MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MARCH 2016

DECISION XXVII/4 TASK FORCE REPORT
FURTHER INFORMATION ON ALTERNATIVES TO OZONE-DEPLETING SUBSTANCES

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Montreal Protocol
On Substances that Deplete the Ozone Layer

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UNEP Technology and Economic Assessment Panel

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DECISION XXVII/4 TASK FORCE REPORT:

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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.

Preface

This report is a follow up to the September 2015 TEAP XXVI/9 Update Task Force Report, submitted to the 27th Meeting of the Parties in Dubai, November 2025.

This March 2016 TEAP XXVII/4 Task Force report is being submitted by the TEAP to the 37th Meeting of the Open-ended Working Group of the Parties to the Montreal Protocol, Geneva, 4-8 April 2016.

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FURTHER INFORMATION ON ALTERNATIVES TO OZONE-DEPLETING SUBSTANCES

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Executive summary

ES1. Introduction

- In response to Decision XXVII/4, this report provides an update from TEAP of information on alternatives to ozone-depleting substances listed in the September 2015 Update XXVI/9 Task Force report and considering the specific parameters outlined in the current Decision.
- Given that Parties will hold two Open-ended Working Group (OEWG) meetings this year, the short timeframe until OEWG-37 in April (focusing on discussion of Decision XXVII/1 on matters related to hydrofluorocarbons (HFCs)), TEAP has taken the approach to provide two reports responding to Decision XXVII/4. This first March 2016 report submitted to the OEWG-37 focuses on the refrigeration and air conditioning (R/AC) sector, and includes updates on alternatives, testing on alternatives under high ambient temperature conditions, discussion of other parameters outlined in the decision, and an extension of the mitigation scenarios to 2050.
- This report also provides revised scenarios of avoiding high-GWP refrigerants and considers how the start date for conversion (2020 versus 2025) and the length of conversion over the extended period affect overall costs and climate impacts.
- A second report will be submitted for OEWG-38 providing updates as new information will become available as well as any updates based on feedback received on the first report at OEWG-37. It will also cover the other sectors (foams, fire protection, metered dose inhalers (MDIs), other medical and non-medical aerosols, and solvents) and other topics not covered in the first report (e.g., alternatives for refrigeration systems on fishing vessels).

  The following sections ES2, ES3 and ES4 further elaborate on the highlights and provide the technical summaries of the report's three main chapters.

ES2. Update on the status of refrigerants

- Chapter 2 mentions 80 fluids which have either been proposed or are being tested in industry programmes, or are pending publication, or have been published in ISO 817 and ASHRAE 34 refrigerant standards since the 2014 RTOC Assessment Report. The majority of these are new mixtures, but traditional fluids and two new molecules are also included. Chapter 2 includes discussions on how refrigerants are classified in refrigerant standards and why safety has become more important.
- There are alternative refrigerants available today with negligible ODP and lower GWP, however, for some applications it can be challenging to reach the same lifetime cost level of the conventional systems while keeping the same performance and size. The search for new alternative fluids may yield more economical solutions, but the prospects of discovering new, radically different fluids are minimal.
- Market dynamics are critical in the rate of adoption of new refrigerants. There is a limit to the number of different refrigerants that a market (customers, sales channels, service companies) can manage. Hence, companies will be selective about where they launch a product, avoiding areas which are saturated, and promoting sales where they see the greatest market potential.
- It is difficult to assign energy efficiency to a refrigerant, because energy efficiency of refrigeration systems is in addition to the refrigerant choice and further related to system configuration and component efficiencies. One approach when assessing the energy efficiency related to a refrigerant is to start with a specific refrigerant and use a system architecture suitable for this refrigerant, while comparing with a reference

system for the refrigerant to be replaced. Other approaches screen alternative refrigerants suitable for a given system architecture. The common methods can be divided into: theoretical and semi-theoretical cycle simulations, detailed equipment simulation models, and laboratory tests of the equipment. In practice the achievable energy efficiency is limited by the cost of the system, as the success in the market depends on a cost-performance trade-off.

- The difficulties in assessing the total warming impact related to refrigerants is discussed, including the difficulty of defining low global warming potential and assessing the energy efficiency related to the use of a refrigerant.
- Total climate impact related to refrigerants consists of direct and indirect contributions. The direct contribution is a function of a refrigerant's GWP, charge amount, emissions due to leakage from the air-conditioning and refrigeration equipment and those associated with the service and disposal of the equipment. The definition of the qualifiers "high", "medium" and "low" in relation to GWP is a qualitative, non-technical choice related to what is acceptable in specific applications. The indirect contribution accounts for the kg CO_2-equivalent emissions generated during the production of the energy consumed by the refrigeration, air- conditioning, and heat pump (RAC&HP) equipment, its operating characteristics, which includes the emissions factor of the local electricity production. In addition, since the indirect contribution (the largest contributor in very low to no leakage or "tight systems") is a function of energy consumption, it is affected by the operating conditions, operating profile, system capacity, system hardware, among others, which makes a comparison difficult in many instances.

ES3. Suitability of alternatives under high ambient temperature (HAT) conditions

- Chapter 3 updates information on research projects testing alternative refrigerants at HAT conditions and on the design of products using alternatives in new and retrofit applications.
- Results from the three projects, PRAHA, AREP-II, and ORNL, indicate a way forward in the search for efficient low-GWP alternatives for high ambient temperature conditions especially when coupled with a full system redesign. The scope of the research for AREP-II and ORNL mostly covered soft-optimized testing (i.e., adjusted expansion device or adjusted charge amount). While the PRAHA project included a change of compressors, suppliers did not custom-design those compressors for the particular applications.
- Further improvements are likely through optimizing heat exchangers circuitry for heat transfer properties and proper compressor sizing and selection.
- Full redesign of systems, including new components, will likely be needed to realise systems, using new alternative refrigerants, to match the performance of existing systems in both capacity as well as energy efficiency. When selecting new refrigerants it is important to consider further increases on the current energy efficiency requirements.
- While the commercialization process of refrigerants can take up to ten years, the commercialization of products using these alternatives will take further time.
- In HAT 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. Due to the requirements for charge limitation according to certain safety standards, the possible product portfolio suitable

for HAT conditions is more limited than for average climate conditions when using the same safety standards.

- Although risk assessment work on flammable refrigerants is an on-going research in some countries, there is a need for a comprehensive risk assessment for A2L & A3 alternatives at installation, servicing and decommissioning at HAT conditions.

ES4. BAU and mitigation demand scenarios for R/AC

- The revised scenarios in this report include an extension of the timescale used from the year 2030 to 2050 and a consideration of the BAU scenario for non-Article 5 countries that includes the EU F-gas regulation as well as the US HFC regulations for specific sectors and sub-sectors. The mitigation scenarios remain the same as in the September 2015 XXVI/9 report as follows:
  - MIT-3: conversion of new manufacturing by 2020 (completed in non-Article 5 Parties; starting 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 (completed in non-Article 5 Parties; starting in Article 5 Parties)
- 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 and September XXVI/9 Task Force report) and shortly thereafter. Estimates made for the 2015 global production of the four main HFCs[1] are presented in the table below (some revisions were made in this report); it shows an upper limit for the combined total of about 510 ktonnes.

Chemical	Best estimate for global HFC production in year 2015 (ktonnes)
HFC-32	94
HFC-125	130
HFC-134a	253
HFC-143a	28

- Over the period 2015-2050, the revised BAU scenario shows
  - 250% growth in the demand in tonnes and in tonnes CO_2-eq. in non-Article 5 Parties;
  - 700% growth in tonnes and a 800% growth in tonnes CO_2-eq. in Article 5 Parties;
  - Growth in demand in the stationary AC and the commercial refrigeration sub-sectors is particularly significant where the stationary AC sub-sector is the one determining the total HFC demand in the sum of the four main HFCs used in R/AC. The total global R/AC demand is calculated to be about 510 ktonnes for the year 2015 for these four HFCs.
- *Conversion period:* the longer the conversion period in mitigation scenarios, the greater the climate impacts (see MIT-3 or MIT-5 from 6 to 12 years) and the resulting overall costs in particular because of continuing servicing needs.

  Delaying the start of conversion: 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

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

Parties over the period 2020-2030 was previously estimated in the different scenarios as follows:

- 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)

- With the scenarios extended to 2050 in this report, the BAU demand for the extended period 2020-2050 increases almost five-fold. In this context, although the differences in reduction between the various mitigation scenarios MIT-3, -4 and -5 remain large, they become proportionately less compared to BAU. Consideration of the intermediate period 2020-2040 may provide a more realistic estimate of the savings that can be realised via the various MIT scenarios in Article 5 countries. The *total* integrated HFC demand for the R/AC sector in Article 5 Parties over 2020-2040 is as follows:

  - BAU: 42,300 Mt CO_2-eq.
  - MIT-3: 10,600 Mt CO_2-eq.; a 75% reduction to BAU (2020-2040)
  - MIT-4: 15,600 Mt CO_2-eq.: a 63% reduction to BAU (2020-2040)
  - MIT-5: 18,800 Mt CO_2-eq.; a 56% reduction to BAU (2020-2040)

- The MIT-3 and MIT-5 scenarios are given for all Parties, but predominantly reflect 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 the principal source of 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 in MIT-3. MIT-5 defers the conversion periods for R/AC sub-sectors and shows the impact of the persisting servicing needs as a result.

- For demand in Article 5 Parties, the following is also of importance:

  - Peak values determined for the refrigerant demand increase with later start of conversion. The peak value for MIT-3 in *2020* is about 820 Mt CO_2-eq. The peak value for MIT-4 in the year *2023*, with conversion of stationary AC starting in 2025, is 25% higher (at 1025 Mt CO_2-eq.), whereas the peak value for demand for MIT-5 in the year *2025* is 62% higher than the one for MIT-3 (at 1330 Mt CO_2-eq.).

  - For MIT-3, the average decline over a period of 10 years after the peak year is 5.3% per year (from 820 down to 390 Mt CO_2-eq. in 2030), for MIT-4 it is 4.5% per year (from 1025 down to 570 Mt CO_2-eq. in 2033) and for MIT-5 it is 5.5% per year (from 1330 down to 605 Mt CO_2-eq.). If the freeze year (which coincides with the peak year) is chosen as the starting point, an average annual reduction of 5% in total demand (manufacturing and servicing) seems feasible for all types of scenarios. These values all apply to a manufacturing conversion period of six years.

- For each separate Article 5 country the peak (freeze) values will still be in the same years for the various MIT scenarios considered, however, annual reduction percentages achievable thereafter may be significantly different per country.

1 Introduction

1.1 Terms of Reference for the XXVII/4 Task Force report

Decision XXVII/4 of the Twenty-seventh 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 (OEWG) at its thirty–seventh meeting, and thereafter an updated report to be submitted to the Twenty Eighth Meeting of the Parties in 2016. In their discussions prior to adoption of this decision, Parties considered a focus primarily on areas where updates to the September 2015 report of the task force of the TEAP addressing the issues of decision XXVI/9, including with regard to information on the availability of alternatives and to extending the mitigation scenarios from the previous report to 2050.

In Decision XXVII/1, paragraph 1, Parties agreed to "work within the Montreal Protocol to an HFC amendment in 2016 by first resolving challenges by generating solutions in the contact group on the feasibility and ways of managing HFCs during Montreal Protocol meetings." Further, in paragraph 4 of that decision, Parties agreed to "hold in 2016 a series of Open-ended Working Group meetings and other meetings, including an extraordinary meeting of the parties." Subsequently, in 2016, Parties will hold the thirty-seventh and thirty-eighth OEWG meetings on 4-8 April and 18-21 July, respectively, along with the third Extraordinary Meeting of the Parties 22-23 July. Given the two OEWG meetings and understanding that the focus of the first OEWG-37 will be on issues related to HFCs, TEAP is providing its response to Decision XXVII/4 in two parts: this first report submitted to OEWG-37 primarily focuses on the refrigeration and air conditioning sector; the second report to be submitted to OEWG-38 will address comments received at OEWG-37 plus focus on updates related to the other sectors including foams, fire protection, medical aerosols, non-medical or technical aerosols, and solvents, where updated information is available to the TEAP. An update report, if appropriate, will be submitted to the Twenty-eighth Meeting of the Parties (MOP-28). The approach taken by TEAP is further discussed below.

1.2 Scope and coverage

The text of Decision XXVII/4 ("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:

Decision XXVII/4: Response to the report by the Technology and Economic Assessment Panel on information on alternatives to ozone-depleting substances

Noting with appreciation the September 2015 report of the task force of the Technology and Economic Assessment Panel addressing the issues listed in subparagraphs 1 (a)–(c) of decision XXVI/9,

1. *To request* the Technology and Economic Assessment Panel, if necessary in consultation with external experts, to prepare a report for consideration by the Open-ended Working Group at its thirty–seventh meeting, and thereafter an updated report to be submitted to the Twenty-Eighth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer in 2016, that would:

(a) Update, where necessary, and provide new information on alternatives to ozone-depleting substances, including not-in-kind alternatives, based on the guidance and assessment criteria provided in subparagraph 1 (a) of decision XXVI/9, and taking into account the most recent findings on the suitability of alternatives under high-ambient temperatures, highlighting in particular:

(i) the availability and market penetration of these alternatives in different regions;

(ii) the availability of alternatives for replacement and retrofit of refrigeration systems in fishing vessels, including in small island countries;

(iii) new substances in development that could be used as alternatives to ODS and that could become available in the near-future;

(iv) the energy efficiency associated with the use of these alternatives;

(v) The total warming impact and total costs associated with these alternatives and the systems where they are used;

(b) Update and extend to 2050 all the scenarios in the Decision XXVI/9 report.

1.3 Composition of the Task Force and approach

The TEAP established a Task Force to prepare the reports responding to Decision XXVII/4. The composition of the Task Force is as follows:

Co-chairs

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

Members:

- Denis Clodic (France, outside expert)
- Daniel Colbourne (UK, member RTOC)
- Martin Dieryckx (Belgium, member RTOC)
- Piotr Domanski (USA, outside expert (NIST))
- Dave Godwin (USA, member RTOC)
- Bassam Elassaad (Lebanon, member RTOC)
- Armin Hafner (Norway, outside expert)
- Samir Hamed (Jordan, member RTOC)
- D. Mohin Lal (India, member RTOC)
- Richard Lawton (UK, member RTOC)
- Simon Lee (UK, member FTOC)
- Tingxun Li (PR China, member RTOC)
- Richard Lord (USA, outside expert)
- Carloandrea Malvicino (Italy, member RTOC)
- Keiichi Ohnishi (Japan, co-chair MCTOC)
- Alaa A. Olama (Egypt, member RTOC)
- Xueqin Pan (France, outside expert)
- Fabio Polonara (Italy, co-chair RTOC)
- Rajan Rajendran (USA, member RTOC)
- Helen Tope (Australia, co-chair MCTOC)
- Dan Verdonik (USA, co-chair HTOC)
- Samuel Yana-Motta (Peru, member RTOC)
- Asbjørn Vonsild (Denmark, member RTOC)
- Jianjun Zhang (PR China, c-chair MCTOC)
- Shiqiu Zhang (PR China, Senior Expert member TEAP)

The structure of the TEAP XXVII/4 Task Force Report was considered by the Task Force and also by TEAP prior to the final formulation of this first report. The factors considered include:

- The relatively short period between the delivery of the final XXVII/9 Report (September 2015) and the preparation of the first XXVII/4 Report to be submitted for OEWG-37.
- The similarity of the criteria set out within Decision XXVII/4 and Decision XXVI/9.

- The importance of avoiding too much repetition and bringing focus on updated information from the previous report.
- 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.

Given the two OEWG meetings, the short timeline for OEWG-37, and understanding that the focus of the first OEWG-37 will be on issues related to HFCs, TEAP has taken an approach of providing a response to Decision XXVII/4 as follows:

- For OEWG-37, TEAP is providing this first Task Force report focused on R/AC only addressing the relevant paragraphs under paragraph 1(a) of the decision including updates on alternatives, research studies on alternatives under high ambient temperature conditions, and extension of mitigation scenarios to 2050.
- For OEWG-38, TEAP is providing a second Task Force report that may incorporate updates to the R/AC sector information based on discussions at OEWG-37, and responds to other parts of the decision, including information on alternatives to refrigeration systems on fishing vessels, and updating and extending scenarios for sectors other R/AC to the extent new information is available.
- For MOP-28, TEAP will provide a Task Force update report, as appropriate, following discussions during OEWG-38).

The chapter layout of this first XXVII/4 Task Force report is as follows:

Executive Summary

Chapter 1 – Intro

Chapter 2 – Update on the status of refrigerants

Chapter 3 – Suitability of alternatives under high ambient temperature conditions

Chapter 4 – BAU and MIT scenarios for A5/non-A5 countries for 1990-2050: R/AC

2 Update of the status on refrigerants

2.1 Introduction

This chapter provides updated information on alternatives in the refrigeration and air conditioning sectors since the TEAP Task Force Decision XXVI/9 report, September 2015 (UNEP, 2015) and as requested in Decision XXVII/4. It includes:

- A presentation of 80 fluids that have been proposed for testing or are being tested in industry programmes, are pending publication, or have been published in ISO 817 and ASHRAE 34 refrigerant standards since the 2014 RTOC Assessment Report. The majority of these are new mixtures, but traditional fluids and two new refrigerants based on a new molecule are also included.
- A description of how refrigerants are classified in the refrigerant standards, while also noting that with the introduction and potential widespread adaptation of refrigerants which are flammable, have higher toxicity and/or operate at notably higher pressures than the conventional ODS refrigerants or alternative non-flammable HFC refrigerants, safety matters have become more important.
- A discussion of the process of making refrigerants available to the market, including the market mechanisms that decides where a refrigerant will be available.
- A discussion the methods of assessing the energy efficiency related to the use of a refrigerant.
- A discussion on the discovery of new refrigerants is included. There are alternative refrigerants available today with negligible ODP and lower GWP, but for some applications it can be challenging to reach the same lifetime cost level of the systems while keeping the same performance or to keep the equipment within a reasonable size. The search for new alternative fluids may yield more economical system designs, but the prospects of discovering new, radically different fluids are minimal.
- A discussion of the total warming impact related to refrigerants is discussed, including the difficulty of defining low global warming potential, which plays an essential role in the total warming impact calculation.

2.2 Refrigerant data

A total of 80 fluids, new and "old", are under investigation as alternatives to ODS refrigerants or higher GWP refrigerants (see (UNEP, 2014) for comparison). The fluids have been proposed for testing, are being tested in industry programmes or are pending publication or have been published in ISO 817 (ISO 817:2014) or ASHRAE 34 (ASHRAE 34:2013) since the 2014 RTOC Assessment report (UNEP, 2014). Of the 80 fluids, 11 are pure substances, of which 10 have been published in ISO 817 or ASHRAE 34, while of the 69 mixtures, 55 have publicly known compositions, but only 17 have been published in the ISO 817 or ASHRAE 34 standards, and of these, 11 were included in the RTOC report (UNEP, 2014).

