternatives are not necessarily interchangeable because of regional or local differences.

Commercially available— Technically and economically feasible alternatives to ozone-depleting propellants (CFCs and HCFCs) are available for all aerosols. Aerosol products were reformulated to use CFC-free propellants, mainly hydrocarbons (butane, propane, isobutane, DME), but also HCFCs and HFCs in specific applications. NIK alternatives, including hand-pumped aqueous sprays, drops and creams, are also used where CFC-containing aerosols might have been used previously. Many external factors affect the selection of a given propellant or alternative, including regulatory approval of products, industry codes of conduct, VOC controls, supplier or regulatory controls on HCFCs and HFC-134a, ease of use, and propellant properties, such as flammability or safety for certain uses.

Regulatory controls for HFC alternatives used as aerosol propellants and solvents are increasingly limiting and/or prohibiting their use where other suitable alternatives are available. Recent regulatory developments affecting HFC use in aerosol products are summarised below.

Recent changes to Japan's Fluorocarbon Recovery and Destruction Law will lead to a phase-down of HFCs. In addition to scheduled HFC phase-down requirements, EU F-gas Regulations, promulgated in 2006 and 2014, specifically prohibit the use of HFCs with GWPs above 150 for the market entry of new aerosols as follows:

- One component foams, from 2008 onwards;
- Novelty aerosols and signal horns, from 2009 onwards; and
- Technical aerosols, from 2018 onwards, except where the aerosol is needed to meet national safety standards or for medical applications.

Technical aerosols containing HFCs are subject to a ban under Swiss legislation. In addition, the European aerosol industry voluntarily began transitioning away from HFCs under a Code of Practice adopted in 2002. HFCs are now only used in aerosols where there are no other safe, practical, economic, or environmentally acceptable alternatives available.

In response to President Obama's Climate Action Plan, US EPA has promulgated a final rule[35] to prohibit certain high-GWP HFC alternatives that were previously listed as acceptable under its Significant New Alternatives Program (SNAP), based on information that suitable alternatives are now available. The final rule for aerosol propellants establishes that, from specified dates in 2016 onwards:

[35] http://www.epa.gov/ozone/snap/regulations.html

- HFC-125 would become an unacceptable alternative;
- HFC-134a would be acceptable only in specific technical and medical aerosols (e.g. MDIs), and would be prohibited in consumer aerosols;
- HFC-227ea would be acceptable only in metered dose inhalers.

Technically proven— Aerosols incorporate propellants and solvents with the appropriate technical properties and characteristics in formulations designed to deliver a product for its intended purpose. The alternatives listed in Table 10-1 are technically proven for use in aerosols, although sometimes only for certain product types depending on the properties of the alternatives and/or the intended product purpose. Some alternatives will not be technically suitable for some formulations.

Hydrocarbons and DME are highly flammable chemicals that are also VOCs that contribute to photochemical smog generation. Like CFCs before them, non-flammable and non-toxic HFCs are often used in aerosols when flammability or toxicity is a consideration. HFCs are also used where emissions of VOC are controlled. However, HFCs are more expensive than hydrocarbons and are therefore mostly used when their properties are necessary for the aerosol product and the advantages outweigh the costs.

HFC-134a is used more commonly as a propellant in technical aerosols where its non-flammable properties have advantages. Extensive respiratory toxicological studies were conducted for HFC-134a (IPACT-1) and HFC-227ea (IPACT-2), which proved their safety as propellants in respiratory use (e.g. MDIs). Any propellant intended for respiratory use, or inhaled medications, requires toxicological tests.

HFC-152a is used more commonly as a propellant in consumer aerosols. HFC-152a has low to moderate flammability, and is used alone, or in blends with hydrocarbons to lower their flammability. HFC-152a is also blended with HFC-134a to produce a propellant with lower GWP and lower flammability. It is also used in jurisdictions that have VOC emission controls.

NIK alternatives are sometimes not as easy to use or achieve lower performance for some applications.

Environmentally sound— Aerosols are a totally emissive use, and so the propellant and solvent can have a direct environmental impact. In some countries, CFCs and HCFCs are prohibited for use in the manufacture of aerosol products. In the United States, and other countries, where use of CFCs from pre-1996 stockpiles is not prohibited, some products are still filled with CFCs; these are being phased out, with final revisions to US regulations underway to address remaining products.

In Article 5 Parties, where the use of HCFCs in aerosols is not prohibited, HCFC-141b is used in medical aerosols, using its cooling effect as it evaporates, despite the fact that the same result can be achieved with hydrocarbon blends. In addition to HCFC-141b, HCFC-22 is also used in China. Other than in Article 5 Parties, it is unlikely that HCFCs are used in medical aerosols elsewhere in any significant quantities. For example, in the United States, sale and distribution of aerosols using HCFCs was banned in 1994 with few exceptions.

Some HFCs, such as HFC-125, -134a, -227ea, -43-10mee, have high GWPs. In some applications, HFC-152a is used because it has a lower GWP than HFC-134a and lower flammability than hydrocarbons. When considering direct impacts, the more climate-friendly alternative propellants include hydrocarbons and their blends, DME, HFO-1234ze(E), carbon dioxide and nitrogen, and NIK alternatives. The more climate-friendly alternative solvents include hydrofluoroethers, oxygenated organic compounds, aliphatic and aromatic solvents, chlorinated chemicals, low-GWP fluorinated chemicals, and NIK alternatives.

In areas with high urban densities, photochemical smog generation can be a major environmental and health problem. Hydrocarbons and oxygenated hydrocarbons, such as DME, are VOCs that contribute to photochemical smog generation. In some jurisdictions, strict VOC controls (e.g. in California) can have an impact on the choice of propellant, where hydrocarbons are avoided.

Economically viable and cost effective— Hydrocarbons and their blends are the most affordable propellant for aerosol products. HFCs are more expensive, and are therefore used by manufacturers for specific applications where a propellant with low flammability and proven safety is needed.

Safety in production and use— The flammability of hydrocarbons, DME, HFC-152a and their flammable blends makes safety a priority in the production and use of aerosols containing these ingredients. Flammable propellants and solvents require special equipment, training and handling in aerosol production, and special precautions in aerosol use.

Easy to use— Pressurised aerosols, using propellants, are sometimes considered more convenient products to use than NIK alternatives such as aqueous sprays, drops and creams. Flammable propellants and solvents require safety precautions in the use of aerosol products.

10. 3 Current and future demand for ODS alternatives

Global aerosol demand is currently estimated at about 14 billion units (cans) per year, with a market size of about USD 55 billion. Recent market analysis[36] indicates that global demand is likely to exceed 18 billion units by 2020, reaching USD 70 billion. Personal care aerosol products accounted for the largest application, with over 40 per cent of global market demand in 2013. Household aerosols were the second largest application, with growing demand for products such as stain removers, water repellents for furnishings, and pre-wash sprays. Growth in personal care and household aerosol products is expected to drive the overall growth in the global market. This analysis also expects demand in asthma inhalers to be limited owing to their HFC use.

Europe was the largest regional aerosol market in 2013, with estimated demand of 5 billion units, accounting for more than 35 per cent of global demand. North America was the second largest regional market. Both of these markets are expected to lose market share to Asia Pacific and Latin America by 2020, owing to regulations controlling VOCs, CFCs, HCFCs and HFCs in the European Union and the United States. Larger market participants, Procter and Gamble, S. C. Johnson, Henkel, and Reckitt Benckiser, are making extensive efforts to develop sustainable alternatives, using less raw material and energy, with lower carbon footprints and high recyclability. Asia Pacific is expected to be the fastest growing regional market owing to its economic development, a growing demand for personal care and household products, and a less stringent regulatory environment.