It is expected that after the first introduction of all 80 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 lower GWP candidates in the future.

For ease of reference, the names of the five largest industry test programs are provided below:

- AHRI Low-GWP Alternative Refrigerants Evaluation Program (AREP). This project is divided into two phases: Phase I (AREP-I), which is finished, and phase II (AREP-II), which is still ongoing.
- "Promoting low-GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (PRAHA)
- "Egyptian Project for Refrigerant Alternatives" (EGYPRA)

- the Oak Ridge National Laboratory (ORNL) “High-Ambient-Temperature Evaluation Program for Low-Global Warming Potential (Low-GWP) Refrigerants”, Phase I (and a new Phase II)

In addition to the programs listed above, several independent or industry-led test campaigns for specific refrigerants are being performed for various applications and climate conditions, for which results will be published when available.

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

The fluids for which 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), and N-20b (A1) for replacing HCFC-22, R-407C;
- ARM-20b (A2L) for replacing HCFC-22, R-404A, R-407C;
- ARM-32b (A1), D42Yb (A1), D42Yz (A1), and ARM-25a (A2) for replacing R-404A;
- ARM-71a (A2L) and HPR2A (A2L) for replacing R-410A.

Table 2-1: Pure substances proposed under various test programs and in ASHRAE 34

Refrigerant Designation	Proposed to replace (from AREP phase I)	Safety Class	Participation in AREP program		High ambient programmes for HCFC-22 and R-410A alternatives			Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m^3)	LFL (kg/m^3)	GWP 100 Year (IPCC5)	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
HCC-1130(E)[**]	HCFC-123	B2						$CHCl$=$CHCl$	trans-dichloro-ethene	96,9	47,7			<1	<1

Notes:
Fluids given with a green background are fluids which were not previously mentioned in the XXVI/9 Task Force report.
× 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 R-744 the sublimation temperature is given instead of boiling point. Triple point is −56,6 °C at 5,2 bar.
**HCC-1130(E) is pending official ASHRAE 34 approval, submitted January 2016.

Table 2-2: Blend refrigerants proposed under various test programs or in 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					
R-514A**	DR-10 (XP30)	HCFC-123	B1						R-1336mzz(Z)/1130 (E) (74,7/25,3)	139,6		1,7	1,7
—	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
R-515A**	HDR-115	HFC-134a	A1						R-1234ze(E)/227ea (88/12)	118,7	-19,2	400	380
R-513B*		HFC-134a	A1						R-1234yf/134a (58,5/41,5)	108,7	−29,9	540	560
—	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
R-456A**		HFC-134a	A1						R-32/134a/1234ze(E) (6/45/49)	101,4	-31,1/ -25,7	630	650
R-407G		HFC-134a	A1						R-32/125/134a (2,5/2,5/95,0)	100,0	-29,1/ -27,2	1 300	1 400

—	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						R-32/125/1234yf/134a (25,2/24,3/23,2/27,3)	86,4	−46,1/ −40,2	1 300	1 400
R-449C*	DR-93	HCFC-22, R-407C	A1					X	R-32/125/1234yf/134a (20/20/31/29)	90,3	−45,5/ −38,5	1 100	1 200
R-453A	RS-70	HCFC-22, R-407C	A1						R-32/125/134a/227ea/600/ 601a (20,0/20,0/53,8/5,0/0,6/0,6)	88,8	-42,2/ -35,0	1 600	1 700
R-407H*		HCFC-22, R-407C	A1						R-32/125/134a (32,5/15,0/52,5)	79,1	-44,6/ -37,6	1 400	1 500
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-452C**	ARM-35	R-404A	A1						R-32/125/1234yf (12,5/61,0/26,5)	101,9	-47,8/ -44,4	2 000	2 200
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-454C*	DR-3	R-404A	A2L		X	X	X	X	R-1234yf/32 (78,5/21,5)	90,8	−45,8/ −38,0	150	150
R-454A	D2Y-65	R-404A	A2L	X	X				R-1234yf/32 (65/35)	80,5	−48,4/ −41,6	240	250
R-457A**	ARM-20a	R-404A	A2L						R-32/1234yf/152a (18/70/12)	87,6		140	150
—	ARM-30a	R-404A	A2L	X					R-1234yf/32 (71/29)	84,7		200	200
R-455A	HDR-110	R-404A	A2L		X				R-32/1234yf/744 (21,5/75,5/3)	87,5	-51,6/ -39,1	150	150
—	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-452B**	DR-55 (XL55)	R-410A	A2L					X	R-32/1234yf/125 (67/26/7)	63,5	-50,9/- 50,0	680	710
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
R-447B**	L-41z	R-410A	A2L						R-32/125/1234ze(E) (68,0/8,0/24,0)	63,1	–50,3/ –46,2	710	750

Notes:
Fluids given with a green background are fluids which were not mentioned in the XXVI/9 Task Force report.
* Indicates refrigerants pending official ASHRAE 34 approval, submitted June 2015.
** Indicates refrigerants pending official ASHRAE 34 approval, submitted January 2016.
◊ DR-7 has changed nominal composition slightly from originally R-1234yf/32 (64/36) to R-1234yf/32 (65/35).

Table 2-3: 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	
HC-290	A3	$CH_3CH_2CH_3$	propane	44,1	−42	0,09	12,5 days			5	
HC-600a	A3	$CH(CH_3)_2$-CH_3	2-methyl-propane (isobutane)	58,1	−12	0,059	6,0 days			~20	
R-717	B2L	NH_3	ammonia	17,0	−33	0,000 22					
R-744	A1	CO_2	carbon dioxide	44,0	$-78^{\Diamond}$	0,072			1	1	

Table 2-4: 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/m^3)	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	

As in the previous Decision XXVI/9 Task Force report, the data sources for Tables 2-1 through 2-4 are as follows:

- "GWP (RTOC)" values are taken from the 2014 RTOC report (UNEP, 2014) where available (they are based on (WMO, 2014)); where not available the value is calculated based on values for pure fluids from the 2014 RTOC report (UNEP, 2014).
- "GWP (IPCC5)" values are taken from the IPCC AR5 report (IPCC, 2014) for pure fluids; for mixtures values are calculated based values for pure fluids from the IPCC AR5 report (IPCC, 2014).
- For Tables 2-1 and 2-2, refrigerant designations, 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 2-1 through 2-4 are taken from the 2014 RTOC report (UNEP, 2014).

2.3 Refrigerant classification and standards

Refrigerants are classified by the refrigerant standard ISO 817 and ASHRAE 34 into 8 classes depending on toxicity and flammability, for instance: A1, A2L, A3 or B2L. The first a letter A or B indicates the toxicity of the fluid:

- A, lower chronic toxicity, have an occupational exposure limit of 400 ppm or greater

- B, higher chronic toxicity, have an occupational exposure limit of less than 400 ppm

The suffix 1, 2L, 2 or 3 indicates the flammability:

- 1, no flame propagation, measured at 60 °C

- 2L, lower flammability, burning velocity not higher than 10cm/s, energy of combustion below 19 MJ/kg and not flammable below 3.5 % volume concentration.

- 2, flammable, energy of combustion below 19 MJ/kg and not flammable below 3.5 % volume concentration.

- 3, higher flammability.

These safety classes are used by the system safety standards, such as ISO 5149, IEC 60335-2-24, IEC 60335-2-40, IEC 60335-2-89, EN378 and ASHRAE 15.

With the introduction and potentially wide use of refrigerants that are flammable, have higher toxicity and/or operate at notably higher pressures than the conventional ODS refrigerants or alternative non-flammable HFC refrigerants, consideration of safety matters has become more important. Accordingly, more attention is presently being paid to the requirements of safety standards and regulations that directly relate to refrigerants that exhibit these characteristics.

For instance, the safety standards sets upper limits on how much refrigerant charge is allowed in a refrigerant circuit, primarily depending on the safety class, location of the equipment, and on the type of people who have access to the equipment; the amount of charge is related to the cooling or heating capacity of the equipment. Using a wall mounted split A/C unit in a $30m^2$ room as an example, the safety standard, in this case IEC 6335-2-40, allows 413 g of HC-290 per refrigeration circuit, while for HFC-32 it allows 5.6 kg charge, due to the different flammability characteristics of the substances. Clearly a more than 10 times higher charge allows higher cooling capacity with HFC-32, and requires higher level of optimising for the low charge when using HC-290.

2.4 Likelihood of new molecules and new radically different blends

There are alternative refrigerants available today with negligible ODP and (lower or) low GWP, but for some applications it can be challenging to reach the same lifetime cost level of the systems while keeping the same performance. The search for new alternative fluids may yield more economical system designs, but as will be explained below, the prospects of discovering new, radically different fluids are minimal.

The alternative refrigerants must have suitable thermodynamic properties, which determine the efficiency and capacity of the system. In addition, they need to satisfy several other criteria, such as zero ODP, low GWP, low toxicity, stability in the system, materials compatibility, acceptable cost, and, if possible, non-flammability, low flammability or low-risk due to flammability. These requirements are difficult to balance.

The list of proposed R-410A and HCFC-22 replacement candidates includes single-component refrigerants (HFC-32, HC-290, HC-1270, HFC-161, R-717, R-744). The list also includes blends, which, in addition to the listed single-component candidates, comprise the unsaturated HFC's such as HFC-1234yf and HFC-1234ze(E), along with traditional HFC refrigerants to achieve the desired attributes of the blend, e.g., low GWP, low flammability, or lubricant compatibility. Through ongoing evaluation studies, the performance potentials of these alternatives are being established.

Significant efforts have been done in the past to find new fluids. A recent study (McLinden, 2015) started with a database of over 150 million chemicals, screening the more than 56,000 small molecules and finding none of them ideal. It can be concluded from the study that the prospects of discovering new refrigerants that would offer better performance than the fluids currently known are minimal.

2.5 Road to availability of alternative refrigerants

As discussed in the Task Force Decision XXVI/9 Report (UNEP, 2015), developing a new fluid is a process where uncertainties are addressed, both regarding what is technically feasible and regarding what can be accepted by the market. It is a process structured in discrete steps, where some are visible to the industry. The commercialisation of a new molecule is complicated and can take significant time, while for mixtures consisting of existing molecules the commercialisation is much faster. Once the fluid is launched in the market, the availability is largely controlled by where there is a market need.

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 therefore 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 steps 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 acronym);
- R-number applied for through ASHRAE 34 (or ISO 817) and is normally accepted;
- 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.

Within the context of development of low GWP refrigerants, one of the most important incentives is the occurrence of relevant legislation that hinders competing fluids or opens pathways for new fluids and creates some measure of certainty for investments into the market.

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 issue for the new mixtures is that many contain one of the two new molecules, HFC-1234yf or HFC-1234ze(E), which may have had only limited production until recently.

Once the fluid is launched in the market, companies will invest in sales where they see the greatest market potential. There is a limit to how many different refrigerants customers, service companies, and sales channels in a given market will accept, and market shares obtained in the early phase tends to be relatively easy to sustain, why companies can be very picky about where they launch a product. Although current availability to the markets and market launch plans for specific fluids are proprietary information, there is however the general rule of thumb that new fluids will be available where a sufficiently large share of users request it.

Two examples of the step from commercial productions to market launch in specific markets are as follows:

- Commercial production of HFC-1234ze(E) started at the end 2014 in manufacturing plants in the US. It is now already commercially used in chillers by companies in the US, EU and Japan; besides this, it is also applied in one-component foam applications. Within two years after the start of commercial production, it is currently commercially available in the US, Europe and most of Asia.
- Commercial production of HCFC-1233zd(E) started by mid-year of 2014 in plants located in the USA. It is used in low pressure centrifugal chillers, which have been released in Europe, the Middle East and other 50 Hz markets; besides that, it is also used in foam applications as a replacement for HFC-245fa. Within two years after the start of commercial production, it is currently commercially available in the US, Europe and most of Asia.

2.6 Energy efficiency in relation to refrigerants

Assessing the energy efficiency associated with a refrigerant is a complicated process, and the results depend on the approach taken. Energy efficiency of refrigeration systems is in addition to the refrigerant choice related to system configuration, component efficiencies, operating conditions, operating profile, system capacity, and system hardware, among others, which makes a consistent comparison difficult in many instances.

One approach is to start with a target refrigerant and use a system architecture suitable for this specific refrigerant, while comparing it with a reference system for the refrigerant to be replaced.

Another approach is to screen for alternative refrigerants suitable for a given system architecture. The common methods for determining the efficiency in this case can be placed into one of three categories:

- theoretical and semi-theoretical cycle simulations
- detailed equipment simulation models, and
- laboratory tests of the equipment.

In a refrigerant selection process, great reliance is placed on cycle simulations for selecting best candidate fluids for further examination either by equipment simulation models or tests of actual equipment.

Most often, cycle simulations employ a refrigerant's thermodynamic properties along with fixed values for temperatures inside the system and fixed compressor isentropic efficiency. These models are popular among refrigeration practitioners because they are simple in principle and easy to use. However, the shortcomings to be kept in mind includes not taking into account the heat transfer properties and pressure drops in a system. Detailed simulation models do not have this shortcoming (Domanski, 2006).

Laboratory tests provide the 'most trusted' information about performance of a refrigerant in a given system. It must be recognized that tests of a new refrigerant in a system optimized for a different refrigerant do not demonstrate the performance potential of the refrigerant tested (Abdelaziz, 2015). In addition to system 'soft-optimization', which includes adjustment of the refrigerant charge and expansion device, 'hard optimization' is necessary, which includes, among others, optimization of the compressor (including the size), refrigerant circuitry in the evaporator and condenser, and the overall system balance.

Hard optimization is a rather involved process. Usually, it is most effectively implemented by concurrent detailed simulations and extensive testing. It can be particularly complicated with blends of significant temperature glide, which offer special challenges in heat exchanger design. Hence, overall system design and successful optimization play a significant role in achieving the refrigerant performance potential in a commercialized product. In practice the hard optimization is also limited by the cost of the system, as the success in the market depends on a cost/performance trade-off. In addition, it is also constrained by commercial availability (e.g., manufacturing ability) for certain components, such as availability of preferred compressor displacement, heat exchanger dimensioning and capability to produce preferred circuitry.

To illustrate the difficulties of assessing the energy efficiency associated with a refrigerant, consider the tests under high ambient temperature conditions described in Chapter 3 of this report:

- Testing temperatures differs from test program to test program.
- Obviously no single temperature can accurately match a real geographical location, so the results do not relate directly to the actual energy consumption in a real situation.
- The units (including technologies) used for testing varied within the same test programs.
- In some tests only the refrigerant is changed, in others the oil or even the compressor.
- Differences in test protocols further contributed to differences in results, for example, adjusting the expansion device, adjusting the charge, or adjusting compressor displacement to match compressor and heat exchanger capacity.
- The cost/performance ratio is an important factor (see above) but it is difficult to analyse in the test programs as other long term parameters need to be considered.

2.7 Climate impact related to refrigerants[2]

There are a number of difficulties in assessing the climate impact including the difficulties of obtaining reliable and accurate data on system leakage rates and determining the carbon

[2] This section includes substantial contributions from J. Steven Brown, Ph.D., P.E., of The Catholic University of America, Washington, D.C., USA

emissions generated, now and in the future, and in producing the energy necessary to power the RAC&HP system.

Climate impact related to refrigerants consists of direct and indirect contributions. The direct contribution is a function of a refrigerant's GWP, charge amount and leakage rates (annual, catastrophic, and during servicing and decommissioning) from the air-conditioning and refrigeration (RAC&HP) equipment. The indirect contribution accounts for the kg CO_2-equivalent emissions generated during the production of the energy consumed by the RAC&HP equipment, its operating characteristics and the emissions factor of the local electricity production. The relative importance of the direct and indirect contributions will depend on the type of system. Systems that are "more leaky", e.g., automotive vehicle air conditioning, typically have larger relative contributions from direct warming than would "tighter systems", e.g., hermetically sealed chiller systems, although this can be offset for systems that have much shorter operating periods or where power is supplied from a source with low carbon content.

There are several metrics that measures the total emissions from a system. Most common are Total Equivalent Warming Impact (TEWI) and Life Cycle Climate Performance (LCCP) which attempts to quantify the total global warming impact by evaluating the RAC&HP system during its lifetime from "cradle to grave" (IIR, 2016). Sometimes, a TEWI calculation may be simplified by neglecting broader effects including manufacture of the refrigerant and equipment, and disposal of the refrigerant and equipment after decommissioning. More in-depth analyses not usually performed also look at the emissions associated with the production and disposal of the equipment, e.g., including the mining and recycling of the metal used to manufacture compressors, heat exchangers, and other components.

To summarize, the most important factors determining the climate impact are:

- The GWP of the refrigerant multiplied with the amount leaking from the system, this is the direct contribution.
- Energy consumption of the system multiplied with the amount of CO_2 generated per unit of energy, this is part of the indirect contribution.

The uncertainty on energy consumption and leakage makes determining the total climate impact difficult.

2.8 The GWP classification issue

To minimize direct climate impact a lower GWP refrigerant can be used. The RTOC 2014 Assessment Report included a taxonomy of GWP values, including what constitutes high, medium, and low GWP (again given in Table 2-5 below). This taxonomy is based on fixed GWP values.

Table 2-5 defines "low" as smaller than 300 and "high" as more than 1000. There are sources that define low as lower than 25, as lower than 100, or as lower than 150 (which results from the 2006 EU MAC directive). It will be clear that "high", "medium" and "low" are qualifiers, related to a scale, and that a number definition of these levels would be a non-technical choice. This also because it is somehow related to what is acceptable in specific applications.

Table 2-5: Classification of 100 year GWP levels

100 Year GWP	Classification
< 30	Ultra-low or Negligible
< 100	Very low
< 300	Low
300-1000	Medium
> 1000	High

> 3000	Very high
> 10000	Ultra-high

For instance, there is a relationship between the pressure, the GWP and the flammability of a refrigerant, as illustrated in Table 2-6, which is also from the RTOC 2014 Assessment Report (UNEP, 2014). The trend can be described as "the higher the pressure, the higher the minimum GWP which is needed for fluids to be non-flammable". The exception to this relationship is R-717 and R-744, which do not fit this pattern. Therefore, what could be an "acceptable" GWP for a high pressure fluid replacing R-410A may not be "acceptable" for a low pressure fluid replacing HFC-134a. But this does not relate to a definition of a GWP classification in an absolute sense.

Table 2-6: 100 year GWPs for synthetic refrigerants and hydrocarbons

Safety Class	**Range of GWP for Alternatives to**		
	HFC-134a	**HCFC-22, R-404A, R-407C, and R-507A**	**R-410A**
A1	540 – 900	950 – 1600	
A2L	≤ 110	200 – 970	280 – 740
A3	14 – 20	1,8 – 5	

The two refrigerants that do not fit this pattern, both being in the category with ultra-low GWP, are R-717 and R-744. These are for many applications considered as alternatives to the current higher GWP HFCs. R-744 is a safety class A1 refrigerant, while R-717 are in class B2L.

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3 Suitability of Alternatives under High Ambient Temperature (HAT) Conditions

This chapter updates information on the results of research projects for testing alternative refrigerants at HAT conditions and on further considerations with respect to designing products using alternatives in new and retrofit applications. For a comprehensive understanding of high ambient and the implications on refrigerant selection, please refer to chapter 7 of (UNEP, 2015), which remains relevant.

3.1 HAT considerations

HAT conditions are an important issue for the design of refrigeration and AC systems. While 35 °C has been designated as comparison condition for performance of standard ambient, there is no definition currently for what constitutes a High Ambient Temperature and consequently a high ambient temperature country (or region). Ambient temperatures are also used in 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 this occurrence will be considered to constitute a high ambient condition.

Chapter 7 of the XXVI/9 report (UNEP, 2015) lists several methods to define HAT conditions using weather profiles, cooling degree days, bin weather data, or the occurrence of a certain temperatures above the globally accepted standard temperature. One of the most used is to define values of ambient dry bulb, dew point, wet bulb temperature, and wind speed corresponding to the various annual percentiles of that are exceeded on average by 0.4%, 1%, 2%, and 5% of the total number of hours in a year equivalent to 8,760 hours (ASHRAE, 2013). These values correspond to 35, 88, 175, and 438 hours per year respectively, for the period of record. By defining the value of the high ambient temperature and using information about the percentiles, the appropriate design conditions for refrigeration and air conditioning equipment can be adopted. There are important references that present the information about temperatures profiles and percentiles of incidence in the several regions of the planet.

As the ambient temperature increases, system load increases and capacity decreases. With increasing ambient temperatures, the condensing pressure and compressor discharge temperatures also increase, thus leading to possible reliability issues. ISO and EN (European Standards) prescribe pressures corresponding to certain design temperatures for the safe operation of a system. This information is required by design engineers to specify material and pipe wall thickness requirements in a system. Table 3-1 is taken from EN378-2:2008 and the equivalent ISO 5149 based on IEC 60721-2-1. The table does not specify what is classified as high ambient temperature.

Table 3-1: Specified Design Temperatures

Ambient Conditions	**< 32 °C**	**<38 °C**	**< 43 °C**	**< 55 °C**
High pressure side with air cooled condenser	55 °C	59 °C	63 °C	67 °C
Low pressure side with heat exchanger exposed to ambient temperature	32 °C	38 °C	43 °C	55 °C

While normally systems are designed for 35 °C (T1 in ISO 5151:2010) with appropriate performance (cf. for example, under 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.

3.2 Testing at HAT conditions

Most of the research and development has traditionally been made at the "standard ambient" of 35°C dry bulb temperature; even lower temperatures are used for some tests (e.g., under AHRI Standard 210/240). The performance of units at different ambient temperatures would then be simulated or extrapolated. The status of the following projects testing refrigerants used in specific equipment operating under high ambient temperature conditions are discussed below:

- "Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (PRAHA) and "Egyptian Project for Refrigerant Alternatives" (EGYPRA);
- the Oak Ridge National Laboratory (ORNL) "High-Ambient-Temperature Evaluation Program for Low-Global Warming Potential (Low-GWP) Refrigerants", Phase I (and ongoing Phase II); and
- the AHRI Low GWP Alternative Refrigerants Evaluation Program (AREP) Phase I (and ongoing Phase II).

3.2.1 PRAHA and EGYPRA 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. PRAHA was launched in 2013 and completed at the end 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 HCFC Phase-out Management Plans (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 EGYPRA tests more blends in different applications. The initiative was launched back in June 2014 and is expected to have the results by the end of 2016.

Both projects built custom made units and testing was done at independent labs at 35, 46, and 50 °C ambient temperatures for PRAHA and an additional 27 °C for EGYPRA, with an "endurance" test at 55°C ambient to ensure continuous operation for two hours when units are run at that temperature. The proposed refrigerants are shown in table 32 below:

Table 3-2: Alternative refrigerants used in PRAHA and EGYPRA projects

Comparable to HCFC-22	Comparable to R-410A
R-290	HFC-32
R-444B (L-20)	R-447A (L-41-1)
DR-3	R-454B (DR-5A)
R-457A (ARM-20a)	ARM-71a

The main finding of the PRAHA project is that some of the alternative refrigerants with higher relative volumetric capacity than HCFC-22 show better COP than was theoretically expected and that the R-410A units and their equivalents are more technologically advanced than the HCFC-22 unit because the development of HCFC-22 units has been stopped for some time. The test results from the rooftop packaged units with larger capacity than the other categories were better than those for smaller units possibly indicating that the capacity of the air conditioner affects the outcome (Chakroun, 2016). 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 summary of results will be available when the final report will be published in April 2016. The outcome of the PRAHA project, other than the testing results, are:

- There is a need to do risk assessment studies at HAT conditions in countries that experience HAT conditions;
- There is a need for a full product re-design taking into consideration the technical issues of heat exchanger optimisation, expansion device selection, charge optimisation, excessive pressure, temperature glide, flammability, oil, and energy efficiency issues;
- The economic impact is still to be considered when the availability and cost of components have been determined by market factors. Todays' price on the market of components is not representative for the cost in the longer term, so alternative methods have to be used to analyse future cost;
- There is need for field testing of the units once a design and alternative refrigerants have been selected by the concerned OEMs

The work by PRAHA and EGYPRA will facilitate the technology transfer and the exchange of experience with 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).

3.2.2 ORNL project

The ORNL project aims to develop an understanding of the performance of low-GWP alternative refrigerants to HCFC and HFC refrigerants under HAT conditions in mini-split air conditioners under Phase I and in roof-top units under the ongoing Phase II.

Phase I: ORNL in cooperation with a panel of international experts designed a test matrix of 84 tests. ORNL and the panel selected the refrigerants based on their GWP, commercial availability and physical properties while considering whether information about the characteristics of the refrigerants is readily available. ORNL conducted tests using two "soft-optimized" ductless mini-split air conditioners have a cooling capacity of 5.25 kWh (1.5 TR). One unit is designed to operate with HCFC-22 refrigerant (2.78 coefficient of performance [COP], equivalent to a 9.5 energy efficiency ratio [EER]). The other is designed to use R-410A refrigerant (3.37 COP, equivalent to an 11.5 EER).

Table 3-3: Alternative refrigerants used in ORNL Project

Comparable to HCFC-22	Comparable to R-410A
N-20b	HFC-32
DR-3	R-447A (L-41-1)
ARM-20b	DR-55
R-444B (L-20a)	ARM-71a
R-290	HPR-2A

The ORNL/TM-1015/536 report has the following conclusion appearing as part of its Executive Summary (reproduced here without changes):

> *The test results from this evaluation program demonstrate that there are several viable alternatives to both R-22 and R-410A at high ambient temperatures. In some cases, there was a significant improvement in the performance of the alternatives over that of the baseline, in terms of both COP and cooling capacity. In other cases,*

the performance of the alternatives fell within 10% of the baseline, which suggests that parity with baseline performance would likely be possible through additional engineering design.

The R-22 alternative refrigerants showed promising results at high ambient temperatures: although both of the A1 alternative refrigerants lagged in performance, some of the A2L refrigerants showed capacity within 5% and efficiency within approximately 10% of the baseline system. The A3 refrigerant (R-290) exhibited higher efficiency consistently; however, it did not match the cooling capacity of the baseline system. The most promising A2L refrigerants exhibited slightly higher compressor discharge temperatures, while the A3 refrigerant exhibited lower compressor discharge temperatures.

The R-410A alternative refrigerants are all in the A2L safety category. Most of them showed significant potential as replacements. R-32 was the only refrigerant that showed consistently better capacity and efficiency; however, it resulted in compressor discharge temperatures that were 12–21°C higher than those observed for the baseline refrigerant. These higher temperatures may negatively impact compressor reliability. DR-55 and HPR-2A had higher COPs than the baseline and matched the capacity of the baseline at both the hot and extreme test conditions. R-447A and ARM-71a had lower cooling capacity than the baseline at all ambient conditions. The system efficiency of R-447A showed improvement over the baseline at high ambient temperatures; for ARM-71a, the efficiency was similar to the baseline at all test conditions.

The efficiency and capacity of the alternative refrigerants could be expected to improve through design modifications that manufacturers would conduct before introducing a new product to market. However, given that the scope of this study covered only soft-optimized testing, no detailed assessment can be made of the extent of potential improvements through design changes. Within the bounds of what is possible in optimizing the units for soft-optimized tests, the ORNL test plan included only minor optimizations, including refrigerant charge, capillary tube length, and lubricant change. Therefore, these are conservative results that probably could be improved through further optimization. Additional optimization, including heat transfer circuiting and proper compressor sizing and selection, would likely yield better performance results for all of the alternative refrigerants.

Losses in cooling capacity are typically easier to recover through engineering optimization than are losses in COP. The primary practical limit to improvements in capacity is the physical size of the unit; but that is not expected to be a significant concern in this case, based on the magnitude of the capacity losses exhibited in this evaluation program. Thus, the COP losses and the increases in compressor discharge temperature are particularly important results of this testing program, in that these variables will be the primary focus of future optimization efforts.
This performance evaluation shows that viable replacements exist for both R-22 and R-410A at high ambient temperatures. Multiple alternatives for R-22 performed well. Many R-410A alternatives matched or exceeded the performance of R-410A. These low-GWP alternative refrigerants may be considered as prime candidate refrigerants for high ambient temperature applications. Before commercialization, engineering optimization carried out by manufacturers can address performance loss, the increase in compressor discharge temperature that many alternatives exhibited (particularly the R-410A alternatives), and any safety concerns associated with flammable alternatives. (Abdelaziz, 2015)

Phase II: ORNL started the second phase of the program testing “Low GWP Refrigerants in High Ambient Temperature Countries” in February 2016, covering roof-top air conditioners in this phase. Results will be published in the second half of 2016.

3.2.3 AREP project

AREP, 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 evaluated 38 refrigerant candidates for replacing HCFC-22 and three HFCs, R-410A, HFC-134a, and R-404A (Amrane, 2013), in applications varying from air conditioners and heat pumps (both package, split and variable refrigerant flow), chillers (screw and centrifugal), refrigeration (commercial and ice machines), refrigerated transport, and bus air-conditioning. Phase II tested 17 refrigerants plus doing more tests at high ambient temperature conditions.

Table 3-4: AREP Phase II low-GWP High Ambient Testing

AREP Phase II Low-GWP High Ambient Test Matrix										
Product	Test companies	High Ambient Conditions	Baseline Refrigerant	ARM-71a	DR-5A	DR-55	HPR2A	L-41-1	L-41-2	HFC-32
34 MBH chiller	Armines	115F	410A		X			X	X	X
14 SEER 3-ton HP	Carrier	125F	410A	X	X		X	X	X	
13 SEER 3-ton HP	Danfoss	115F and 125F	410A		X				X*	X**
14 SEER 3-ton split HP	Goodman	115F and 125F	410A							X***
5-ton packaged	Lennox	115F	410A	X	X	X	X		X	X
4-ton packaged	Trane	125F	410A		X	X				X
6-ton packaged	Zamilac	125F	410A							X

* L-41-2 at wet suction, no HAT
**HFC-32 with same charge and with optimized charge
*** HFC-32 with standard POE oil and with prototype POE oil

AREP concluded its first phase in 2013 and the second phase began in early 2014.

For high ambient testing, seven entities tested three residential split units, four rooftops, one chiller, and several compressors. The results were compared to baseline of R-410A units. Refrigerant candidates are shown in table 3-5 below (Schultz, 2016a). Refrigerants were tested at 115 °F (46.1 °C) and 125 °F (52.6 °C). The tests were either a drop-in or a soft optimization with a change in refrigerant charge and/or expansion device.

The conclusion from AREP-II (Schultz, 2016a) is that general trends in HAT performance are similar for all alternative refrigerants. Systems with alternatives generally provided similar to higher capacities than R-410A systems at HAT conditions, i.e., showing a smaller decrease in capacity as ambient temperatures increase.

AREP-II was conducted by several entities with different test protocols which contributed to differences in results. The different tests varied from drop-in to soft-optimized tests adjusting the expansion device for similar superheat, or adjusting the charge for a similar sub-cooling. The results shown below are extracted from some of the test reports of AREP-II that are available publically on-line and are as presented at a special ASHRAE session in January 2016. They do not represent a conclusion on behalf of AREP-II since there was none published.

A drop-in test for ARM-71a, R-454B (DR-5A), HPR2A, R-446A (L-41-1), and R-447A (L-41-2) at 125 °F (51.6 °C) showed slightly less capacity for all systems compared to systems with R-410A. ARM-71a, DR-5A, and HPR2A charged systems resulted in 3-6% better efficiency. The discharge pressure at that condition was lower for all refrigerants compared to R-410A, while the discharge temperatures were equal or slightly higher than R-410A (Burns, 2016).

A test using a prototype oil for HFC-32 prevented breaks in the operation of the unit at 52 °C as it did when the original polyolester (POE) oil was used. HFC-32 showed higher compressor (isentropic) efficiency and lower volumetric efficiency with POE oil than R-410A at rating conditions, but better efficiencies in both tests with prototype HFC-32 oil (Li, 2016).

In another test, a variable speed drive was used to equalize the capacity with the R-410A base unit capacity. DR-55 and DR-5A required no to little adjustment to the compressor displacement, while HFC-32 required a 8% reduction in compressor displacement to match heat exchanger capacity. All three refrigerants were slightly less sensitive to variations in ambient temperatures resulting in somewhat higher capacities and efficiencies at high ambient temperatures compared to R-410A (Schultz, 2016b).

AREP-II included a system drop-in test for a water chiller, a category not tested by the other projects, for ARM-71a, R-454B (DR-5A), HPR2A, R-446A (L-41-1), and R-447A (L-41-2), and HFC-32 at various temperatures between 30 °C and 46 °C. The test showed a similar degradation in relative efficiency for all refrigerants of about 30% between and 35 and 46 °C. The degradation in relative cooling capacity on the other hand was less steep. HFC-32 showed an increase in discharge pressure at higher temperatures; however, using a receiver resulted in reducing that pressure (Zoughaib, 2016).

3.2.4 Common remarks on the three testing projects

A summary of the four projects is found in Table 3-5 below. The table outlines the types of equipment and alternative refrigerants tested, the conditions at which the tests were carried out, and the constraints on the prototype building or optimization process.

As mentioned in Chapter 2 above, assessing the R/AC equipment energy efficiency associated with a refrigerant is a complicated process, and the results depend on the approach taken. Energy efficiency of R/AC systems is in addition to the refrigerant thermodynamic and transport properties related to system configuration, component efficiencies, operating conditions, operating profile, system capacity, and system hardware, among others, which makes a consistent comparison difficult in many instances. Laboratory tests provide the 'most trusted' information about performance of a refrigerant in a given system. It is recognized that tests of a new refrigerant in a system optimized for a different refrigerant do not demonstrate the performance potential of the refrigerant tested (Abdelaziz, 2015). In addition to system 'soft-optimization', which includes adjustment of the refrigerant charge and expansion device, 'hard optimization' is necessary, which is a rather involved process and includes, amongst others, optimization of the compressor (including the size), refrigerant circuitry in the evaporator and condenser, and the overall system balance. Hard optimization is usually most effectively implemented by concurrent detailed simulations and extensive testing. It can be particularly complicated with refrigerant blends characterized by a significant temperature glide, which offer special challenges in heat exchanger design. Hence, overall system design and successful optimization play a significant role in achieving the refrigerant performance potential in a commercialized product. In practice, the hard optimization is also limited by the cost of the system, as the success in the market depends on a cost/performance trade-off. In addition, it is also constrained by commercial availability (e.g., manufacturing ability) for certain components, such as availability of preferred compressor displacement, heat exchanger dimensioning and capability to produce preferred circuitry.

Table 3-5: Summary of the three testing projects

	Program	PRAHA	EGYPRA	ORNL – Phase I (Mini-split AC)	AREP-II
1	Type of test	Custom built test prototypes, comparing with base units: HCFC-22 and R-410A	Custom built test prototypes, comparing with base units: HCFC-22 and R-410A	Soft optimization tests, comparing with base units: HCFC-22 and R-410A	Soft optimization or drop in of individual units tested against a base R-410A unit
2	No. of prototypes	13 prototypes, each specific capacity and refrigerant built by one or two OEMs, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 22	28 prototypes, each specific one capacity and one refrigerant built by one OEM, compared with base refrigerants: HCFC-22 and R-410A. Total prototype and base units = 37	2 commercially available units, soft modified to compare with base refrigerants: HCFC-22 and R-410a	22 units from different OEMs ranging from splits to water chillers
3	No. of categories	60 Hz: Window 18 MBH; Mini Split 24 MBH 50 Hz: Ducted 36 MBH; Packaged 90 MBH	50 Hz: Mini Split 12 MBH; Mini Split 18 MBH; Mini Split 24 MBH; Central 120 MBH; Micro Channel 120 MBH	60 Hz: Split unit 18 MBH R22 eq.; Split unit 18 MBH R-410A eq.	60Hz: 34 MBH chiller, 2x 36 MBH split, 48 MBH packaged, 60 MBH packaged, 72 MBH packaged
4	Testing 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	EOS 4814 and 3795 (ISO 5151) T1, T2, and T3 conditions	ANSI/AHRI Standard 210/240 and ISO 5153 T3 (2010) condition	ANSI/AHRI 210/240, at T1, T3, and 125 °F
5	Prototypes supplied and tests performed	Prototypes built at six OEMs, test at Intertek	Prototypes built at eight OEMs, test at NREA (local test laboratory in Egypt)	ORNL, one supplier – soft optimization in situ	Individual suppliers, testing at own premises
6	Refrigerants tested	Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3 Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A)	Eq. to HCFC-22: HC-290, R-444B (L-20), DR-3, R-457A (ARM-32d) Eq. to R-410A: HFC-32, R-447A (L-41-1), R-454B (DR-5A), ARM-71d	Eq. to HCFC-22:N-20B, DR-3, ARM-20B, R-444B (L-20A), HC-290 Eq. to R-410A: HFC-32, R-447A (L-41-1), DR-55, ARM-71d, HPR-2A	Eq. to R-410A: HFC-32, DR-5A, DR-55, L-41-1, L-41-2, ARM-71a, HPR2A
7	Expected delivery dates	Testing completed end of 2015 Final report end March 2016	Final Report end of 2016	Final Report October 2015	Final Report October 2015
8	Constraints	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	To build new prototype with dedicated compressors for the selected refrigerants with the condition to meet same design capacities of the selected models in comparison to the HCFC-22 and R-410A units	To change some components of the two prototypes to accommodate the different refrigerants, within a "soft optimisation" process	(1) Drop-in; (2)Soft optimization by advjusting expansion device, adjusting charge amount; (3) One case of compressor speed adjustment using variable speed drives
9	Other components	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	N/A	N/A	N/A

The tests under high ambient temperature conditions described above illustrate the difficulties of assessing the energy efficiency associated with a refrigerant, considering:

- Testing temperatures differs from test program to test program.
- Obviously no single temperature can accurately match a real geographical location, so the results do not relate directly to the actual energy consumption in a real situation.
- The units used for testing vary within the same test programs.
- In some tests only the refrigerant is changed, in others the oil is changed or even the compressor.
- Differences in test protocols further contributed to differences in results, for example: adjusting the expansion device for similar evaporator superheat, adjusting the charge for a similar sub-cooling, or adjusting compressor displacement to match compressor capacity to heat exchanger capacity.