According to publicly available information on the intended application of net supply of fluorocarbon gases from the European Environment Agency, the European Union's net HFC supply intended for aerosol production was 8,400 tonnes in 2013, accounting for about 10 per cent of total net HFC supply and 11 million tonnes CO_2-equivalent, at an average GWP for constituent HFCs of 1286.[37]

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[36] *Aerosol Market Analysis by Application (Personal Care, Household, Paint, Medical) and Segment Forecasts to 2020*, Grand View Research, December 2014, ISBN 978-1-68038-288-4, http://www.grandviewresearch.com/industry-analysis/aerosol-market, accessed May 2015. *Aerosol Market To Be Worth $70.15 Billion, Growing At CAGR Of 3.1% From 2014 To 2020: New Report By Grand View Research, Inc.*, GlobeNewswire, http://globenewswire.com/news-release/2014/12/09/689728/10111568/en/Aerosol-Market-To-Be-Worth-70-15-Billion-Growing-At-CAGR-Of-3-1-From-2014-To-2020-New-Report-By-Grand-View-Research-Inc.html, accessed May 2015.

[37] Aggregated data reported by undertakings on the production, import and export of fluorinated greenhouse gases (HFCs, PFCs and SF6) in the European Union. The European Union Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases (the 'F-Gas Regulation') introduced requirements for producers, importers and exporters of F-gases to report to the European Commission on the quantities produced, imported and exported in each calendar year, including information on the main intended applications of the F-gases quantities

These data include quantities used in MDI production (HFC-134a and HFC-227ea). The Consumer Specialty Products Association (CSPA) of the United States estimated that in 2008, the majority of aerosol products using HFC-152a were consumer aerosols, with total use of 21,417 tonnes, and the majority of aerosol products using HFC-134a were technical products, with total use of 3,242 tonnes. These data do not include quantities used in MDI production. Based on these data, while the European Union's aerosol market is the largest overall, its HFC consumption for aerosols is smaller than in the United States. This might reflect market variations in aerosol propellant and solvent choices based on the different industry and regulatory environments for HFCs and VOCs. In 2013, Japan used about 170 tonnes HFC-134a and 320 tonnes HFC-152a in non-MDI aerosol applications.

China produced about 1.5 billion aerosol units in 2013. In technical aerosols, China used several hundred tonnes HFC-134a, mainly as a propellant for holiday ribbon sprays for export, which is expected to migrate to lower GWP propellants owing to export market pressure. HFC-152a is also used in technical aerosols, with estimates ranging from 100-1,000 tonnes. Medical aerosol products are common in China where production has been growing rapidly. For non-MDI medical aerosols, production was between 120-130 million units in 2014, with some HFC propellants (300-400 tonnes), and also DME, carbon dioxide and HCFCs (2,300 tonnes HCFC-22 and 600 tonnes HCFC-141b, which is used as a blend with HCFC-22).[38] The number of non-MDI medical aerosols is relatively large when compared with the total 1.5 billion aerosols produced in China in 2013.

In 2010, the total GWP-weighted amount of HFCs used in aerosol production has been estimated as 54 million tonnes CO_2-equivalent, or 5 per cent of total GWP-weighted HFC consumption[39]. Consumer and technical aerosols are estimated to account for about three-quarters of GWP-weighted HFC consumption in aerosol production, and medical aerosols, including MDIs, for the remaining quarter[40].

reported. Net supply takes into account production, imports and exports for the intended application. HFC data for solvents used in aerosols may be included in the aerosols or the solvents category. The solvents category has an order of magnitude lower figure for HFC consumption. This dataset uses GWPs from IPCC's Fourth Assessment Report, 2007. http://www.eea.europa.eu/data-and-maps/data/fluorinated-greenhouse-gases-aggregated-data-1. Accessed April 2015. European Environment Agency, *Fluorinated greenhouse gases 2013, Aggregated data reported by companies on the production, import and export of fluorinated greenhouse gases in the European Union*, EEA Technical report, No 15/2014. http://www.eea.europa.eu/publications/f-gases-2013/.

[38] Updated data compared with recently published tonnages estimated by MTOC in its 2014 Assessment Report, based on new estimates from industry in China.

[39] US EPA, *Transitioning to Low-GWP Alternatives in Non-Medical Aerosols*, EPA 430-F-13-013, April 2013.

[40] This market breakdown of GWP-weighted HFC consumption updates information provided in the 2014 Assessment, *2014 Report of the UNEP Medical Technical Options Committee*, which was originally based on data contained in U.S. Environmental Protection Agency, EPA 430-F-13-013, www.epa.gov, April 2013. Further work is underway to re-evaluate global HFC consumption in aerosols, and may become available next year.

Medical aerosols, mainly MDIs, are estimated to use about 11,000 metric tonnes HFCs, or about 16 million tonnes CO_2-equivalent. Based on an analysis of greenhouse gas data available from the UNFCCC[41], fluorocarbon gas data available from the European Environment Agency, and industry HFC consumption data for global MDI production[42], a rough estimate of global HFC-134a consumption in aerosols excluding MDIs would be about 10,000 tonnes, or 13 million tonnes CO_2-equivalent. Similarly, an analysis of global aerosol production, aerosol weight, and propellant charge, results in a rough estimate of global HFC-134a consumption of about 9,500 tonnes[43].

Non-MDI medical aerosols are estimated to represent around 1 per cent globally of all aerosol production, with approximately 250-300 million units per year. HFC propellants are used in less than 10 per cent of these aerosols, with less than 1,000 tonnes HFCs per year.

The aerosol industry in the United States considers HFC consumption to be flat or declining [44]. Global production of HFC-containing aerosols is likely to be growing very slowly, if at all, and this is not likely to change in the near future. Nevertheless, there may be individual countries where HFC aerosol production is growing. Production is likely to increase in Article 5 Parties while it flattens or declines in non-Article 5 Parties.

10.1.3 Costs and benefits of avoiding high-GWP alternatives

The majority of aerosols migrated to non-fluorocarbon alternatives. HFC use is often limited by the market itself, either owing to cost, safety or regulatory reasons, or to applications where VOC controls might limit hydrocarbon use, or where a propellant with low flammability and/or proven safety is needed. Nevertheless, HFC consumption in this sector is ranked as the third largest after the refrigeration and air conditioning and foams sectors, and aerosols are a totally emissive use. There could be significant environment benefits in selecting more low-GWP and climate-friendly alternatives and by avoiding high-GWP propellants and solvents. In many cases, HFC propellants and solvents can be substituted with low-GWP options. Low-GWP propellants and solvents are commercially and widely available, and NIK alternatives are commercially available where they are suited for the purpose.

The reformulation of aerosols to use alternative low-GWP propellants and solvents, or the development of NIK technologies as replacements, would incur costs to industry. It appears that it is technically feasible to replace HFC-134a used in consumer aerosols with alternatives, based on the US EPA proposal to prohibit its use in this application. It also appears that it is technically feasible for new technical aerosols to begin to transition away from high-GWP HFCs based on the European Union’s 2018 prohibition, except where the aerosol is needed to meet national safety standards or for medical applications. It seems industry analysts consider it possible that, as the European Union and the United States introduce HFC restrictions, some production may shift to countries with more relaxed regulatory environments, with expectations for declining growth in the European Union and the United States and increasing growth elsewhere, particularly Asia Pacific. Global export markets may challenge these predictions as producers shift production to suit export markets, such as indicated by China moving away from HFC-134a use in technical aerosols.

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[41] http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php

[42] T.J. Noakes, Mexichem Fluor, United Kingdom, personal communications, 2015.

[43] Aerosol weight and propellant charge vary greatly. However, if it is assumed that 0.5% of all aerosols use HFC-134a, that those aerosols have an average weight of 300 grs and a propellant charge of 45%, this results in a rough estimate of 9,450 metric tonnes HFC-134a.

[44] ICF International, *Market Characterization of the U.S. Aerosols Industry*, May 2014 for the Stratospheric Protection Division, Office of Air and Radiation, US EPA.

In some markets or for some products there may be significant challenges in adopting low-GWP options to existing HFC uses in aerosols, and their use may not be feasible. High-GWP HFCs may be difficult to avoid for some technical products where their properties are currently needed and no suitable alternative exists. Nevertheless, it is worth noting that the Montreal Protocol did not authorise these uses as essential when it considered similar CFC-containing aerosols, except MDIs.

It is difficult to quantify the costs of conversion of high-GWP HFC-containing aerosol products to low-GWP and NIK alternatives. Costs may include reformulation, redesign, production re-engineering, safety, training and education, product testing, and consumer information, and will depend on the application, the market and its regulatory environment.

11 List of acronyms and abbreviations

AHRI	American Heating and Refrigeration Institute
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
CEFIC	European Chemical Industry Council
CEN	European Committee for Standardisation
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
COP	Coefficient of Performance
DPI	Dry Powder Inhaler
EPA	US Environmental Protection Agency
EU	European Union
FIC	Fluoroiodocarbon
FK	Fluoroketone
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HCO	Oxygenated hydrocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
HFO	Hydrofluoroolefin
HTOC	Halons Technical Options Committee
IIR	International Institute for Refrigeration
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCA	Life Cycle Analysis
LCCP	Life Cycle Climate Performance
MBH	Thousand BTUs per Hour
MDI	Metered Dose Inhaler
MTOC	Medical Technical Options Committee
NFPA	National Fire Protection Association
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEL	Occupational Exposure Limit
R/AC	Refrigeration and Air Conditioning (also RACHP)
RTOC	Refrigeration, AC and Heat Pumps Technical Options Committee
SNAP	Significant New Alternatives Policy
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TLV	Threshold Limit Value
UL	Underwriters Laboratories Inc.
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compound

Annex 1 – Report to OEWG-36 on updates to the XXVI/9 report

A1. 1 Considerations for updated report – Decision XXVI/9 Task Force report

In accordance with Decision XXVI/9, a report has been made available to the meeting of the 36th OEWG, and an update report will be submitted to the Twenty-Seventh Meeting of the Parties, that addresses the information requested by Parties in that decision.

Considerations for the updates have been submitted in writing and were discussed with Parties during an informal discussion session, Wednesday lunchtime. TEAP XXVI/9 Task Force members discussed with interested Parties the feasibility of potential updates considering both the update requested within the scope of Decision XXVI/9 as well as the timeline for completing the updated report in early September to meet the deadline for submission of documents to the 27th MOP. The considerations can be summarized as follows:

A1. 2 Scenarios

1. In general, all assumptions made in scenarios should be well explained, so that Parties are fully aware how scenarios are constructed, in how far these scenarios might reflect reality, or whether they are mainly used to demonstrate the impact of certain parameters –or the impact of changing parameters-- on high GWP HFC demand during the period 2010-2030.
2. Further explanation why the GWP of 300 had been selected was considered as one of the first requirements. This would also hold for other parameters and why they were chosen.
3. One Article 5 Party asked to consider longer conversions periods (6 years was considered too short), later starts of conversion than 2020 or 2025 as well as conversion of only certain percentages of manufacturing equipment, since there was not yet evidence that alternatives would be fully available in 2020 or soon thereafter. The lag was noted from when Article 2 countries adopt the alternatives in the market before the Article 5 Parties transition; this lag should be about 10 years. A sensitivity analysis was suggested.
4. Introduction of a longer time period than up to 2030, e.g. until 2050, was also considered necessary, in particular also if longer conversion periods would be studied. This is also related to the fact that certain amendment proposals consider time schedules that go far beyond 2030.
5. One Party mentioned that it would be revealing if a separate study could be made for the update report which identified crucial sectors that would be important to transition in order to meet a certain reduction obligation in a certain year.
6. Where the XXVI/9 report shows many results for Article 5 Parties, expansion of the scenario material for non-Article 5 Parties was considered necessary (a suggestion already made directly after the XXVI/9 presentation). It was asked whether market interactions related to equipment (exports, imports) had been considered, if not, whether this could be investigated for the update report.

A1. 3 Costs

1. Costs calculations for non-RAC and production sectors need to be clearer, while taking into account relevant ExCom decisions, such as the ones related to financing stage II HPMPs and demonstration projects. This is also related to the costs of the alternatives on the market and those not yet on the market.
2. Costs should also be analysed dependent on the start of the conversion and the duration of the conversion period. A global estimate of costs and benefits up to the year 2050 was also considered desirable.
3. One request was submitted to present the non R/AC costings in a clearer way.

A1. 4 High Ambient Temperature (HAT) Conditions

1. A more precise analysis and parameters for definition of a high ambient temperature country or region was considered desirable.
2. Another Party mentioned the consideration of the alternatives for HAT countries or regions, the HCFC consumption by sector of these countries/regions as well as the types of equipment used.
3. Testing data of projects, if completed, should be listed and analysed if possible. Performance of various alternatives will be important, however, a Life Cycle Climate Performance evaluation of possible alternatives was considered even more important.

A1. 5 Alternatives

1. The status of the various alternatives as well as their markets should be more precisely described. This in particular related to the 70 alternatives mentioned. Expansion of information on regional and international standards in the update report was also emphasized by several Parties.

Annex 2 - Additional Tables for Total, New Manufacturing, and Servicing Demand

Below tables are given for the total demand, new manufacturing and servicing demand (used for cost calculations in chapter 6):

- for non-Article 5 and Article 5 Parties
- for all R/AC sub-sectors
- for the BAU, MIT-3 and MIT-5 scenarios:

- *Table A6-1: Demand in tonnes for new manufacturing plus servicing (total demand) for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-2: Demand in tonnes for new manufacturing only for non-Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-3: Demand in tonnes for servicing only for non-Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-4: Demand in ktonnes CO_2-eq. for new manufacturing plus servicing (total demand) for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-5: Demand in ktonnes CO_2-eq.for new manufacturing only for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-6: Demand in ktonnes CO_2-eq.for servicing only for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-7: Demand in tonnes for servicing and new manufacturing (total demand) for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-8: Demand in tonnes for new manufacturing only for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios*

- *Table: A6-9: Demand in tonnes for servicing only for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-10: Demand in ktonnes CO_2-eq. for new manufacturing plus servicing (total demand) for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-11: Demand in ktonnes CO_2-eq. for new manufacturing only for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

- *Table A6-12: Demand in ktonnes CO_2-eq. for servicing only for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios*