The efficiency and capacity of the alternative refrigerants could be expected to improve through design modifications that manufacturers would conduct before introducing a new product to market. However, given that the scope of the research mostly covered soft-optimized testing, no detailed assessment can be made of the extent of potential improvements through design changes (Abdelaziz, 2015). Soft optimization affected limited areas such as capillary tube length or expansion device changes, refrigerant charge, and the type of lubricant. While the PRAHA project included a change of compressors, suppliers had no time to properly design those compressors for the particular applications. Results could probably be improved through further optimization such as heat transfer circuiting and proper compressor sizing and selection; however, there is a particular need for a redesign of systems including new components.

Losses in cooling capacity are typically easier to recover through engineering optimization than are losses in COP. The primary practical limit to improvements in capacity and COP is the physical size of the unit. COP losses and the increases in compressor discharge temperature are particularly important in so far that these variables will be the primary focus of future optimization efforts. Before commercialization, engineering optimization carried out by manufacturers can address performance loss and the increase in compressor discharge temperature that many alternatives exhibited as well as safety concerns associated with flammable alternatives. The cost/performance ratio in the long term will be an important factor.

3.3 Further considerations

Chapter 7 of the September 2015 XXVI/9 Task Force Report (UNEP, 2015) discussed additional topics related to HAT conditions: a definition of options for HAT conditions, design considerations, research projects, energy efficiency and regulations related to energy efficiency, current/future alternative chemicals and technologies for air conditioning under HAT conditions, and considerations for refrigeration systems under HAT conditions including not-in-kind technologies (UNEP, 2015). That information is not repeated here, but in view of the initial results of the testing under HAT conditions discussed above, some of those considerations are further highlighted below.

On energy efficiency: In regions with HAT conditions, legislations which set minimum energy performance standard (MEPS) values on air conditioners are emerging quickly. Most of the countries require third party verification of declared performance. Higher minimum energy efficiencies are being announced on a regular basis, and this tendency may continue. As examples, Bahrain recently announced MEPS values and regulation of labelling air conditioners and Saudi Arabia is moving closer to releasing their regulation for large air conditioners and chillers expected in the second quarter of 2016.

When selecting new refrigerants, it is important to consider further increases on the current minimum energy efficiency requirements. To the extent increases in MEPS are not met by current models, this offers the opportunity for manufacturers to implement new refrigerants while redesigning equipment for those new refrigerants.

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

In HAT 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. 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.

As concluded from the testing projects, special design of both components and products is needed for the new alternatives to meet the performance of systems in both capacity as well as efficiency requirements. While the commercialization process of refrigerants can take up to ten years, as seen from chapter 2, the commercialization of products using these alternatives will take further time.

As HCFC-22 air conditioning products get phased-out for some applications, the industry is turning to available technology using higher GWP refrigerants with higher discharge pressures like R-410A or comparable pressures like R-407C, depending on the application. One exception is HFC-32 which has seen a limited release for room air conditioners following the change-over to HFC-32 in Japan. HC-290 products, which have potential due to the favourable performance of HC-290 compared to HCFC-22 at HAT conditions, are not yet commercially available in many countries although some of the local suppliers are busy researching and designing such products.

On retrofits: 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 are needed. Modifying the electrical connections to meet the requirements needed for flammable refrigerants is an additional cost that needs to be taken into consideration. This cost is the same for A3 or A2L refrigerants and mostly due to changing the location of the controls in order to reduce the risk of a spark.

For HAT conditions, the 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 for each type 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.

On safety: 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 some commercial refrigeration appliances, are available, although IEC 60335-2-89 needs to be adapted to allow larger charges of flammable refrigerants that are required for the bigger capacities of air conditioners working at HAT conditions. 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.

Another important aspect of safety standards is that their value is tied to the degree of compliance, and this makes training of system builders and service technicians an important part of implementing safety standards. The cost of the above certification, including the third-party certification cost and including the training cost, should be considered.

Although risk assessment work on flammable refrigerants is an on-going research in some countries, there is a need for a comprehensive risk assessment for A2L & A3 alternatives at installation, servicing and decommissioning practices at HAT conditions and field testing of units.

3.4 References

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4 BAU and MIT scenarios for Article 5 and non-Article 5 Parties for 1990-2050: Refrigeration and Air Conditioning

This chapter is organized as follows:

4.1 Expansion of scenarios
4.2 Method used for calculation
4.3 HFC consumption and production data
4.4 Non-Article 5 scenarios
4.5 Article 5 scenarios
4.6 Demand and benefit numbers

4.1 Expansion of scenarios

The previous Decision XXVI/9 paragraph 1 (c) asks to revise the scenarios: "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 current Decision XXVII/4 requests to expand the scenarios to the period 1990-2050, twenty years after 2030 which was the last year in the scenarios used in the XXVI/9 Task Force report (UNEP, 2015).

The following scenarios have again been calculated, which apply to the R/AC sector only for this first report of the XXVII/4 Task Force submitted to OEWG-37:

a. A BAU scenario: In non-Article 5 countries this implies consideration of the F-gas regulation in the EU and regulations in the USA making certain HFCs unacceptable for certain sub-sectors by specific dates. This implies that, in the BAU calculation, certain high GWP substances in specific subsectors are replaced by low or lower GWP substances. In this way it responds to comments the XXVI/9 Task Force already received at OEWG-36 and at MOP-27. The changes incorporated mainly apply to commercial refrigeration and, to a small degree, to stationary air conditioning. In Article 5 Parties, economic growth percentages expected for the period 2015-2050 are virtually the same as the ones in the XXVI/9 report.
b. An MIT-3 scenario: A 2020 *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 2020 in Article 5 Parties, now with consequences for the period 2020-2050.
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, now with consequences for the period 2020-2050.
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, now with consequences for the period 2020-2050

For Article 5 Parties, manufacturing conversion projects would need preparation to be funded; it would also take a certain period of time before conversion projects would have been approved by a funding authority, so that they can be initiated. 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 (see sections 4.5.3 and 4.5.5 taken from UNEP, 2015).

In this chapter the 1990-2050 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 figures are given 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 presented 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 figures are given in tonnes and in ktonnes CO_2-eq.

4.2 Method used for calculation

A "bottom-up" method has been used to predict the demand for R/AC equipment, as in the XXVI/9 Task Force report (UNEP, 2015). 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)), less (3) what is recovered and reused from the bank (i.e., material reclaimed from equipment decommissioned). 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 regions) 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.

Further information on sub-sectors, equations used and information on how the installed base is being considered can be found in the XXVI/9 Task Force report (UNEP, 2015).

As in the XXVI/9 report, the GWP for low GWP replacement refrigerants has been chosen 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 (as an estimated average between very low GWP refrigerants and others, such as HFC-32 and various blends under investigation). The choice has been made on the basis of averaging and is not related to GWP considerations presented in Table 2-6. In MACs, replacement refrigerants are assumed to have negligible GWP.

Growth rates for equipment production have been slightly changed (in two cases) compared to the rates used in the XXVI/9 Task Force report, in order to give a more realistic approach in the period after 2030. In this report, the growth rates apply as given in Table 4-1 below.

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. Details on lifetime and annual leakage are given in (Table 5-2 in) the XXVI/9 report (UNEP, 2015).

Table 4-1: Growth rates for high-GWP HFCs in the various R/AC manufacturing sub-sectors during the periods 2010-2020 and 2020-2050 (a negative growth rate may still imply a positive growth in the number of equipment, assumes that low-GWP alternatives are increasingly applied in a BAU scenario and also in MIT scenarios until the conversion starts in specific years)

<table>
<tr><th>Period</th><th>Sub-sector</th><th>non-Article 5</th><th>Article 5</th></tr>
<tr><td rowspan="6">2010-2020</td><td>Domestic refrigeration</td><td>-3.9%</td><td>5.8%</td></tr>
<tr><td>Industrial refrigeration</td><td>5.1%</td><td>1.8%</td></tr>
<tr><td>Transport refrigeration</td><td>0.9%</td><td>1.8%</td></tr>
<tr><td>Commercial refrigeration</td><td>-4.4%</td><td>1.8%</td></tr>
<tr><td>Stationary AC</td><td>1.2%</td><td>1%</td></tr>
<tr><td>Mobile AC</td><td>0.54%</td><td>5%</td></tr>
<tr><td rowspan="6">2020-2050</td><td>Domestic refrigeration
(2030-2050)</td><td rowspan="5">3%</td><td>5.8%
(4.5%)</td></tr>
<tr><td>Transport refrigeration</td><td>4.5%</td></tr>
<tr><td>Commercial refrigeration</td><td>4.5%</td></tr>
<tr><td>Stationary AC (2020-2030)
(2030-2050)</td><td>1%
(1.5%)</td></tr>
<tr><td>Mobile AC</td><td>5%</td></tr>
<tr><td>Industrial refrigeration</td><td>4%</td><td>3.7%</td></tr>
</table>

The calculation method covers the period from 1990 until 2050, as requested in Decision XXVII/4. Table 4-1 gives the growth rates assumed for new manufacturing in the various R/AC sub-sectors. The growth rate assumed in the manufacturing sector is only one parameter in the scenario calculations. The total demand for a sub-sector is calculated using parameters such as equipment lifetime, equipment leakage, charge at new manufacturing etc. This implies that, if the annual growth rate in a manufacturing sub-sector would be 1-5%, the annual growth rate of the total demand for that subsector can be several percent higher, e.g., varying from 3 to about 10%. These percentages can also be derived from the BAU Tables 4-7 and 4-8 and from the more detailed tables in the Annex.

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. The 2010 RTOC Assessment Report (RTOC, 2010) describes a simple approach that gives a quality index expressed in percentages. Further elaboration can be found in the XXVI/9 report. 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 ranges from *-10% to +30%.*

As mentioned in the XXVI/9 report (UNEP, 2015), estimates should be cross-checked with reported HFC consumption and production data, specified per refrigerant (or blend).

4.3 HFC consumption and production data

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 has been given in the XXVI/9 Task Force report (UNEP, 2015).

Data on HFC emissions are reported annually by developed countries, i.e., 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), these reports enable a first estimate for the production of most HFCs in the Annex I Parties to be made.

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 uses almost the same estimates (as in the XXVI/9 report) for HFC production of the four main HFCs in Table 4-2 below (here has been added the estimated production of HFC-134a in one country). These four HFCs are the main ones used in the R/AC sector, except for HFC-134a which is also applied in several other sectors (foams, aerosols, MDIs). It shows a total HFC production of about 510 ktonnes for these four HFCs, forecast for the year 2015 (about 930 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 for certain years are reasonably reliable global estimates and have been 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.

Table 4-2: 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	156^	253
HFC-143a	21	<10	11	17	28

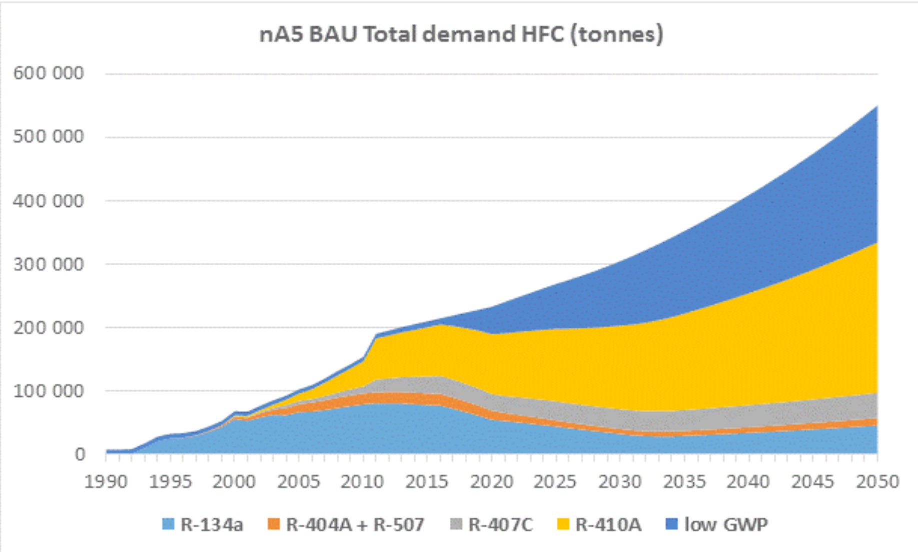
Note: (*) Global production is equal to non-Article 5 plus Article 5 country (China, minor other) production
Note: (**) Estimate from Rigby (2013)
Note: (^) New value for this report

4.4 Non-Article 5 scenarios up to 2050

4.4.1 BAU scenario

The figures below present the results of the Non-Article 5 scenario calculations:

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



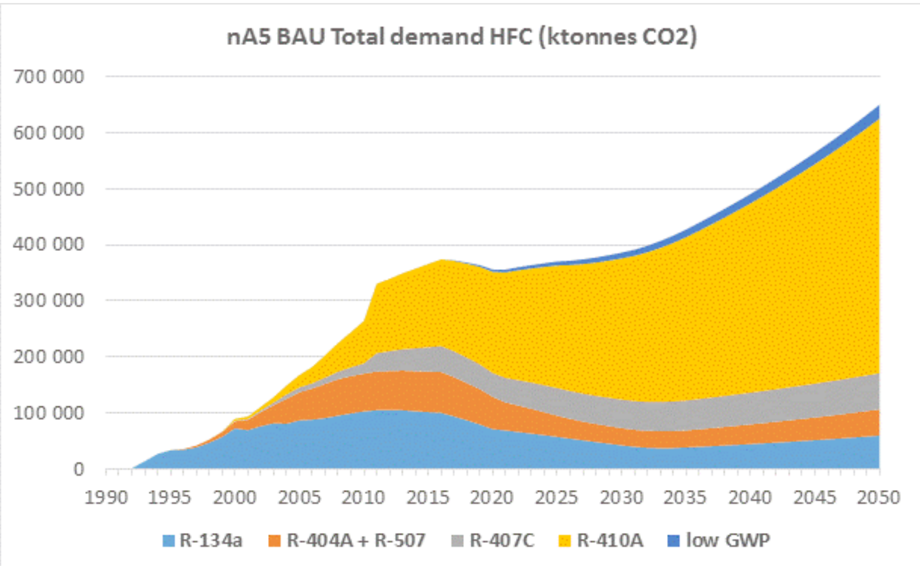
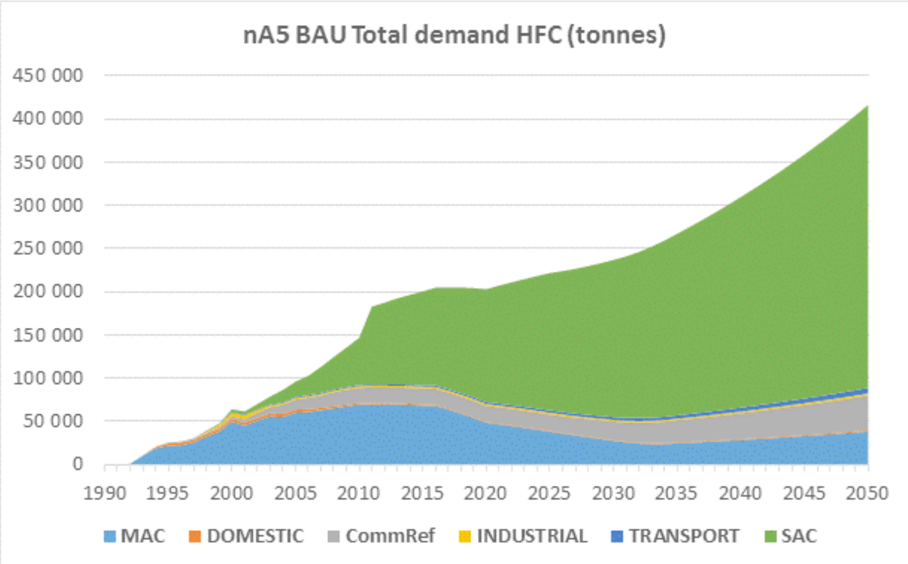


Figure 4-1: Non-Article 5 BAU scenario with subdivision for the various refrigerants or refrigerant blends in tonnes and ktonnes CO_2-eq.

Figure 4-1 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 ktonnes CO_2-eq.). The amount of low-GWP refrigerants in the BAU scenario increases rapidly after 2020, because the BAU scenario includes the EU F-gas regulation as well as the US measures that enter into force as of 2016-2021 (e.g. low GWP in manufacturing of MACs). Over the period 2010-2050, the importance of R-410A and also R-407C for stationary AC becomes more and more dominant, with an increase of a factor 2 in tonnes and in GWP weighted tonnes between 2015 and 2050.

Figure 4-2 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 ktonnes CO_2-eq.). By 2030-2050, stationary AC accounts for more than 80% of the GWP adjusted tonnage (even when using low growth percentages, as given in Table 4-1). This is due to the fact that only a small amount of regulatory restrictions have been built in.



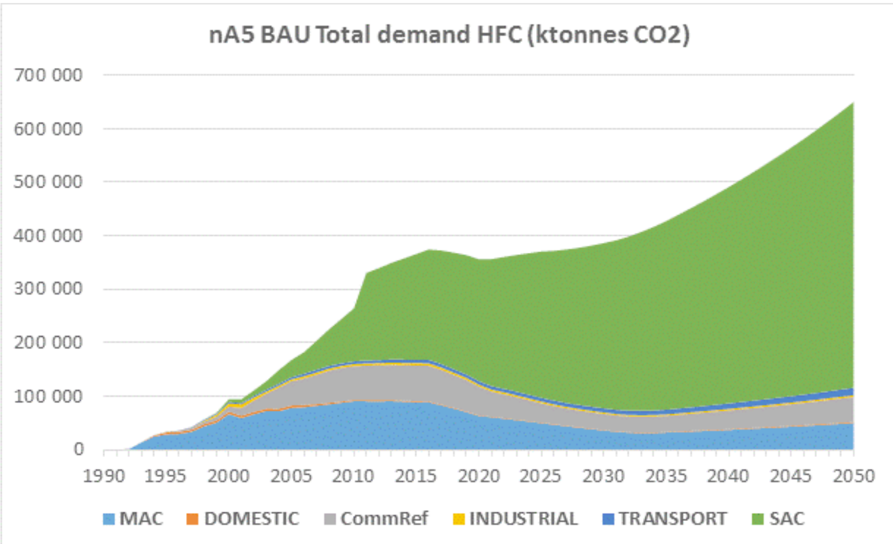
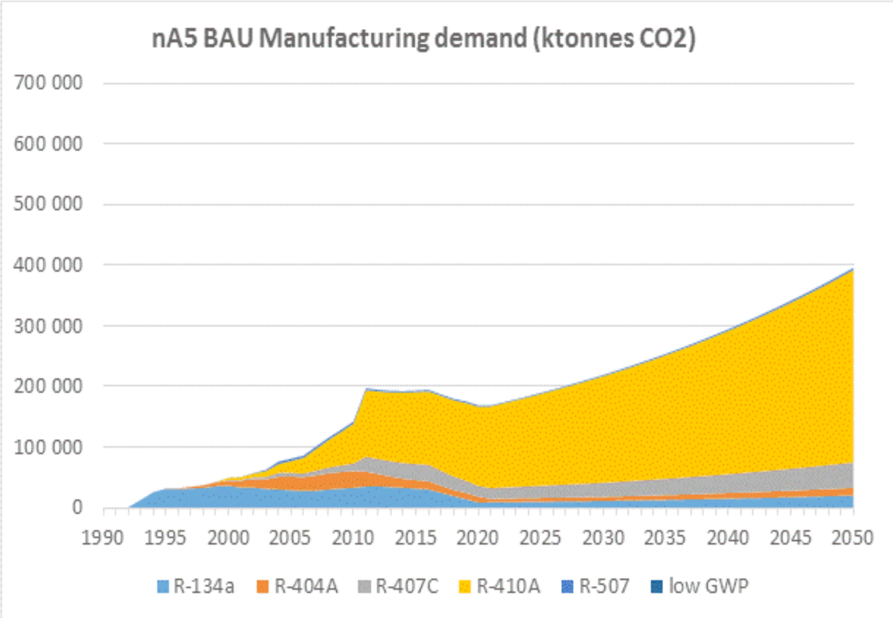


Figure 4-2: Non-Article 5 BAU scenario; subdivision for the various R/AC sub-sectors

Figure 4-3 below is in principle the same as in the XXVI/9 report (UNEP, 2015). It is surprising that, with the assumptions used, the percentage of R-404A in manufacturing decreases sharply, servicing remains (with the assumptions on the servicing percentage) and increases again after 2033 due to economic growth. The low GWP fraction remains very moderate in ktonnes CO_2-eq., but that number implies a much larger percentage in tonnes.



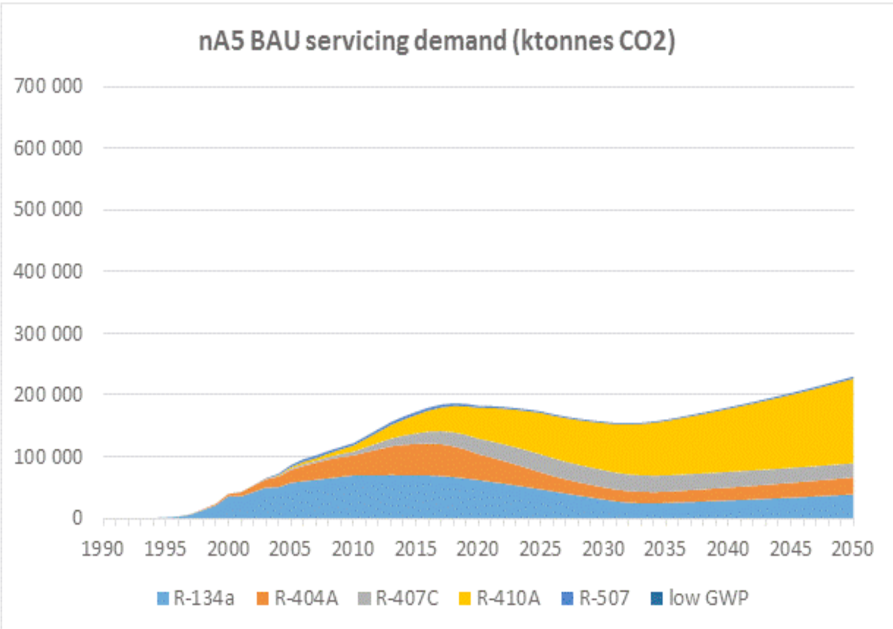


Figure 4-3: New manufacturing and servicing parts of the non-Article 5 BAU scenario with a subdivision for the various R/AC sub-sectors

4.4.2 MIT-3 scenario

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 4-4, 4-5 and 4-6.

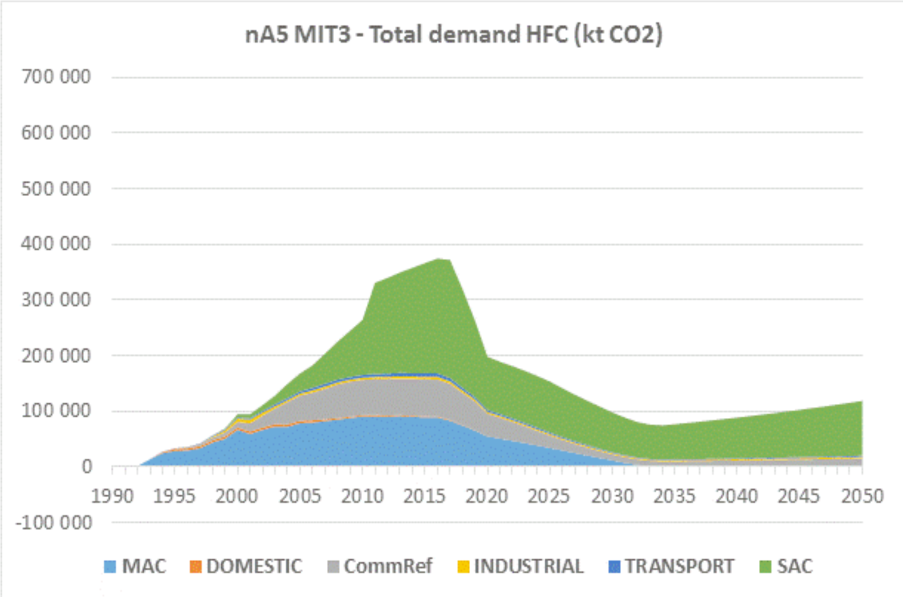


Figure 4-4: Total demand for the Non-Article 5 MIT-3 scenario with a subdivision for the various R/AC sub-sectors

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. This is a major difference with the BAU scenario in which stationary AC is not addressed in this manner.

Figure 4-4 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 transition in new manufacturing as of 2020, high-GWP refrigerants in these sector decrease, being replaced by low-GWP refrigerants that will account for more than 80% of total demand between 2020 and 2050.

What becomes again clear here, that is that the minimum demand is reached by 2032-2033, after which the demand increases again, in particular due to growth in stationary AC.

So, there is a large improvement in climate impact, although with a GWP of 300, the large refrigerant volumes considered still have a certain climate impact.

In Figure 4-5, 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.

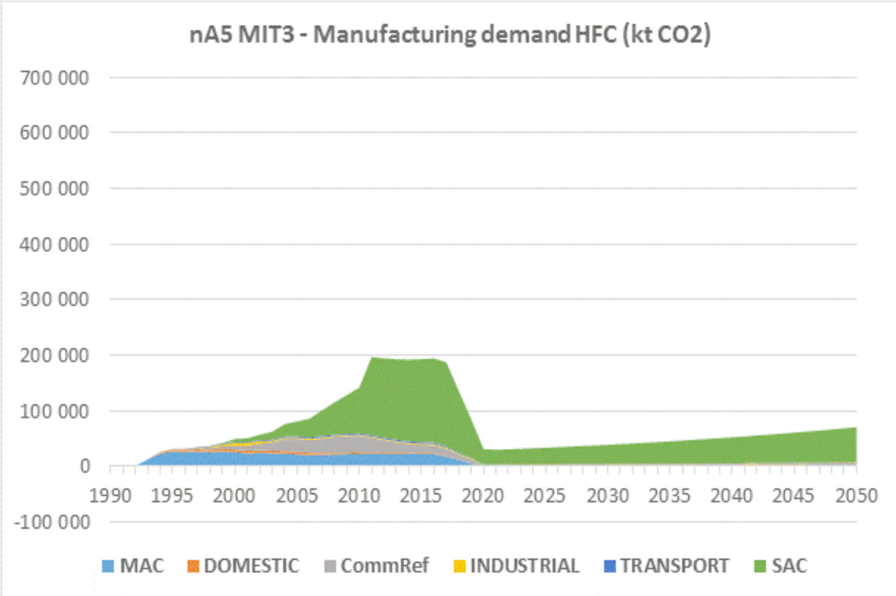


Figure 4-5: Non-Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors in ktonnes CO_2-eq. (assuming manufacturing conversion over a period of 3 years, 2017-2020).

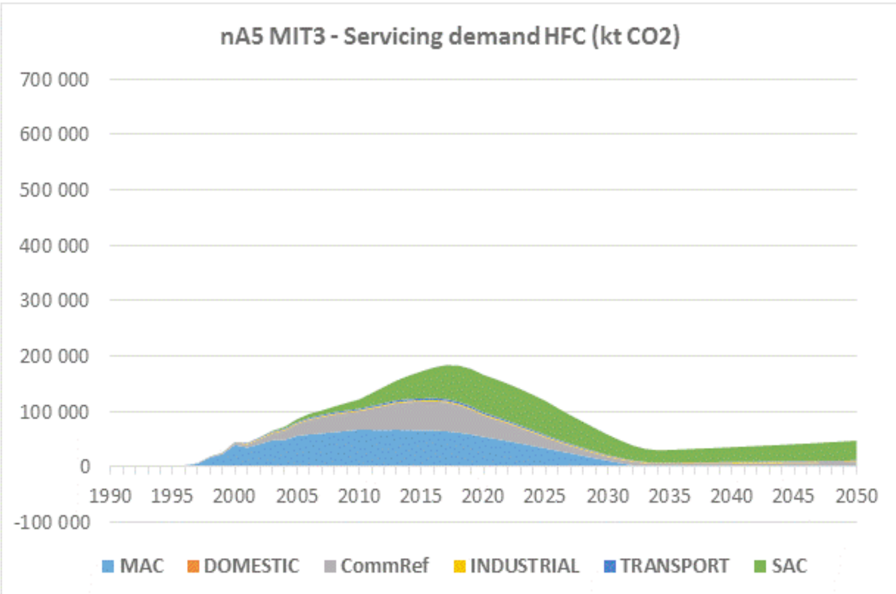


Figure 4-6: Non-Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (assuming manufacturing conversion over the period 2017-2020)

Figure 4-6 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 2032, increases again due to economic growth after 2033.

4.4.3 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, the new manufacturing and servicing demand are shown in Figs 4-7, 4-8 and 4-9.

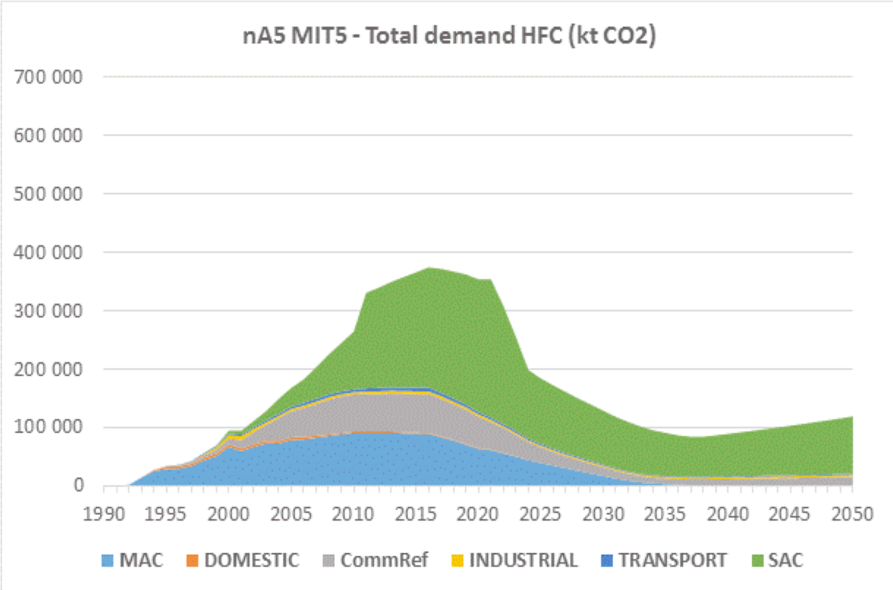


Figure 4-7: Non-Article 5 MIT-5 scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 4-4 for MIT-3)

Figure 4-7 includes both manufacturing and servicing, and is similar to Fig 4-5 for MIT-3. Figure 4-8 shows the same data for HFCs used in new manufacturing only.

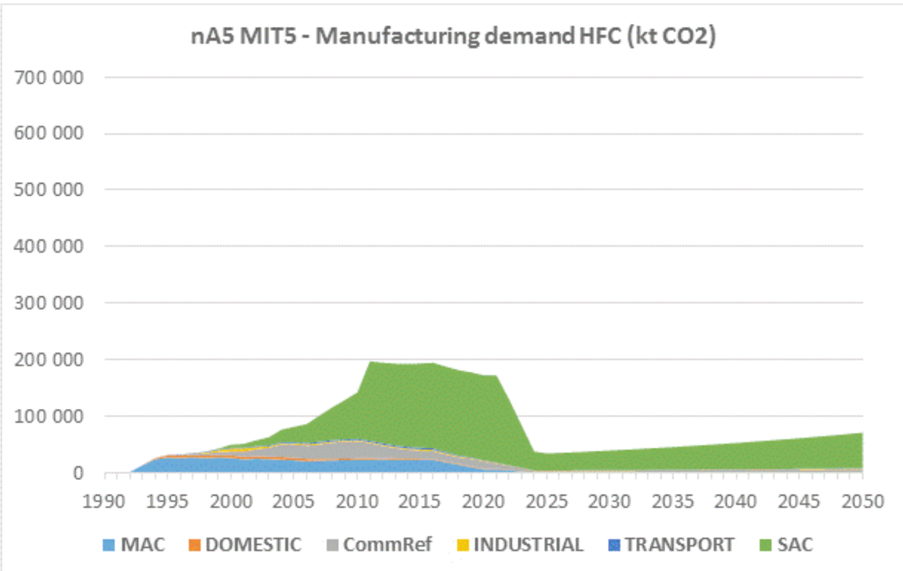


Figure 4-8: Non-Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in GWP weighted terms (compare Fig. 4-5 for MIT-3)

In 2020, demand for new manufacturing is at about 180 Mt CO_2-eq, and demand for servicing is also at about 180 Mt CO_2-eq, but after 2025, the picture becomes different. New manufacturing demand decreases to less than 30 Mt CO_2-eq, whereas this value is reached around the year 2037 in servicing. This is an issue that needs to borne in mind, i.e., that servicing will be delaying non-Article 5 reductions expressed in Mt CO_2-eq. After a minimum in the demand in new manufacture and service, demand will increase again after 2035-2037 (5 years later than in MIT-3), due to economic growth assumed.

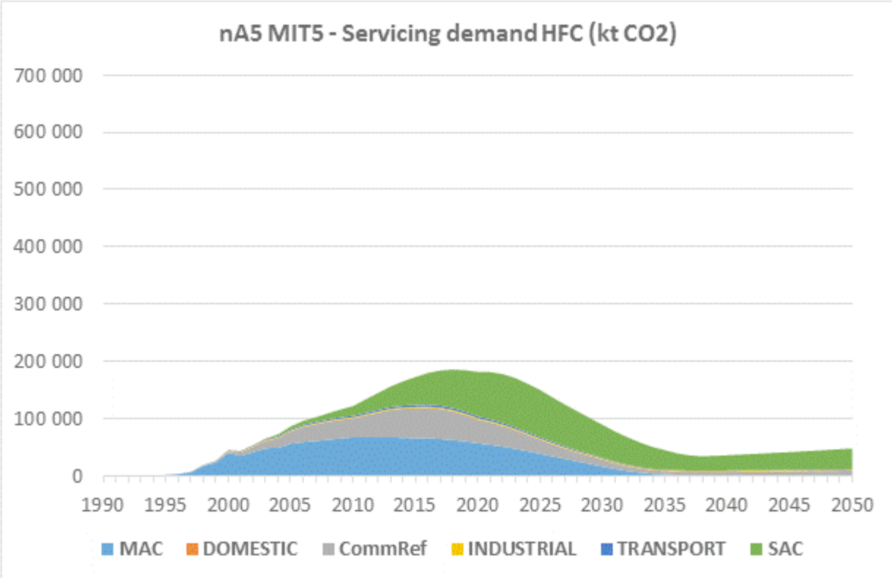


Figure 4-9: Non-Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors in GWP weighted terms (compare Fig. 4-6 for MIT-3)

4.5 Article 5 scenarios

4.5.1 BAU scenario

Figure 4-10 below shows the Article 5 refrigerant BAU demand, with a subdivision for the different high GWP refrigerants and the low-GWP ones, both in tonnes and in GWP weighted terms (in CO_2-eq.).

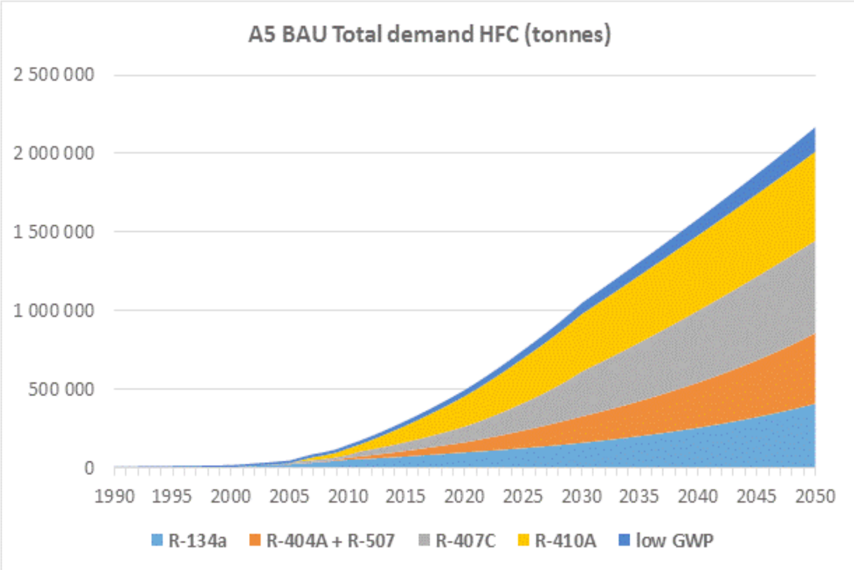
The low-GWP refrigerants applied here are again only visible in tonnes and cannot be really seen in the scale when adjusted for GWP, shown in GWP weighted terms. In the 2020-2030 period, the high-GWP refrigerant R-404A, which is used in commercial refrigeration, becomes increasingly important in GWP 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 combined demand for non-Article 5 and Article 5 Parties of 510 ktonnes is somewhat higher than the 475 ktonnes estimate for global HFC production for the R/AC sector in 2015 (about 7% higher); total HFC production also includes HFC-134a production for other sectors.