Table A6-1: Demand in tonnes for new manufacturing plus servicing (total demand) for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (new manufacturing plus servicing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	1.876	1.451	957	954	862
		HC-600a	362	415	545	786	1.156
	Commercial	HFC-134a	2.256	2.373	2.400	2.395	2.104
		R-404A + R-507	15.305	16.093	16.282	16.691	19.655
		Low GWP					
	Industrial	HFC-134a	1.041	1.113	1.148	1.188	1.233
		R-404A + R-507	603	743	828	1.077	1.405
		Low GWP	6.649	11.429	13.362	16.016	19.382
	Transport	HFC-134a	222	213	302	371	483
		R-404A + R-507	1.176	1.540	1.474	1.589	1.720
		Low GWP					
	SAC growth rate 1,2% between 2010-2020	HFC-134a	4.032	4.468	1.422	994	226
		R-410A	39.385	77.354	94.230	114.001	131.319
		R-407C	11.195	26.802	34.942	43.946	50.402
		Low GWP					
	MAC	HFC-134a	69.670	68.359	66.643	70.967	77.448
		Low GWP					
nA5 3-year conversion 2020	Domestic	HFC-134a	1.876	1.451	2	1	1
		HC-600a	362	415	1.500	1.739	2.017
	Commercial	HFC-134a	2.256	2.373	2.400	2.395	2.104
		R-404A + R-507	15.305	16.093	11.762	4.764	1.658
		Low GWP	0	0	5.718	11.933	17.975
	Industrial	HFC-134a	1.041	1.113	1.148	1.188	1.233
		R-404A + R-507	603	743	333	256	199
		Low GWP	6.649	11.429	13.362	16.016	19.382
	Transport	HFC-134a	222	213	302	371	483
		R-404A + R-507	1.176	1.540	787	511	189
		Low GWP	0	0	687	1.078	1.531
	SAC	HFC-134a	4.032	4.468	1.422	994	226
		R-410A	39.385	77.354	22.337	15.831	4.127
		R-407C	11.195	26.802	13.987	10.417	2.716
		Low GWP	0	0	92.848	131.699	174.879
	MAC	HFC-134a	69.670	68.359	43.246	27.154	9.966
		Low GWP	0	0	23.396	43.813	67.482
nA5 3-year conversion 2025	Domestic	HFC-134a	1.876	1.451	957	1	1
		HC-600a	362	415	545	1.739	2.016
	Commercial	HFC-134a	2.256	2.373	2.400	2.395	2.104
		R-404A + R-507	15.305	16.093	16.282	7.663	4.557
		Low GWP	0	0	0	9.028	15.078
	Industrial	HFC-134a	1.041	1.113	1.148	1.188	1.233
		R-404A + R-507	603	743	828	363	282
		Low GWP	6.649	8.898	10.932	13.445	16.538
	Transport	HFC-134a	222	213	302	371	483
		R-404A + R-507	1.176	1.540	1.474	745	423
		Low GWP	0	0	0	844	1.297
	SAC	HFC-134a	4.032	4.468	1.422	994	226
		R-410A	39.385	77.354	94.230	26.474	14.768
		R-407C	11.195	26.802	34.942	17.420	9.721
		Low GWP	0	0	0	114.053	157.233
	MAC	HFC-134a	69.670	68.359	66.643	40.689	23.501
		Low GWP	0	0	0	30.278	53.947

Table A6-2: Demand in tonnes for new manufacturing only for non-Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (new manufacturing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	1.872	1.449	955	953	861
		HC-600a	362	415	545	786	1.155
	Commercial	HFC-134a	2.027	1.786	665	771	894
		R-404A + R-507	7.006	3.028	5.510	6.387	7.404
		Low GWP					
	Industrial	HFC-134a	327	397	418	439	461
		R-404A + R-507	345	420	441	606	810
		Low GWP	2.653	3.884	4.726	5.750	6.995
	Transport	HFC-134a	45	57	142	164	191
		R-404A + R-507	578	738	571	662	767
		Low GWP					
	SAC growth rate 1,2% between 2010-2020	HFC-134a	3.387	3.118	0	0	0
		R-410A	34.160	61.755	68.084	78.927	91.499
		R-407C	7.513	16.313	18.000	20.866	24.190
		Low GWP					
	MAC	HFC-134a	17.728	17.622	16.851	19.535	22.647
		Low GWP					
nA5 3-year conversion 2020	Domestic	HFC-134a	1.872	1.449	0	0	0
		HC-600a	362	415	1.500	1.739	2.016
	Commercial	HFC-134a	2.027	1.786	665	771	894
		R-404A + R-507	7.006	3.028	990	0	0
		Low GWP	0	0	4.520	6.387	7.404
	Industrial	HFC-134a	327	397	418	439	461
		R-404A + R-507	345	420	4	0	0
		Low GWP	2.412	3.884	4.726	5.750	6.995
	Transport	HFC-134a	45	57	142	164	191
		R-404A + R-507	578	738	0	0	0
		Low GWP	0	0	571	662	767
	SAC growth rate 1,5% between 2010-2020	HFC-134a	3.387	3.118	0	0	0
		R-410A	34.160	61.755	0	0	0
		R-407C	7.513	16.313	0	0	0
		Low GWP	0	0	84.480	99.794	115.688
	MAC	HFC-134a	17.728	17.622	0	0	0
		Low GWP	0	0	16.851	19.535	22.647
nA5 3-year conversion 2025	Domestic	HFC-134a	1.872	1.449	955	0	0
		HC-600a	362	415	545	1.739	2.016
	Commercial	HFC-134a	2.027	1.786	665	771	894
		R-404A + R-507	7.006	3.028	5.510	0	0
		Low GWP	0	0	0	6.387	7.404
	Industrial	HFC-134a	327	397	418	439	461
		R-404A + R-507	345	420	441	0	0
		Low GWP	2.412	3.884	4.726	5.750	6.995
	Transport	HFC-134a	45	57	142	164	191
		R-404A + R-507	578	738	571	0	0
		Low GWP	0	0	0	662	767
	SAC growth rate 1,5% between 2010-2020	HFC-134a	3.387	3.118	0	0	0
		R-410A	34.160	61.755	68.084	0	0
		R-407C	7.513	16.313	18.000	0	0
		Low GWP	0	0	0	99.794	115.688
	MAC	HFC-134a	17.728	17.622	16.851	0	0
		Low GWP	0	0	0	19.535	22.647

Table A6-3: Demand in tonnes for servicing only for non-Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (servicing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	4	2	2	1	1
		HC-600a	0	0	0	0	1
	Commercial	HFC-134a	229	587	1.735	1.624	1.210
		R-404A + R-507	8.299	13.065	10.772	10.304	12.251
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	714	716	730	749	772
		R-404A + R-507	258	323	387	471	595
		Low GWP	4.345	7.545	8.636	10.266	12.387
	Transport	HFC-134a	177	156	160	207	292
		R-404A + R-507	598	802	903	927	953
		Low GWP	0	0	0	0	0
	SAC growth rate 1,2% between 2010-2020	HFC-134a	645	1.350	1.422	994	226
		R-410A	5.225	15.599	26.146	35.074	39.820
		R-407C	3.682	10.489	16.942	23.080	26.212
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	51.942	50.737	49.792	51.432	54.801
		Low GWP	0	0	0	0	0
nA5 3-year conversion 2020	Domestic	HFC-134a	4	2	2	1	1
		HC-600a	0	0	0	0	1
	Commercial	HFC-134a	229	587	1.735	1.624	1.210
		R-404A + R-507	8.299	13.065	10.772	4.764	1.658
		Low GWP	0	0	1.198	5.546	10.571
	Industrial	HFC-134a	714	716	730	749	772
		R-404A + R-507	258	323	329	256	199
		Low GWP	4.237	7.545	8.636	10.266	12.387
	Transport	HFC-134a	177	156	160	207	292
		R-404A + R-507	598	802	787	511	189
		Low GWP	0	0	116	416	764
	SAC growth rate 1,5% between 2010-2020	HFC-134a	645	1.350	1.422	994	226
		R-410A	5.225	15.599	22.337	15.831	4.127
		R-407C	3.682	10.489	13.987	10.417	2.716
		Low GWP	0	0	8.368	31.905	59.191
	MAC	HFC-134a	51.942	50.737	43.246	27.154	9.966
		Low GWP	0	0	6.545	24.278	44.835
nA5 3-year conversion 2025	Domestic	HFC-134a	4	2	2	1	1
		HC-600a	0	0	0	0	0
	Commercial	HFC-134a	229	587	1.735	1.624	1.210
		R-404A + R-507	8.299	13.065	10.772	7.663	4.557
		Low GWP	0	0	0	2.641	7.674
	Industrial	HFC-134a	714	716	730	749	772
		R-404A + R-507	258	323	387	363	282
		Low GWP	4.237	5.014	6.206	7.695	9.543
	Transport	HFC-134a	177	156	160	207	292
		R-404A + R-507	598	802	903	745	423
		Low GWP	0	0	0	182	530
	SAC growth rate 1,5% between 2010-2020	HFC-134a	645	1.350	1.422	994	226
		R-410A	5.225	15.599	26.146	26.474	14.768
		R-407C	3.682	10.489	16.942	17.420	9.721
		Low GWP	0	0	0	14.259	41.545
	MAC	HFC-134a	51.942	50.737	49.792	40.689	23.501
		Low GWP	0	0	0	10.743	31.300