However, the above 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).

Figure 4-11 shows the Article 5 refrigerant BAU demand for the different sub-sectors. The demand is again given in tonnes and in GWP weighted terms (ktonnes CO_2-eq.). The BAU model predicts that between 2015 and 2050, overall demand increases by a factor of 7-8, to about 4.5 Gt CO_2. Stationary AC increases substantially, but the commercial refrigeration sub-sector also is important in GWP terms, due to the use of the high-GWP R-404A.



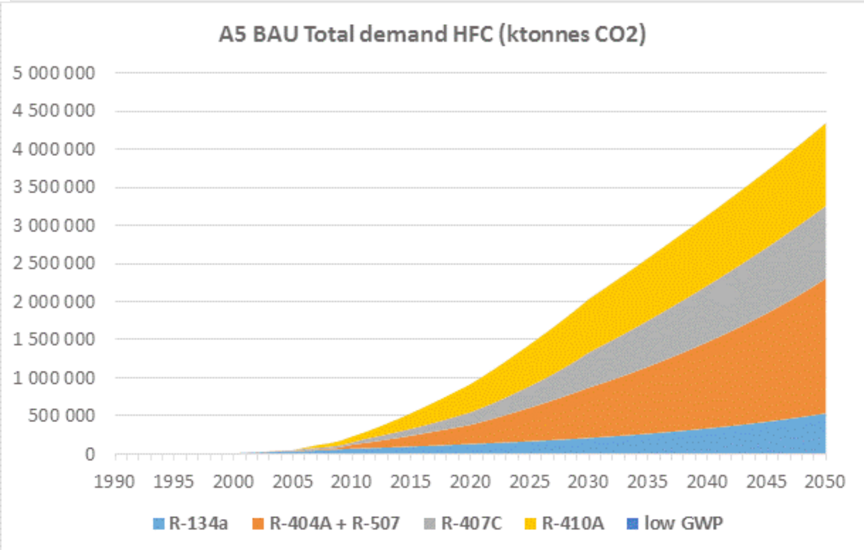
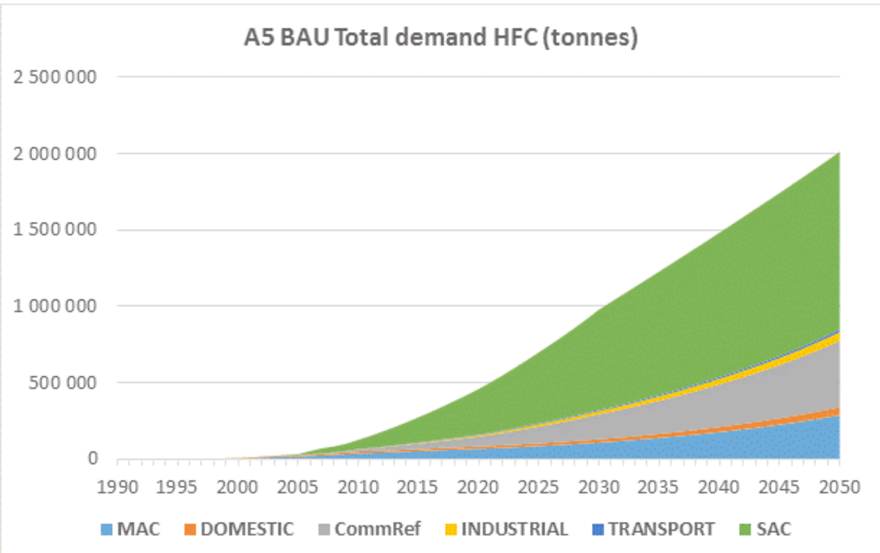


Figure 4-10: Article 5 BAU scenario with a subdivision for the various refrigerants and refrigerant blends in tonnes and ktonnes CO_2-eq.



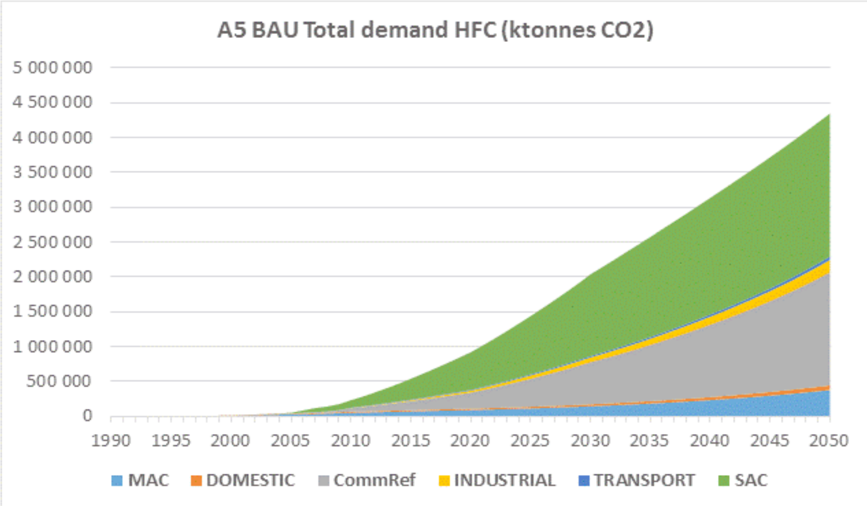


Figure 4-11: Article 5 BAU scenario with a subdivision for the various sub-sectors in tonnes and ktonnes CO_2-eq.

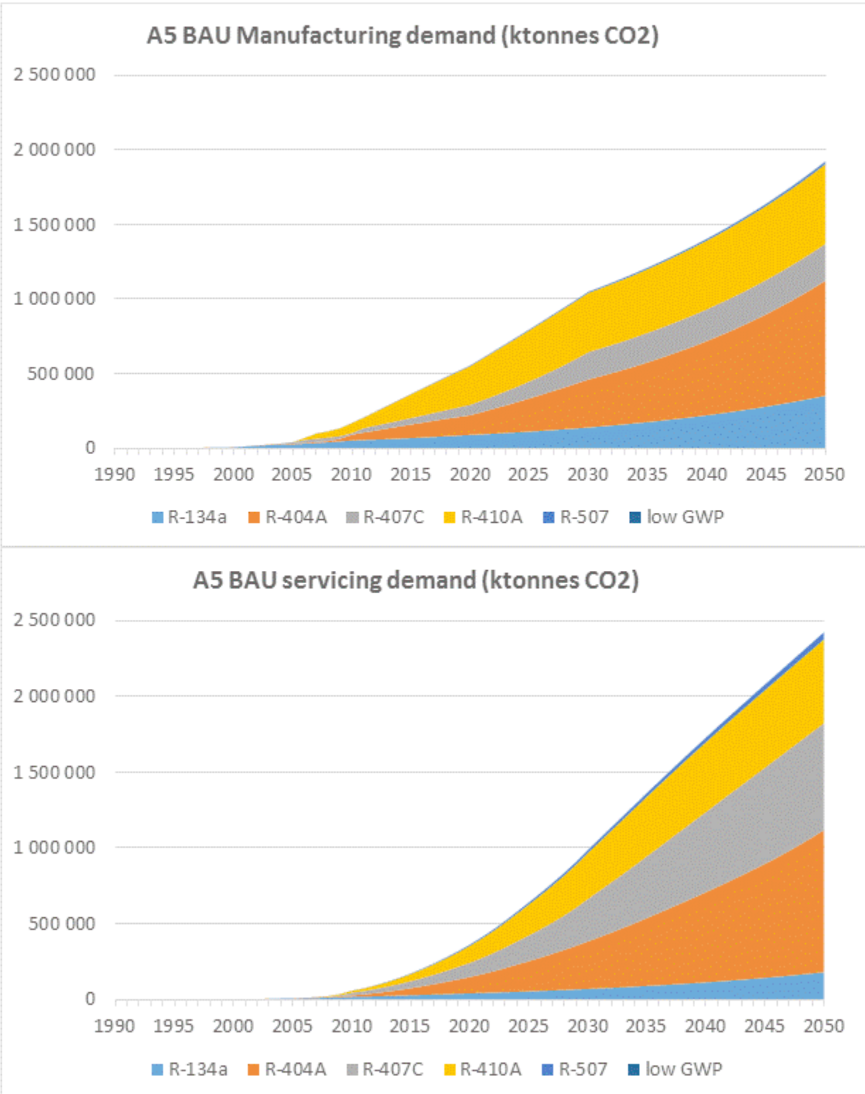


Figure 4-12: Article 5 BAU scenario with new manufacturing and servicing demand for the various refrigerants (both in ktonnes CO_2-eq.)

Figure 4-12 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 follows in the BAU scenario (in ktonnes, not in ktonnes CO_2-eq.):

- 2015: new manufacturing 195 kt, servicing 100 kt
- 2020: new manufacturing 300 kt, servicing 200 kt
- 2030: new manufacturing 530 kt, servicing 515 kt
- 2050: new manufacturing 915 kt, servicing 1080 kt

4.5.2 MIT-3 scenario

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 the refrigerant blends assumed to have an average GWP of 300. Conversion has been assumed to take six years for Article 5 Parties, and the manufacturing capacity is modelled to convert in equal portions per year during the period 2020-2025 (six years). The following graphs are for the Article 5 MIT-3 scenario, split into in the various R/AC sub-sectors.

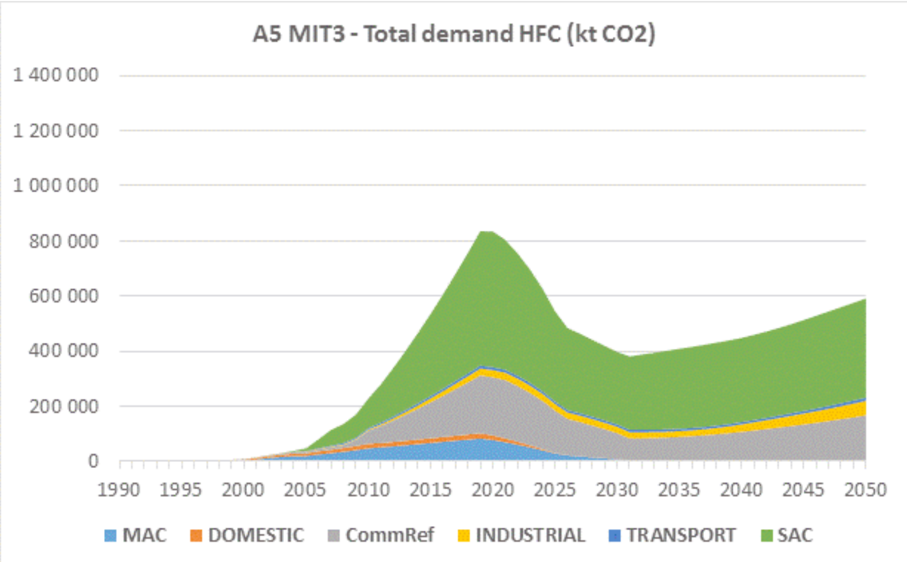


Figure 4-13: Article 5 MIT-3 scenario with the demand for the R/AC sub-sectors, including both new manufacturing and servicing

Figure 4-13 shows the steep decrease in the first six 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 after 2025-2030. 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, the relative importance of these refrigerants is now much lower in the GWP weighted graph. The demand increases again (even with a large percentage low GWP refrigerants) after 2032, due to assumed economic growth.

In Figure 4-14, 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, then starts to increase again due to economic growth.

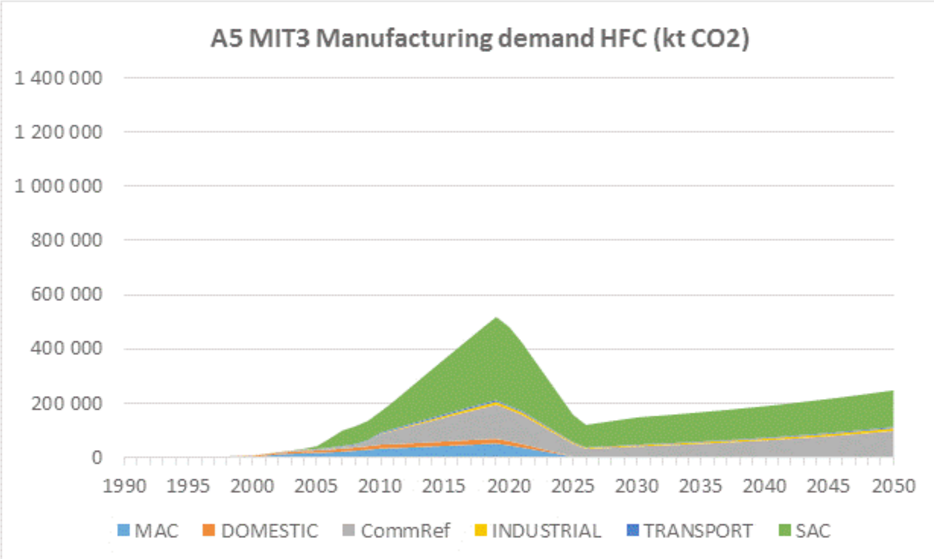


Figure 4-14: Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors in ktonnes CO_2-eq. (compare Fig. 4-5 for non-Article 5 manufacturing demand)

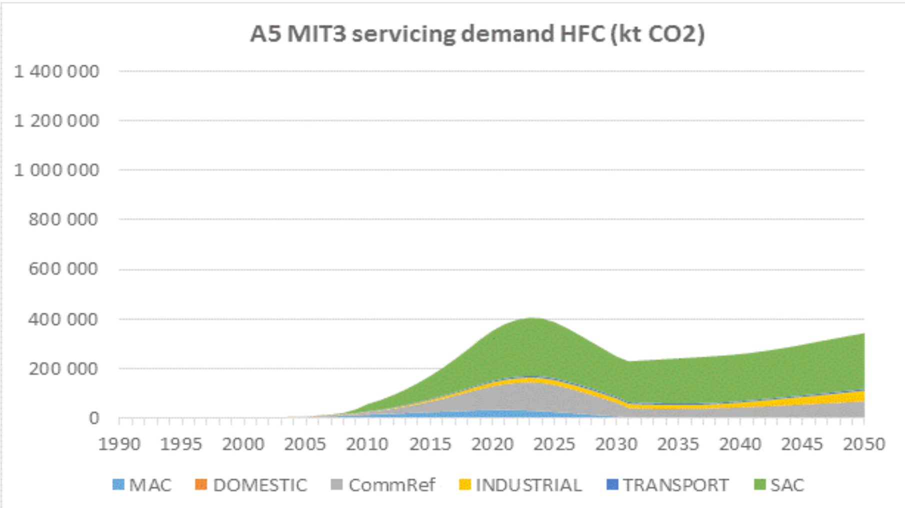


Figure 4-15: Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (compare Fig. 4-6 for non-Article 5 servicing demand)

Figure 4-15 shows the amounts of high-GWP refrigerants in ktonnes 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). Amounts (expressed in GWP weighted terms) will increase again after 2030-2032.

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

Figure 4-16 shows the demand dependent on the rate of conversion or the length of the conversion period, which is an important parameter (unchanged from what was given in (UNEP, 2015)). 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.

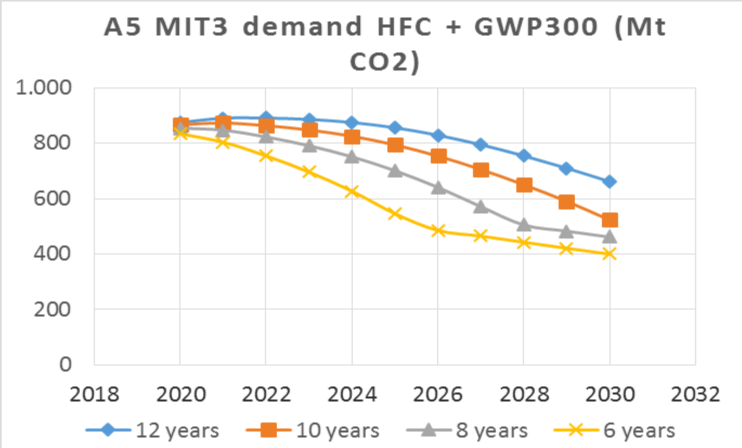


Figure 4-16: Article 5 MIT-3 demand scenario for all R/AC sectors for new manufacturing conversion periods of 6-8-10-12 years in Mt CO_2-eq. (UNEP, 2015)

A twelve year 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). Ten 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 relationship of the shape of the curves to the conversion period. There are also cost implications. A six year conversion period would imply twice the costs in the first six 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).

4.5.4 MIT-4 scenario

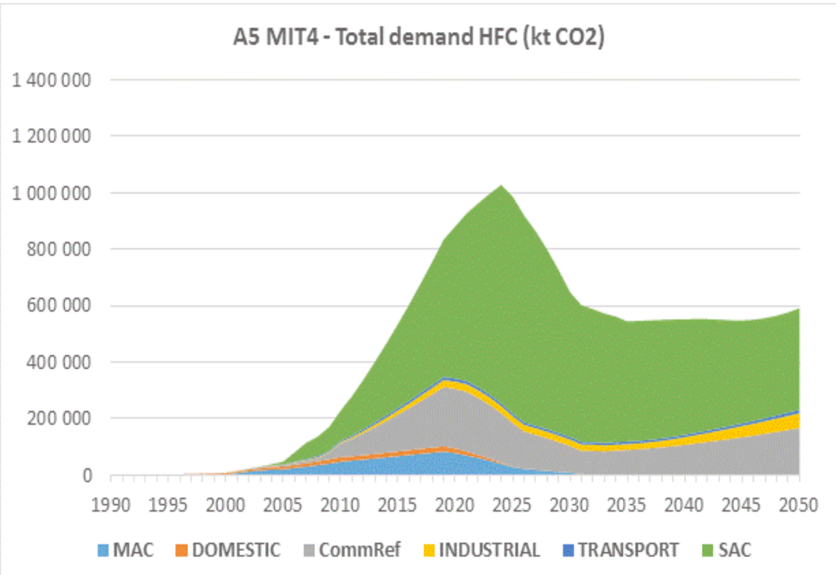


Figure 4-17: Article 5 MIT-4 total demand scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 4-13 for MIT-3)

Figure 4-17 includes both manufacturing and servicing, and is the same as Fig 4-13 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 4-18 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.

Demand in GWP weighted terms increases again after 2030-2032.