Table A6-4: Demand in ktonnes CO_2-eq.for new manufacturing plus servicing (total demand) for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (new manufacturing plus servicing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	2.438	1.887	1.244	1.240	1.120
		HC-600a	7	8	11	16	23
	Commercial	HFC-134a	2.933	3.084	3.120	3.113	2.735
		R-404A + R-507	60.388	63.498	64.242	65.865	77.564
		Low GWP					
	Industrial	HFC-134a	1.353	1.447	1.492	1.544	1.603
		R-404A + R-507	2.375	2.926	3.263	4.242	5.535
		Low GWP	1	2	2	3	4
	Transport	HFC-134a	289	277	393	483	629
		R-404A + R-507	4.634	6.066	5.807	6.260	6.776
		Low GWP					
	SAC growth rate 1,2% between 2010-2020	HFC-134a	5.241	5.808	1.848	1.293	294
		R-410A	75.619	148.520	180.922	218.882	252.133
		R-407C	18.135	43.419	56.606	71.193	81.652
		Low GWP					
	MAC	HFC-134a	90.571	88.867	86.636	92.257	100.683
		Low GWP					
nA5 3-year conversion 2020	Domestic	HFC-134a	2.438	1.887	2	2	1
		HC-600a	7	8	30	35	40
	Commercial	HFC-134a	2.933	3.084	3.120	3.113	2.735
		R-404A + R-507	60.388	63.498	46.395	18.792	6.542
		Low GWP	0	0	1.715	3.580	5.392
	Industrial	HFC-134a	1.353	1.447	1.492	1.544	1.603
		R-404A + R-507	2.375	2.926	1.314	1.009	785
		Low GWP	1	2	2	3	4
	Transport	HFC-134a	289	277	393	483	629
		R-404A + R-507	4.634	6.066	3.102	2.015	745
		Low GWP	0	0	206	323	459
	SAC	HFC-134a	5.241	5.808	1.848	1.293	294
		R-410A	75.619	148.520	42.886	30.396	7.923
		R-407C	18.135	43.419	22.660	16.876	4.401
		Low GWP	0	0	27.854	39.510	52.464
	MAC	HFC-134a	90.571	88.867	56.220	35.300	12.956
		Low GWP	0	0	23	44	67
nA5 3-year conversion 2025	Domestic	HFC-134a	2.438	1.887	1.244	2	1
		HC-600a	7	8	11	35	40
	Commercial	HFC-134a	2.933	3.084	3.120	3.113	2.735
		R-404A + R-507	60.388	63.498	64.242	30.227	17.977
		Low GWP	0	0	0	2.708	4.523
	Industrial	HFC-134a	1.353	1.447	1.492	1.544	1.603
		R-404A + R-507	2.375	2.926	3.263	1.429	1.112
		Low GWP	1	2	2	3	4
	Transport	HFC-134a	289	277	393	483	629
		R-404A + R-507	4.634	6.066	5.807	2.936	1.666
		Low GWP	0	0	0	253	389
	SAC	HFC-134a	5.241	5.808	1.848	1.293	294
		R-410A	75.619	148.520	180.922	50.829	28.354
		R-407C	18.135	43.419	56.606	28.221	15.748
		Low GWP	0	0	0	34.216	47.170
	MAC	HFC-134a	90.571	88.867	86.635	52.896	30.551
		Low GWP	0	0	0	30	54

Table A6-5 Demand in ktonnes CO_2-eq. for new manufacturing only for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (new manufacturing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	2.434	1.883	1.241	1.238	1.119
		HC-600a	7	8	11	16	23
	Commercial	HFC-134a	2.635	2.321	865	1.002	1.162
		R-404A + R-507	27.645	11.962	21.757	25.222	29.239
		Low GWP					
	Industrial	HFC-134a	424	516	543	570	600
		R-404A + R-507	1.359	1.653	1.737	2.386	3.190
		Low GWP	1	1	1	2	2
	Transport	HFC-134a	58	74	184	214	248
		R-404A + R-507	2.278	2.907	2.250	2.608	3.023
		Low GWP					
	SAC growth rate 1,2% between 2010-2020	HFC-134a	4.403	4.053	0	0	0
		R-410A	65.586	118.570	130.720	151.541	175.677
		R-407C	12.171	26.428	29.159	33.804	39.188
		Low GWP					
	MAC	HFC-134a	23.046	22.908	21.907	25.396	29.441
		Low GWP					
nA5 3-year conversion 2020	Domestic	HFC-134a	2.434	1.883	0	0	0
		HC-600a	7	8	30	35	40
	Commercial	HFC-134a	2.635	2.321	865	1.002	1.162
		R-404A + R-507	27.645	11.962	3.909	0	0
		Low GWP	0	0	1.356	1.916	2.221
	Industrial	HFC-134a	424	516	543	570	600
		R-404A + R-507	1.359	1.653	17	0	0
		Low GWP	1	1	1	2	2
	Transport	HFC-134a	58	74	184	214	248
		R-404A + R-507	2.278	2.907	0	0	0
		Low GWP	0	0	171	199	230
	SAC	HFC-134a	4.403	4.053	0	0	0
		R-410A	65.586	118.570	2.434	0	0
		R-407C	12.171	26.428	543	0	0
		Low GWP	0	0	25.344	29.938	34.707
	MAC	HFC-134a	23.046	22.908	0	0	0
		Low GWP	0	0	17	20	23
nA5 3-year conversion 2025	Domestic	HFC-134a	2.434	1.883	1.241	0	0
		HC-600a	7	8	11	35	40
	Commercial	HFC-134a	2.635	2.321	865	1.002	1.162
		R-404A + R-507	27.645	11.962	21.757	0	0
		Low GWP	0	0	0	1.916	2.221
	Industrial	HFC-134a	424	516	543	570	600
		R-404A + R-507	1.359	1.653	1.737	0	0
		Low GWP	1	1	1	2	2
	Transport	HFC-134a	58	74	184	214	248
		R-404A + R-507	2.278	2.907	2.250	0	0
		Low GWP	0	0	0	199	230
	SAC	HFC-134a	4.403	4.053	0	0	0
		R-410A	65.586	118.570	130.720	0	0
		R-407C	12.171	26.428	29.159	0	0
		Low GWP	0	0	0	29.938	34.707
	MAC	HFC-134a	23.046	22.908	21.907	0	0
		Low GWP	0	0	0	20	23

Table A6-6: Demand in ktonnes CO_2-eq. for servicing only for non-Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (servicing)							
			2010	2015	2020	2025	2030
nA5 BAU	Domestic	HFC-134a	4	4	3	2	1
		HC-600a	0	0	0	0	0
	Commercial	HFC-134a	298	763	2.255	2.111	1.573
		R-404A + R-507	32.743	51.536	42.485	40.643	48.325
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	929	931	949	974	1.003
		R-404A + R-507	1.016	1.273	1.526	1.856	2.345
		Low GWP	0	1	1	2	2
	Transport	HFC-134a	231	203	209	269	381
		R-404A + R-507	2.356	3.159	3.557	3.652	3.753
		Low GWP	0	0	0	0	0
	SAC growth rate 1,2% between 2010-2020	HFC-134a	838	1.755	1.848	1.293	294
		R-410A	10.033	29.950	50.202	67.341	76.456
		R-407C	5.964	16.991	27.447	37.389	42.464
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	67.525	65.959	64.729	66.861	71.242
		Low GWP	0	0	0	0	0
nA5 3-year conversion 2020	Domestic	HFC-134a	4	4	2	2	1
		HC-600a	0	0	0	0	0
	Commercial	HFC-134a	298	763	2.255	2.111	1.573
		R-404A + R-507	32.743	51.536	42.486	18.792	6.542
		Low GWP	0	0	359	1.664	3.171
	Industrial	HFC-134a	929	931	949	974	1.003
		R-404A + R-507	1.016	1.273	1.297	1.009	785
		Low GWP	0	1	1	2	2
	Transport	HFC-134a	231	203	209	269	381
		R-404A + R-507	2.356	3.159	3.102	2.015	745
		Low GWP	0	0	35	124	229
	SAC	HFC-134a	838	1.755	1.848	1.293	294
		R-410A	10.033	29.950	40.452	30.396	7.923
		R-407C	5.964	16.991	22.117	16.876	4.401
		Low GWP	0	0	2.510	9.572	17.757
	MAC	HFC-134a	67.525	65.959	56.220	35.300	12.956
		Low GWP	0	0	6	24	44
nA5 3-year conversion 2025	Domestic	HFC-134a	4	4	3	2	1
		HC-600a	0	0	0	0	0
	Commercial	HFC-134a	298	763	2.255	2.111	1.573
		R-404A + R-507	32.743	51.536	42.485	30.227	17.977
		Low GWP	0	0	0	792	2.302
	Industrial	HFC-134a	929	931	949	974	1.003
		R-404A + R-507	1.016	1.273	1.526	1.429	1.112
		Low GWP	0	1	1	2	2
	Transport	HFC-134a	231	203	209	269	381
		R-404A + R-507	2.356	3.159	3.557	2.936	1.666
		Low GWP	0	0	0	54	159
	SAC	HFC-134a	838	1.755	1.848	1.293	294
		R-410A	10.033	29.950	50.202	50.829	28.354
		R-407C	5.964	16.991	27.447	28.221	15.748
		Low GWP	0	0	0	4.278	12.463
	MAC	HFC-134a	67.525	65.959	64.728	52.896	30.551
		Low GWP	0	0	0	10	31

Table A6-7: Demand in tonnes for servicing and new manufacturing (total demand) for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (new manufacturing plus servicing)							
			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	12.941	13.329	15.333	18.242	21.634
		HC-600a	3.083	5.747	10.141	15.684	23.446
	Commercial	HFC-134a	2.743	5.089	9.356	11.910	15.018
		R-404A + R-507	11.343	31.391	55.505	97.823	148.283
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	720	1.320	2.255	3.730	6.074
		R-404A + R-507	599	3.132	6.266	10.969	15.212
		Low GWP	19.347	23.571	28.991	36.291	46.469
	Transport	HFC-134a	544	1.075	1.982	2.608	3.104
		R-404A + R-507	1.143	1.881	2.192	3.135	4.195
		Low GWP	0	0	0	0	0
	SAC	HFC-134a	1.091	2.315	4.556	5.849	7.087
		R-410A	40.975	106.661	192.770	284.682	364.845
		R-407C	16.543	55.278	101.216	174.433	285.500
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	36.354	51.396	66.680	84.928	108.190
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	12.941	13.329	12.953	1.296	549
		HC-600a	3.083	5.747	12.560	33.551	47.007
	Commercial	HFC-134a	2.743	5.089	9.356	11.910	15.018
		R-404A + R-507	11.343	31.391	50.015	30.606	9.868
		Low GWP	0	0	7.717	90.805	180.173
	Industrial	HFC-134a	720	1.320	2.255	3.730	6.074
		R-404A + R-507	599	3.132	5.774	4.392	2.883
		Low GWP	19.347	23.571	28.991	36.291	46.469
	Transport	HFC-134a	544	1.200	2.509	3.419	4.228
		R-404A + R-507	1.143	2.156	2.470	1.125	0
		Low GWP	0	0	301	3.007	5.808
	SAC	HFC-134a	1.091	2.315	4.556	5.849	7.087
		R-410A	40.975	106.661	170.273	65.015	18.972
		R-407C	16.543	55.278	92.804	58.029	20.684
		Low GWP	0	0	30.909	336.071	610.690
	MAC	HFC-134a	36.354	51.396	59.636	22.153	6.375
		Low GWP	0	0	7.044	62.775	101.185
A5 6-year conversion 2025	Domestic	HFC-134a	12.941	13.329	15.333	15.442	1.541
		HC-600a	3.083	5.747	10.141	18.529	44.635
	Commercial	HFC-134a	2.743	5.089	9.356	11.910	15.018
		R-404A + R-507	11.343	31.391	55.505	88.798	45.752
		Low GWP	0	0	0	9.024	102.531
	Industrial	HFC-134a	720	1.320	2.255	3.730	6.074
		R-404A + R-507	599	3.132	6.266	10.200	7.108
		Low GWP	19.347	23.571	28.991	36.291	46.469
	Transport	HFC-134a	544	1.075	1.982	2.608	3.104
		R-404A + R-507	1.143	1.881	2.192	2.845	1.154
		Low GWP	0	0	0	290	3.041
	SAC	HFC-134a	1.091	2.315	4.556	5.849	7.087
		R-410A	40.975	106.661	192.770	254.067	104.162
		R-407C	16.543	55.278	101.216	160.942	108.166
		Low GWP	0	0	0	44.105	438.017
	MAC	HFC-134a	36.354	51.396	66.680	76.006	28.027
		Low GWP	0	0	0	8.922	80.163