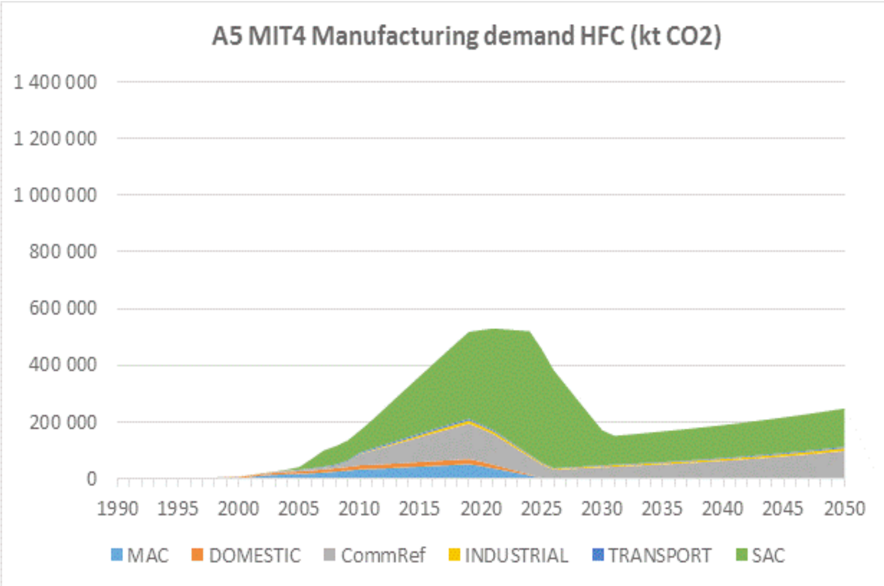


Figure 4-18: Article 5 MIT-4 scenario for new manufacturing demand for the various R/AC sub-sectors in ktonnes CO_2-eq. (compare Fig. 4-14 for MIT-3)

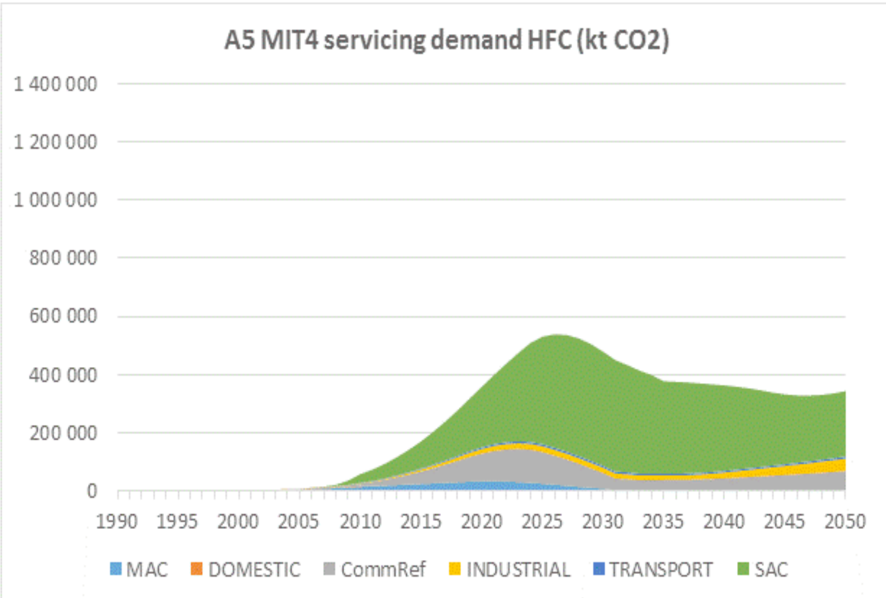


Figure 4-19: Article 5 MIT-4 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (stationary AC starting in 2025, and assuming a conversion of manufacturing over a period of six years) (compare Fig. 4-15 for MIT-3)

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.

4.5.5 Impact of manufacturing conversion periods in the MIT-4 scenario

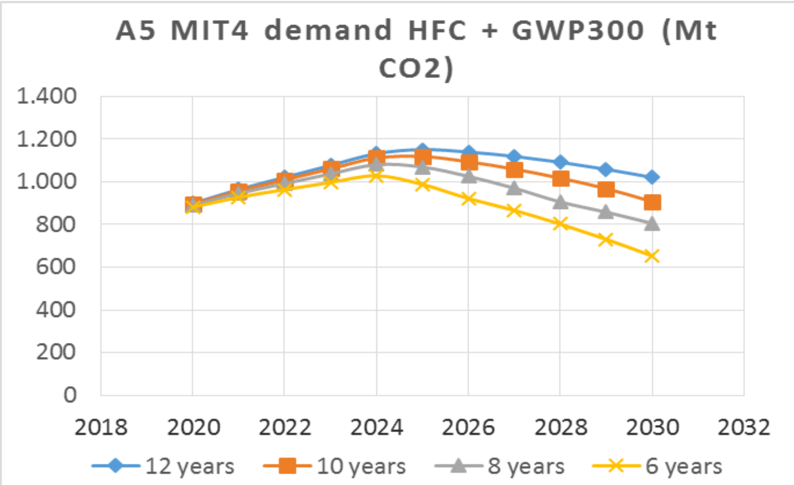


Figure 4-20: Article 5 MIT-4 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years in Mt CO_2-eq. (compare Figure 5-16 for the MIT-3 scenario) (UNEP, 2015)

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. 4-20 gives the four curves for the six, eight, ten and 12 years manufacturing conversion periods for all refrigeration and AC sub-sectors together (as in (UNEP, 2015)). The delayed manufacturing conversion for stationary AC from 2020 to 2025 makes a large difference in the high-GWP demand.

For a six year conversion period, the HFC demand for MIT-3 and MIT-4 is projected for 2030 as (compare Figs. 4-16 and 4-20):

- 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 five 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 five years for starting SAC conversion, and a six year manufacturing conversion period, means that the overall costs have to be considered over a longer period than six years (i.e., over 12 years (rather than six years)).

4.5.6 MIT-5 scenario

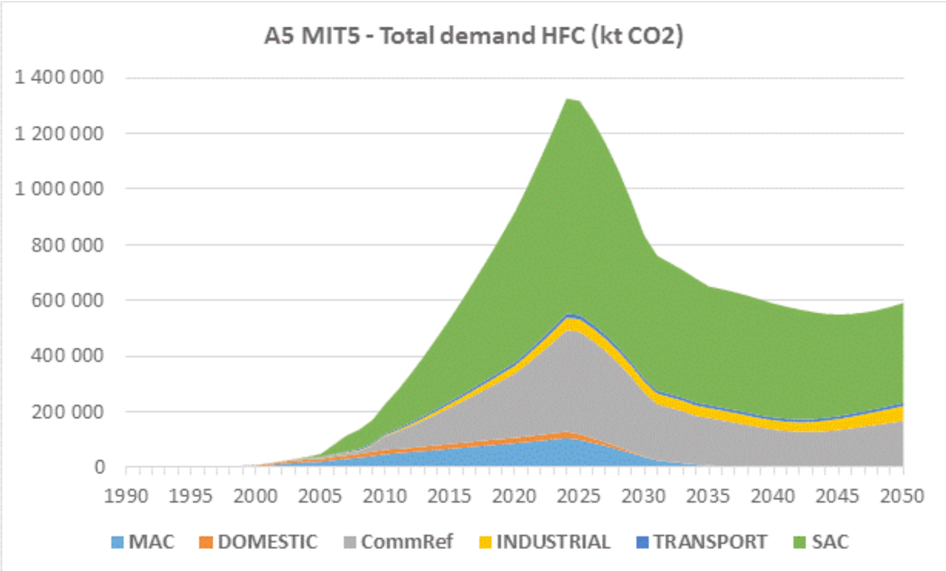


Figure 4-21: Article 5 MIT-5 scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 4-13 and 4-17 for MIT-3 and MIT-4)

Figure 4-21 includes both manufacturing and servicing, and is similar to Figs 4-13 and 4-17 for MIT-3 and MIT-4 (replacement refrigerant blends at a GWP of 300; six year manufacturing conversion).

Figure 4-22 also shows the same data just for HFCs used in new manufacturing. All sub-sectors decline to zero new manufacturing demand at the same time (as in MIT-3).

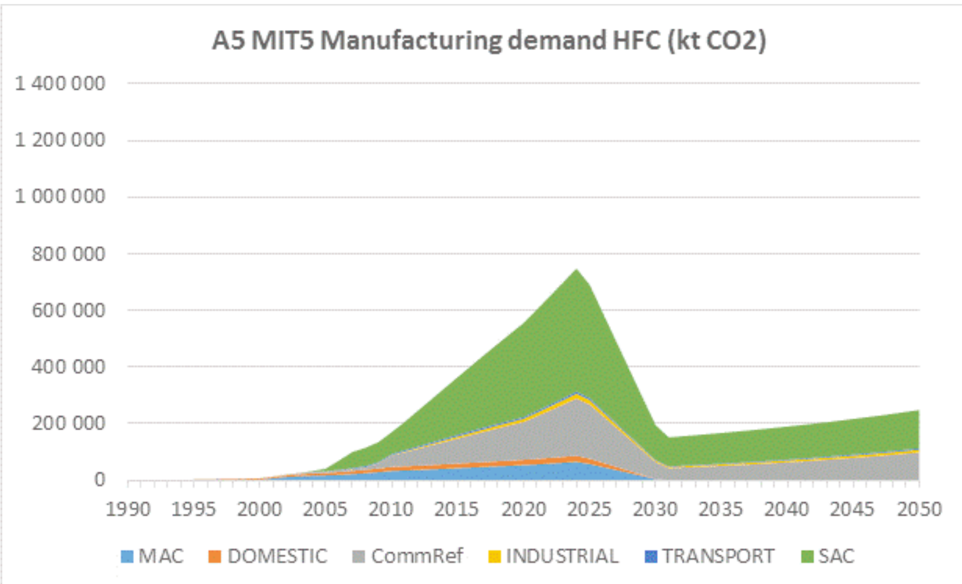


Figure 4-22: Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in ktonnes CO_2-eq. (manufacturing conversion over a period of six years) (compare Figure 4-14 and 4-19 for MIT-3 and MIT-4)

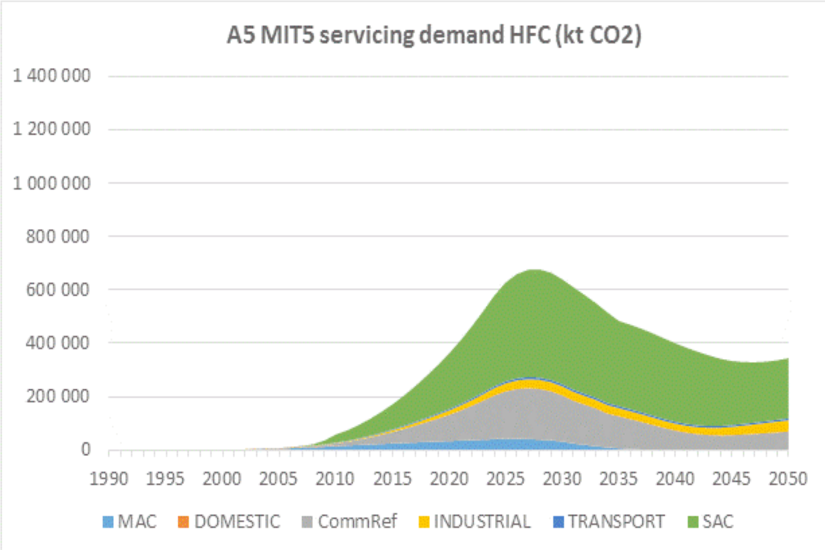


Figure 4-23: Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (assuming a conversion of manufacturing over a period of six years) (compare Figure 4-15 and 4-19 for MIT-3 and MIT-4)

In 2025, demand for new manufacturing peaks at about 760 Mt CO_2-eq, and demand for servicing is about 650 Mt CO_2-eq. After 2030, the manufacturing demand has gone down to a little more than 100 Mt CO_2-eq., then increases again due to assumed economic growth to more than 200 Mt CO_2-eq.

Servicing demand peaks at about 660 Mt CO_2-eq., due to the late conversions of all sub-sectors, then decreases until around 2045 to about 330 Mt CO_2-eq., after which year it starts to increase again (economic growth assumed).

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

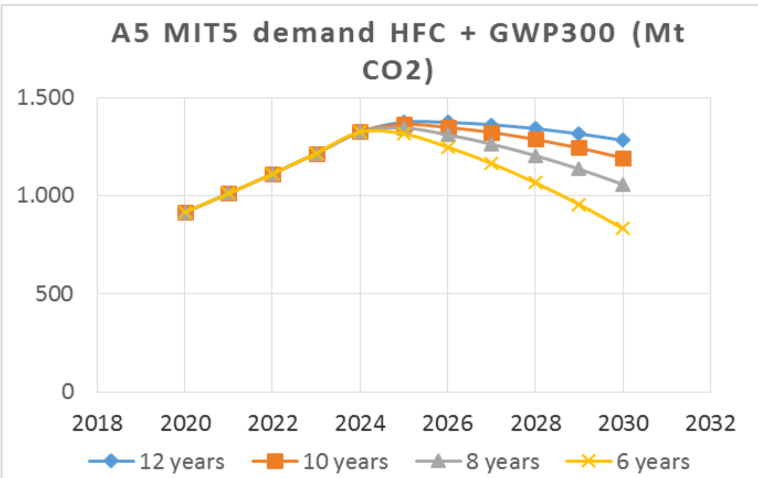


Figure 4-24: Article 5 MIT-5 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years (compare Figures 4-16 and 4-21 for the MIT-3 and MIT-4 scenarios) (UNEP, 2015)

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

Fig. 4-24 gives the 4 curves for the six, eight, ten and 12 years manufacturing conversion periods for all refrigeration and AC sub-sectors together (again unchanged from what was given in (UNEP, 2015)). The delayed manufacturing conversion for all sub-sectors as of 2025 makes a large difference. While demand for a six 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 six 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 five 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 will therefore be larger than for MIT-3 and MIT-4. In the case of a six year manufacturing conversion period, overall costs will have to be covered over six years (expansion to 12 years does not seem desirable given the climate impact numbers).

4.6 Refrigerant demand and mitigation benefit numbers

On the basis of the development of the demand for the various refrigerants and their 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 extend to 2050 the non-Article 5 and Article 5 demand in tonnes and Mt-CO_2 eq. for BAU, MIT-3 and MIT-5 scenarios.

Table 4-3: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2050 in non-Article 5 Parties (tonnes)

		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**
		2030	**2035**	**2040**	**2045**	**2050**
nA5 BAU	HFC-134a	82,356	93,316	108,107	125,265	145,166
	R-404A + R-507	22,780	26,151	30,221	34,960	40,470
	R-407C	50,402	58,256	67,534	78,291	90,760
	R-410A	131,319	151,966	176,170	204,229	236,758
	Low GWP	17,694	21,170	25,071	29,334	34,188
	Total	**307,395**	**350,859**	**407,103**	**472,079**	**547,342**

Table 4-4: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2050 in non-Article 5 Parties (ktonnes CO_2-eq.)

		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**
nA5 BAU	HFC-134a	107,064	121,311	140,539	162,845	188,716
	R-404A + R-507	89,875	103,180	119,238	137,936	159,679
	R-407C	81,652	94,374	109,405	126,831	147,032
	R-410A	252,133	291,774	338,246	392,120	454,575
	Low GWP	27	32	38	44	51
	Total	**530,751**	**610,671**	**707,466**	**819,776**	**950,053**

Table 4-5: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2050 in non-Article 5 Parties (tonnes)

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**
		2030	**2035**	**2040**	**2045**	**2050**
nA5 3-year conversion 2020	HFC-134a	14,013	3,941	4,497	5,153	5,923
	R-404A + R-507	2,046	155	121	94	73
	R-407C	2,716	0	0	0	0
	R-410A	4,127	0	0	0	0
	Low GWP	252,410	353,069	409,796	475,307	551,172
	Total	**268,453**	**357,165**	**414,414**	**480,554**	**557,168**

Table 4-6: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2050 in non-Article 5 Parties (ktonnes CO_2-eq.)

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**
MIT-3		**2030**	**2035**	**2040**	**2045**	**2050**
nA5 3-year conversion 2020	HFC-134a	9,301	5,124	5,846	6,699	7,700
	R-404A + R-507	8,072	611	475	370	288
	R-407C	4,401	0	0	0	0
	R-410A	7,923	0	0	0	0
	Low GWP	58,396	72,898	84,498	97,948	113,542
	Total	**88,093**	**78,633**	**90,819**	**105,017**	**121,530**

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, thereafter the decrease will be much slower (values are already very low);
- The demand for the stationary AC sub-sector decreases enormously between 2025 and 2030, because virtually all requirements for high-GWP refrigerants disappear. The amount of low-GWP refrigerants in climate terms now becomes very relevant (due to the remaining GWP of 300 assumed for low-GWP refrigerant blends).

A number of tables containing the demand data in tonnes and ktonnes CO_2-eq. extended to 2050 for the BAU, MIT-3 and MIT-5 scenarios in Article 5 Parties are given below.

Table 4-7: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2050 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**
		2030	**2035**	**2040**	**2045**	**2050**
A5 BAU	R134a	161,107	204,027	257,413	324,537	409,494
	R404A + R507	167,690	223,579	287,745	361,077	449,614
	R407C	285,500	372,998	457,406	532,391	587,361
	R410A	364,845	427,266	479,588	524,488	566,180
	Low GWP	69,915	85,957	104,807	127,577	155,209
	Total	**1,049,057**	**1,313,827**	**1,586,959**	**1,870,070**	**2,167,858**

Table 4-8: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU scenario) for the period 2010-2050 in Article 5 Parties (ktonnes CO_2-eq.)

		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**
		2030	**2035**	**2040**	**2045**	**2050**
A5 BAU	HFC-134a	209,440	265,234	334,637	421,897	532,343
	R-404A + R-507	661,025	881,313	1,134,195	1,423,289	1,772,283
	R-407C	462,511	604,256	740,997	862,474	951,525
	R-410A	700,502	820,350	920,809	1,007,017	1,087,066
	Low GWP	478	601	752	940	1,171
	Total	**2,033,956**	**2,571,754**	**3,131,390**	**3,715,617**	**4,344,388**

- 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 and by a factor of 7-8 during 2015-2050;
- 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 4-9: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2050 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**
MIT-3		**2030**	**2035**	**2040**	**2045**	**2050**
A5 6-year conversio n 2020	HFC-134a	39,331	39,386	47,809	57,936	70,499
	R-404A + R-507	12,751	2,970	1,576	3,306	5,077
	R-407C	20,684	13,059	4,411	0	0
	R-410A	18,972	13,467	4,267	0	0
	Low GWP	991,332	1,244,943	1,528,895	1,808,828	2,092,281
	Total	**1,083,070**	**1,313,825**	**1,586,958**	**1,870,070**	**2,167,857**

Table 4-10: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-3 scenario) for the period 2010-2050 in Article 5 Parties (ktonnes CO_2-eq.)