Table A6-8: Demand in tonnes for new manufacturing only for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (new manufacturing)							
			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	11.234	12.812	14.610	17.323	20.540
		HC-600a	2.622	5.557	9.740	14.957	22.252
	Commercial	HFC-134a	2.617	4.779	8.726	10.874	13.551
		R-404A + R-507	9.216	20.804	31.030	52.412	76.790
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	406	650	1.040	1.663	2.661
		R-404A + R-507	238	1.613	2.532	3.972	4.435
		Low GWP	3.305	4.242	5.579	7.566	10.645
	Transport	HFC-134a	321	551	948	964	981
		R-404A + R-507	877	1.241	1.158	1.660	2.290
		Low GWP	0	0	0	0	0
	SAC	HFC-134a	862	1.587	2.923	3.072	3.229
		R-410A	34.583	82.577	134.702	178.540	206.625
		R-407C	6.107	26.645	43.128	69.810	112.998
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	25.061	32.577	40.822	52.100	66.495
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	11.234	12.812	12.238	580	0
		HC-600a	2.622	5.557	12.112	31.700	42.792
	Commercial	HFC-134a	2.617	4.779	8.726	10.874	13.551
		R-404A + R-507	9.216	20.804	26.172	4.495	0
		Low GWP	0	0	4.858	46.529	74.984
	Industrial	HFC-134a	406	650	1.040	1.663	2.661
		R-404A + R-507	238	1.613	2.132	230	0
		Low GWP	3.305	4.242	5.579	7.566	10.645
	Transport	HFC-134a	321	644	1.292	1.346	1.403
		R-404A + R-507	877	1.472	1.311	163	0
		Low GWP	0	0	268	2.154	3.273
	SAC	HFC-134a	862	1.587	2.923	3.072	3.229
		R-410A	34.583	82.577	113.983	10.182	0
		R-407C	6.107	26.645	36.495	3.981	0
		Low GWP	0	0	27.353	234.187	319.623
	MAC	HFC-134a	25.061	32.577	34.293	2.481	0
		Low GWP	0	0	6.529	49.619	66.495
A5 6-year conversion 2025	Domestic	HFC-134a	11.234	12.812	14.610	14.533	688
		HC-600a	2.622	5.557	9.740	17.747	42.104
	Commercial	HFC-134a	2.617	4.779	8.726	10.874	13.551
		R-404A + R-507	9.216	20.804	31.030	44.426	5.149
		Low GWP	0	0	0	7.986	71.642
	Industrial	HFC-134a	406	681	1.140	1.911	3.202
		R-404A + R-507	238	2.474	4.397	4.696	0
		Low GWP	3.305	4.443	6.120	9.600	18.144
	Transport	HFC-134a	321	551	948	964	981
		R-404A + R-507	877	1.241	1.158	1.402	137
		Low GWP	0	0	0	258	2.152
	SAC	HFC-134a	862	1.587	2.923	3.072	3.229
		R-410A	34.583	82.577	134.702	150.481	9.936
		R-407C	6.107	26.645	43.128	58.838	5.433
		Low GWP	0	0	0	39.031	304.254
	MAC	HFC-134a	25.061	32.577	40.822	43.830	3.166
		Low GWP	0	0	0	8.270	63.328

Table: A6-9 Demand in tonnes for servicing only for Article 5 Parties for the period 2010-2030 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (servicing)			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	1.707	517	723	919	1.094
		HC-600a	461	190	401	727	1.194
	Commercial	HFC-134a	126	310	630	1.036	1.467
		R-404A + R-507	2.127	10.587	24.475	45.411	71.493
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	314	670	1.215	2.067	3.413
		R-404A + R-507	361	1.519	3.734	6.997	10.777
		Low GWP	16.042	19.329	23.412	28.725	35.824
	Transport	HFC-134a	223	524	1.034	1.644	2.123
		R-404A + R-507	266	640	1.034	1.475	1.905
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	229	728	1.633	2.777	3.858
		R-410A	6.392	24.084	58.068	106.142	158.220
		R-407C	10.436	28.633	58.088	104.623	172.502
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	11.293	18.819	25.858	32.828	41.695
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	1.707	517	715	716	549
		HC-600a	461	190	448	1.851	4.215
	Commercial	HFC-134a	126	310	630	1.036	1.467
		R-404A + R-507	2.127	10.587	23.843	26.111	9.868
		Low GWP	0	0	2.859	44.276	105.189
	Industrial	HFC-134a	314	670	1.215	2.067	3.413
		R-404A + R-507	361	1.519	3.642	4.162	2.883
		Low GWP	16.042	19.329	23.412	28.725	35.824
	Transport	HFC-134a	223	556	1.217	2.073	2.825
		R-404A + R-507	266	684	1.159	962	0
		Low GWP	0	0	33	853	2.535
	SAC	HFC-134a	229	728	1.633	2.777	3.858
		R-410A	6.392	24.084	56.290	54.833	18.972
		R-407C	10.436	28.633	56.309	54.048	20.684
		Low GWP	0	0	3.556	101.884	291.067
	MAC	HFC-134a	11.293	18.819	25.343	19.672	6.375
		Low GWP	0	0	515	13.156	34.690
A5 6-year conversion 2025	Domestic	HFC-134a	1.707	517	723	909	853
		HC-600a	461	190	401	782	2.531
	Commercial	HFC-134a	126	310	630	1.036	1.467
		R-404A + R-507	2.127	10.587	24.475	44.372	40.603
		Low GWP	0	0	0	1.038	30.889
	Industrial	HFC-134a	314	639	1.115	1.819	2.872
		R-404A + R-507	361	658	1.869	5.504	7.108
		Low GWP	16.042	19.128	22.871	26.691	28.325
	Transport	HFC-134a	223	524	1.034	1.644	2.123
		R-404A + R-507	266	640	1.034	1.443	1.017
		Low GWP	0	0	0	32	889
	Industrial	HFC-134a	229	728	1.633	2.777	3.858
		R-410A	6.392	24.084	58.068	103.586	94.226
		R-407C	10.436	28.633	58.088	102.104	102.733
		Low GWP	0	0	0	5.074	133.763
	MAC	HFC-134a	11.293	18.819	25.858	32.176	24.861
		Low GWP	0	0	0	652	16.835

Table A6-10: Demand in ktonnes CO_2-eq. for new manufacturing plus servicing (total demand) for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (new manufacturing plus servicing)							
			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	16.823	17.327	19.933	23.715	28.125
		HC-600a	62	115	203	314	469
	Commercial	HFC-134a	3.566	6.615	12.162	15.484	19.524
		R-404A + R-507	44.723	123.759	218.844	385.658	584.559
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	937	1.716	2.931	4.849	7.896
		R-404A + R-507	2.359	12.341	24.689	43.217	59.936
		Low GWP	0	0	0	0	0
	Transport	HFC-134a	707	1.398	2.577	3.390	4.035
		R-404A + R-507	4.502	7.411	8.635	12.354	16.530
		Low GWP	0	0	0	0	0
	SAC	HFC-134a	1.418	3.009	5.923	7.603	9.213
		R-410A	78.671	204.789	370.118	546.589	700.502
		R-407C	26.799	89.550	163.971	282.581	462.511
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	47.261	66.815	86.684	110.406	140.647
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	16.823	17.327	16.839	1.685	714
		HC-600a	62	115	251	671	940
	Commercial	HFC-134a	3.566	6.615	12.162	15.484	19.524
		R-404A + R-507	44.723	123.759	197.206	120.755	39.113
		Low GWP	0	0	1.647	19.749	40.982
	Industrial	HFC-134a	937	1.716	2.931	4.849	7.896
		R-404A + R-507	2.359	12.341	22.749	17.303	11.359
		Low GWP	0	0	148	1.973	3.699
	Transport	HFC-134a	707	1.398	2.577	3.390	4.035
		R-404A + R-507	4.502	7.411	7.738	3.839	427
		Low GWP	0	0	68	648	1.226
	SAC	HFC-134a	1.418	3.009	5.923	7.603	9.213
		R-410A	78.671	204.789	326.924	124.828	36.425
		R-407C	26.799	89.550	150.343	94.007	33.508
		Low GWP	0	0	9.273	100.821	183.207
	MAC	HFC-134a	47.261	66.815	77.527	28.799	8.288
		Low GWP	0	0	7	63	102
A5 6-year conversion 2025	Domestic	HFC-134a	16.823	17.327	19.933	20.074	2.003
		HC-600a	62	115	203	371	893
	Commercial	HFC-134a	3.566	6.615	12.162	15.484	19.524
		R-404A + R-507	44.723	123.759	218.844	350.091	180.501
		Low GWP	0	0	0	2.707	30.759
	Industrial	HFC-134a	937	1.716	2.931	4.849	7.896
		R-404A + R-507	2.359	12.341	24.689	40.190	28.006
		Low GWP	0	0	0	231	2.431
	Transport	HFC-134a	707	1.398	2.577	3.390	4.035
		R-404A + R-507	4.502	7.411	8.635	11.209	4.547
		Low GWP	0	0	0	87	912
	SAC	HFC-134a	1.418	3.009	5.923	7.603	9.213
		R-410A	78.671	204.789	370.118	487.808	199.992
		R-407C	26.799	89.550	163.971	260.727	175.229
		Low GWP	0	0	0	13.232	131.405
	MAC	HFC-134a	47.261	66.815	86.684	98.808	36.435
		Low GWP	0	0	0	9	80

Table A6-11: Demand in ktonnes CO_2-eq. for new manufacturing only for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (new manufacturing)							
			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	14.993	16.655	18.993	22.520	26.702
		HC-600a	52	111	195	299	445
	Commercial	HFC-134a	3.402	6.213	11.344	14.136	17.617
		R-404A + R-507	36.328	81.998	122.316	206.575	302.644
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	528	845	1.352	2.162	3.460
		R-404A + R-507	937	6.354	9.976	15.650	17.476
		Low GWP	0	0	0	0	0
	Transport	HFC-134a	417	717	1.232	1.254	1.276
		R-404A + R-507	3.455	4.891	4.564	6.542	9.022
		Low GWP	0	0	0	0	0
	SAC	HFC-134a	1.121	2.063	3.800	3.993	4.197
		R-410A	66.400	158.547	258.628	342.797	396.720
		R-407C	9.893	43.164	69.868	113.092	183.057
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	32.579	42.350	53.069	67.730	86.443
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	14.604	16.655	15.910	754	0
		HC-600a	52	111	242	634	856
	Commercial	HFC-134a	3.402	6.213	11.344	14.136	17.617
		R-404A + R-507	36.328	81.998	103.166	17.714	0
		Low GWP	0	0	1.457	13.959	22.495
	Industrial	HFC-134a	528	845	1.352	2.162	3.460
		R-404A + R-507	937	6.354	8.401	908	0
		Low GWP	0	0	120	1.122	1.331
	Transport	HFC-134a	417	717	1.232	1.254	1.276
		R-404A + R-507	3.455	4.891	3.766	432	0
		Low GWP	0	0	61	465	687
	SAC	HFC-134a	1.121	2.063	3.800	3.993	4.197
		R-410A	66.400	158.547	218.847	19.549	0
		R-407C	9.893	43.164	59.121	6.449	0
		Low GWP	0	0	8.206	70.256	95.887
	MAC	HFC-134a	32.579	42.350	44.581	3.225	0
		Low GWP	0	0	7	50	66
A5 6-year conversion 2025	Domestic	HFC-134a	14.604	16.655	18.994	18.893	894
		HC-600a	52	111	195	355	842
	Commercial	HFC-134a	3.402	6.213	11.344	14.136	17.617
		R-404A + R-507	36.328	81.998	122.316	175.098	20.289
		Low GWP	0	0	0	2.396	21.493
	Industrial	HFC-134a	528	845	1.352	2.162	3.460
		R-404A + R-507	937	6.354	9.976	13.193	84
		Low GWP	0	0	0	187	1.337
	Transport	HFC-134a	417	717	1.232	1.254	1.276
		R-404A + R-507	3.455	4.891	4.564	5.524	542
		Low GWP	0	0	0	78	646
	SAC	HFC-134a	1.121	2.063	3.800	3.993	4.197
		R-410A	66.400	158.547	258.628	288.923	19.076
		R-407C	9.893	43.164	69.868	95.318	8.802
		Low GWP	0	0	0	11.709	91.276
	MAC	HFC-134a	32.579	42.350	53.069	56.980	4.116
		Low GWP	0	0	0	8	63

Table A6-12: Demand in ktonnes CO_2-eq. for servicing only for Article 5 Parties for the period 2010-2030 and for the six major sub-sectors for the BAU, MIT-3 and MIT-5 scenarios

In ktonnes CO2 equivalents (servicing)							
			2010	2015	2020	2025	2030
A5 BAU	Domestic	HFC-134a	1.830	672	940	1.195	1.423
		HC-600a	10	4	8	15	24
	Commercial	HFC-134a	164	402	818	1.348	1.907
		R-404A + R-507	8.395	41.761	96.528	179.083	281.915
		Low GWP	0	0	0	0	0
	Industrial	HFC-134a	409	871	1.579	2.687	4.436
		R-404A + R-507	1.422	5.987	14.713	27.567	42.460
		Low GWP	0	0	0	0	0
	Transport	HFC-134a	290	681	1.345	2.136	2.759
		R-404A + R-507	1.047	2.520	4.071	5.812	7.508
		Low GWP	0	0	0	0	0
	SAC	HFC-134a	297	946	2.123	3.610	5.016
		R-410A	12.271	46.242	111.490	203.792	303.782
		R-407C	16.906	46.386	94.103	169.489	279.454
		Low GWP	0	0	0	0	0
	MAC	HFC-134a	14.682	24.465	33.615	42.676	54.204
		Low GWP	0	0	0	0	0
A5 6-year conversion 2020	Domestic	HFC-134a	2.219	672	929	931	714
		HC-600a	10	4	9	37	84
	Commercial	HFC-134a	164	402	818	1.348	1.907
		R-404A + R-507	8.395	41.761	94.040	103.041	39.113
		Low GWP	0	0	190	5.790	18.487
	Industrial	HFC-134a	409	871	1.579	2.687	4.436
		R-404A + R-507	1.422	5.987	14.348	16.395	11.359
		Low GWP	0	0	28	851	2.368
	Transport	HFC-134a	290	681	1.345	2.136	2.759
		R-404A + R-507	1.047	2.520	3.972	3.407	427
		Low GWP	0	0	7	183	539
	SAC	HFC-134a	297	946	2.123	3.610	5.016
		R-410A	12.271	46.242	108.077	105.279	36.425
		R-407C	16.906	46.386	91.222	87.558	33.508
		Low GWP	0	0	1.067	30.565	87.320
	MAC	HFC-134a	14.682	24.465	32.946	25.574	8.288
		Low GWP	0	0	0	13	36
A5 6-year conversion 2025	Domestic	HFC-134a	2.219	672	939	1.181	1.109
		HC-600a	10	4	8	16	51
	Commercial	HFC-134a	164	402	818	1.348	1.907
		R-404A + R-507	8.395	41.761	96.528	174.993	160.212
		Low GWP	0	0	0	311	9.266
	Industrial	HFC-134a	409	871	1.579	2.687	4.436
		R-404A + R-507	1.422	5.987	14.713	26.997	27.922
		Low GWP	0	0	0	44	1.094
	Transport	HFC-134a	290	681	1.345	2.136	2.759
		R-404A + R-507	1.047	2.520	4.071	5.685	4.005
		Low GWP	0	0	0	9	266
	SAC	HFC-134a	297	946	2.123	3.610	5.016
		R-410A	12.271	46.242	111.490	198.885	180.916
		R-407C	16.906	46.386	94.103	165.409	166.427
		Low GWP	0	0	0	1.523	40.129
	MAC	HFC-134a	14.682	24.465	33.615	41.828	32.319
		Low GWP	0	0	0	1	17