		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**	**534,858**	**834,313**	**546,467**	**400,658**
		2030	**2035**	**2040**	**2045**	**2050**
A5 6-year conversion 2020	HFC-134a	49,670	51,201	62,151	75,316	91,649
	R-404A + R-507	50,899	11,716	6,210	13,024	20,005
	R-407C	33,508	21,156	7,146	0	0
	R-410A	36,425	25,856	8,192	0	0
	Low GWP	230,156	299,573	365,941	426,394	481,920
	Total	**400,658**	**409,502**	**449,640**	**514,734**	**593,574**

The following can be observed for the Article 5 Parties, in the case of the 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, it decreases again to the 2015 level in the year 2025;
- The most surprising result is that the demand in climate terms is reduced by only 20-25% in the year 2030, compared to 2015 (of course, it is much higher in the year 2020). 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.

Table 4-11: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-5 scenario) for the period 2010-2050 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**
MIT-5		**2030**	**2035**	**2040**	**2045**	**2050**
A5 6-year conversion 2025	HFC-134a	60,851	44,532	48,104	58,047	70,499
	R-404A + R-507	54,014	29,994	11,445	3,515	5,077
	R-407C	108,166	30,160	21,180	7,194	0
	R-410A	104,162	83,830	55,193	16,085	0
	Low GWP	714,856	1,125,310	1,451,035	1,785,231	2,092,281
	Total	**1,042,049**	**1,313,826**	**1,586,957**	**1,870,072**	**2,167,857**

Table 4-12: Current and future refrigerant demand for (refrigerant) ODS alternatives (MIT-5 scenario) for the period 2010-2050 in Article 5 Parties (ktonnes CO_2-eq.)

		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	163,791	260,727	175,229
	R-410A	78,761	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**
		2030	**2035**	**2040**	**2045**	**2050**
A5 6-year conversion 2025	HFC-134a	79,106	57,892	62,535	75,460	91,649
	R-404A + R-507	214,824	118,243	45,115	13,846	20,005
	R-407C	175,229	48,859	34,312	11,654	0
	R-410A	199,992	160,953	105,970	30,882	0
	Low GWP	166,332	265,216	342,666	419,344	481,920
	Total	**835,483**	**651,163**	**590,598**	**551,186**	**593,574**

In Tables 4-11 and 4-12 above, the following can be observed for the Article 5 Parties and the MIT-5 scenario:

- The MIT-5 scenario represents a much higher climate impact than the MIT-3 scenario. For the future, the question remains which scenario could or would be the most likely one that Article 5 Parties can and will follow;

- The demand for various high-GWP HFCs in Article 5 Parties is calculated to increase by a factor of 1.7 between 2015 and 2020 and by a factor 1.45 between 2020 and 2025, expressed in ktonnes $CO_{2\text{-eq.}}$. (this corresponds more or less to the same growth in refrigerant demand in tonnes);
- One might conclude that the proposed MIT-5 manufacturing conversion is not expected to be too 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 definitely possible taking into account the pace of acceptance for many alternatives anticipated at present.

Table 4-13: Refrigerant demand for (refrigerant) ODS alternatives in the BAU, MIT-3, MIT-4 and MIT-5 scenarios for various periods in Article 5 Parties (n.b., in Mt CO_2-eq.); the total concerns the total refrigerant demand over the period 2020-2050

Period	2020-2030	2031-2040	2041-2050	Total
A5 BAU	16016	26321	37874	80211
A5 MIT-3	6349	4202	5257	15808
A5 MIT-4	9762	5798	5540	21100
A5 MIT-5	12069	6696	5719	24484

Table 4-14: Refrigerant demand for (refrigerant) ODS alternatives in the BAU, MIT-3, MIT-4 and MIT-5 scenarios for the periods 2020-2030, 2020-2040 and 2020-2050 in Article 5 Parties (n.b., in Mt CO_2-eq.); in brackets the saving for the various MIT scenarios compared to BAU in that period is given

Period	2020-2030	2020-2040	2020-2050
A5 BAU	16016	42337	80211
A5 MIT-3	6349 (0,604)	10551 (0,751)	15808 (0,803)
A5 MIT-4	9762 (0,390)	15560 (0,632)	21100 (0,737)
A5 MIT-5	12069 (0,246)	18765 (0,557)	24484 (0,695)

(As already presented in the XXVI/9 report (UNEP, 2015)) Table 4-13 (and 4-14) 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: *6,400 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 the case of the MIT-4 scenario, with a reduction of about 6200 Mt CO_2-eq. compared to BAU, there is a saving of almost 40% from BAU. The MIT-5 reduction of 4,000 Mt CO_2-eq. represents a smaller saving of 25% from BAU for this 2020-2030 period.

Values change calculated for the three scenarios in Mt CO_2-eq. through 2050:

BAU: *80,200 Mt CO_2-eq.*
MIT-3: *15,800 Mt CO_2-eq.*
MIT-4: *21,000 Mt CO_2-eq.*
MIT-5: *24,500 Mt CO_2-eq.*

The MIT-3 reduction from BAU represents a saving of 80%. In the case of the MIT-4 scenario there is a saving of about 75% while the MIT-5 reduction of 56,000 Mt CO_2-eq. compared to BAU represents a savings of 70% from BAU. There are still differences between the various MIT scenarios. However, the BAU demand for the entire period 2020-2050 becomes so large that the differences in reduction between the various mitigation scenarios MIT-3, -4 and -5 become less relevant.

A more reasonable estimate of the savings that can be realised via the various MIT scenarios may be the consideration of the period 2020-2040;

BAU:	*42,300 Mt CO_2-eq.*	
MIT-3:	*10,600 Mt CO_2-eq.*	*75% saving compared to BAU*
MIT-4:	*15,600 Mt CO_2-eq.*	*63% saving compared to BAU*
MIT-5:	*18,800 Mt CO_2-eq.*	*56% saving compared to BAU.*

Another way to look at this is to analyse the trends in demand that are observed, as follows:

- Peak values determined for the refrigerant demand increase with a later start of conversion. The peak value for MIT-3 in *2020* is about 820 Mt CO_2-eq. The peak value for MIT-4 in the year *2023*, with conversion of stationary AC starting in 2025, is 25% higher (at 1025 Mt CO_2-eq.), whereas the peak value for demand for MIT-5 in the year *2025* is 62% higher than the one for MIT-3 (at 1330 Mt CO_2-eq.).
- For MIT-3, the average decline over a period of ten years after the peak year is 5.3% per year (from 820 down to 390 Mt CO_2-eq. in 2030), for MIT-4 it is 4.5% per year (from 1025 down to 570 Mt CO_2-eq. in 2033) and for MIT-5 it is 5.5% per year (from 1330 down to 605 Mt CO_2-eq.). If the freeze year (which coincides with the peak year) is chosen as the starting point, an average annual reduction of 5% in total demand (manufacturing and servicing) seems feasible for all types of scenarios. These values all apply to a manufacturing conversion period of six years.
- For each separate Article 5 country the peak (freeze) values will still be in the same years for the various MIT scenarios considered, however, annual reduction percentages achievable thereafter may be significantly different per country.

4.7 References

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5 List of acronyms and abbreviations

AHRI	Air Conditioning, Heating and Refrigeration Institute
AREP	Alternative Refrigerants Evaluation Program
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
CEN	European Committee for Standardisation
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
COP	Coefficient of Performance
EPA	US Environmental Protection Agency
EU	European Union
GWP	Global Warming Potential
HC	Hydrocarbon
HCC	Hydrochlorocarbon
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HCO	Oxygenated hydrocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HTOC	Halons Technical Options Committee
IIR	International Institute for Refrigeration
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
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEL	Occupational Exposure Limit
R/AC	Refrigeration and Air Conditioning (also RAC&HP)
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 - Updated Tables for total, new manufacturing, and servicing demand

Below updated tables until 2050 (compared to 2030 in the XXVI/9 TF report) are given for the total demand, new manufacturing and servicing demand (data used for the scenario graphs in chapter 4):

- for non-Article 5 and Article 5 Parties
- for the major 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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 2010-2050 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	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	1876	1451	957	954	862	999	1158	1342	1556
		HC-600a	362	415	545	786	1156	1340	1553	1801	2087
	Commercial	HFC-134a	2256	2373	2400	2395	2104	2013	2334	2705	3136
		R-404A + R-507	15305	16093	11907	7478	5667	5457	6326	7334	8502
		Low GWP	0	0	4373	9213	13988	18396	21326	24723	28661
	Industrial	HFC-134a	1041	1113	1148	1188	1233	1343	1484	1661	1875
		R-404A + R-507	603	743	491	378	218	193	213	203	178
		R-22	1323	675	455	306	206	139	0	0	0
		Low GWP	6649	8898	11269	13764	16735	19994	23621	27625	32207
	Transport	HFC-134a	222	213	302	371	483	585	679	787	912
		R-404A + R-507	1176	1540	917	833	705	626	588	543	491
		Low GWP	0	0	557	756	1014	1314	1662	2065	2532
	SAC	HFC-134a	4032	4468	1422	994	226	0	0	0	0
		R-410A	39385	77354	94230	114001	131319	151966	176170	204229	236758
		R-407C	11195	26802	26172	30349	31368	32918	34890	37176	39826
		Low GWP	0	0	8770	13597	19034	25337	32644	41115	50935
	MAC	HFC-134a	69670	68359	48425	38118	27509	24564	28477	33013	38271
		Low GWP	0	0	18218	32849	49939	63812	73975	85758	99417
nA5 MIT-3	Domestic	HFC-134a	1876	1451	2	1	1	0	0	0	0
		HC-600a	362	415	1500	1739	2017	2338	2710	3142	3642
	Commercial	HFC-134a	2256	2373	2400	2395	2104	2013	2334	2705	3136
		R-404A + R-507	15305	16093	10320	4207	759	0	0	0	0
		Low GWP	0	0	5962	12483	18896	23854	27653	32057	37163
	Industrial	HFC-134a	1041	1113	1148	1188	1233	1343	1484	1661	1875
		R-404A + R-507	603	743	322	219	121	88	100	76	36
		Low GWP	6649	8898	11438	13923	16831	20099	23736	27752	32348
	Transport	HFC-134a	222	213	302	371	483	585	679	787	912
		R-404A + R-507	1176	1540	730	484	162	0	0	0	0
		Low GWP	0	0	744	1105	1558	1940	2249	2608	3023
	SAC	HFC-134a	4032	4468	1422	994	226	0	0	0	0
		R-410A	39385	77354	22337	15831	4127	0	0	0	0
		R-407C	11195	26802	13904	11080	4215	0	0	0	0
		Low GWP	0	0	92513	129552	170632	210221	243704	282520	327518
	MAC	HFC-134a	69670	68359	41871	25932	8755	0	0	0	0
		Low GWP	0	0	24772	45035	68704	88376	102452	118770	137687
nA5 MIT-5	Domestic	HFC-134a	1876	1451	957	1	1	1	1	0	0
		HC-600a	362	415	545	1739	2016	2338	2710	3142	3642
	Commercial	HFC-134a	2256	2373	2400	2395	2104	2013	2334	2705	3136
		R-404A + R-507	15305	16093	11907	4983	1535	57	0	0	0
		Low GWP	0	0	4690	12483	18896	23854	27653	32057	37163
	Industrial	HFC-134a	1041	1113	1148	1188	1233	1343	1484	1661	1875
		R-404A + R-507	603	743	491	277	159	126	162	156	123
		Low GWP	6649	8898	11269	13885	16793	20061	23674	27672	32262
	Transport	HFC-134a	222	213	302	371	483	585	679	787	912
		R-404A + R-507	1176	1540	872	531	209	23	0	0	0
		Low GWP	0	0	602	1058	1511	1917	2249	2608	3023
	SAC	HFC-134a	4032	4468	1422	994	226	0	0	0	0
		R-410A	39385	77354	94230	26474	14768	1761	0	0	0
		R-407C	11195	26802	26172	14906	8041	2012	0	0	0
		Low GWP	0	0	8770	115904	156984	203045	243704	282520	327518
	MAC	HFC-134a	69670	68359	48425	29702	12514	1943	0	0	0
		Low GWP	0	0	18218	41265	64934	86433	102452	118770	137687

Table A6-2: Demand in tonnes for new manufacturing only for non-Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	1872	1449	955	953	861	998	1157	1341	1554
		HC-600a	362	415	545	786	1155	1339	1553	1800	2087
	Commercial	HFC-134a	2027	1786	665	771	894	1036	1201	1393	1614
		R-404A + R-507	7006	3028	2262	1787	2072	2402	2784	3228	3742
		Low GWP	0	0	3248	4600	5332	6182	7166	8308	9631
	Industrial	HFC-134a	327	397	418	439	461	535	620	719	833
		R-404A + R-507	345	420	153	97	16	19	22	26	30
		R-22	320	0	0	0	0	0	0	0	0
		Low GWP	2412	3884	5013	5938	7027	8146	9444	10948	12692
	Transport	HFC-134a	45	57	142	164	191	221	256	297	344
		R-404A + R-507	578	738	89	131	152	176	204	236	274
		Low GWP	0	0	482	531	616	714	827	959	1112
	SAC	HFC-134a	3387	3118	0	0	0	0	0	0	0
		R-410A	34160	61755	68084	78927	91499	106072	122966	142552	165257
		R-407C	7513	16313	10791	12350	14317	16597	19241	22306	25858
		Low GWP	0	0	7209	8516	9873	11445	13268	15382	17831
	MAC	HFC-134a	17728	17622	4573	5430	6295	7297	8460	9807	11369
		Low GWP	0	0	12279	14105	16352	18956	21976	25476	29533
nA5 MIT-3	Domestic	HFC-134a	1872	1449	0	0	0	0	0	0	0
		HC-600a	362	415	1500	1739	2016	2337	2709	3141	3641
	Commercial	HFC-134a	2027	1786	665	771	894	1036	1201	1393	1614
		R-404A + R-507	7006	3028	990	0	0	0	0	0	0
		Low GWP	0	0	4520	6387	7404	8584	9951	11536	13373
	Industrial	HFC-134a	327	397	418	439	461	535	620	719	833
		R-404A + R-507	345	420	4	0	0	0	0	0	0
		Low GWP	2412	3884	5162	6035	7044	8165	9466	10974	12721
	Transport	HFC-134a	45	57	142	164	191	221	256	297	344
		R-404A + R-507	578	738	0	0	0	0	0	0	0
		Low GWP	0	0	601	662	767	890	1031	1195	1386
	SAC	HFC-134a	3387	3118	0	0	0	0	0	0	0
		R-410A	34160	61755	1268	0	0	0	0	0	0
		R-407C	7513	16313	335	0	0	0	0	0	0
		Low GWP	0	0	84480	99794	115688	134115	155476	180239	208946
	MAC	HFC-134a	17728	17622	0	0	0	0	0	0	0
		Low GWP	0	0	17005	19535	22647	26254	30435	35283	40902
nA5 MIT-5	Domestic	HFC-134a	1872	1449	955	0	0	0	0	0	0
		HC-600a	362	415	545	1739	2016	2337	2709	3141	3641
	Commercial	HFC-134a	2027	1786	665	771	894	1036	1201	1393	1614
		R-404A + R-507	7006	3028	2262	0	0	0	0	0	0
		Low GWP	0	0	3248	6387	7404	8584	9951	11536	13373
	Industrial	HFC-134a	327	397	418	439	461	535	620	719	833
		R-404A + R-507	345	420	153	0	0	0	0	0	0
		Low GWP	2412	3884	5013	6035	7044	8165	9466	10974	12721
	Transport	HFC-134a	45	57	142	164	191	221	256	297	344
		R-404A + R-507	578	738	89	0	0	0	0	0	0
		Low GWP	0	0	482	662	767	890	1031	1195	1386
	SAC	HFC-134a	3387	3118	0	0	0	0	0	0	0
		R-410A	34160	61755	68084	0	0	0	0	0	0
		R-407C	7513	16313	10791	0	0	0	0	0	0
		Low GWP	0	0	7209	99794	115688	134115	155476	180239	208946
	MAC	HFC-134a	17728	17622	4573	0	0	0	0	0	0
		Low GWP	0	0	12279	19535	22647	26254	30435	35283	40902

Table A6-3: Demand in tonnes for servicing only for non-Article 5 Parties for the period 2010-2050 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (servicing)

			2010	2015	2020	2025	2030	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	4	2	2	1	1	1	1	1	2
		HC-600a	0	0	0	0	1	1	0	1	0
	Commercial	HFC-134a	229	587	1735	1624	1210	977	1133	1312	1522
		R-404A + R-507	8299	13065	9645	5691	3595	3055	3542	4106	4760
		Low GWP	0	0	1125	4613	8656	12214	14160	16415	19030
	Industrial	HFC-134a	714	716	730	749	772	808	864	942	1042
		R-404A + R-507	258	323	338	281	202	174	191	177	148
		R-22	1003	675	455	306	206	139	0	0	0
		Low GWP	4237	5014	6256	7826	9708	11848	14177	16677	19515
	Transport	HFC-134a	177	156	160	207	292	364	423	490	568
		R-404A + R-507	598	802	828	702	553	450	384	307	217
		Low GWP	0	0	75	225	398	600	835	1106	1420
	SAC	HFC-134a	645	1350	1422	994	226	0	0	0	0
		R-410A	5225	15599	26146	35074	39820	45894	53204	61677	71501
		R-407C	3682	10489	15381	17999	17051	16321	15649	14870	13968
		Low GWP	0	0	1561	5081	9161	13892	19376	25733	33104
	MAC	HFC-134a	51942	50737	43852	32688	21214	17267	20017	23206	26902
		Low GWP	0	0	5939	18744	33587	44856	51999	60282	69884
nA5 MIT-3	Domestic	HFC-134a	4	2	2	1	1	0	0	0	0
		HC-600a	0	0	0	0	1	1	1	1	1
	Commercial	HFC-134a	229	587	1735	1624	1210	977	1133	1312	1522
		R-404A + R-507	8299	13065	9330	4207	759	0	0	0	0
		Low GWP	0	0	1442	6096	11492	15270	17702	20521	23790
	Industrial	HFC-134a	714	716	730	749	772	808	864	942	1042
		R-404A + R-507	258	323	318	219	121	88	100	76	36
		Low GWP	4237	5014	6276	7888	9787	11934	14270	16778	19627
	Transport	HFC-134a	177	156	160	207	292	364	423	490	568
		R-404A + R-507	598	802	730	484	162	0	0	0	0
		Low GWP	0	0	143	443	791	1050	1218	1413	1637
	SAC	HFC-134a	645	1350	1422	994	226	0	0	0	0
		R-410A	5225	15599	21069	15831	4127	0	0	0	0
		R-407C	3682	10489	13569	11080	4215	0	0	0	0
		Low GWP	0	0	8033	29758	54944	76106	88228	102281	118572
	MAC	HFC-134a	51942	50737	41871	25932	8755	0	0	0	0
		Low GWP	0	0	7767	25500	46057	62122	72017	83487	96785
nA5 MIT-5	Domestic	HFC-134a	4	2	2	1	1	1	1	0	0
		HC-600a	0	0	0	0	0	1	1	1	1
	Commercial	HFC-134a	229	587	1735	1624	1210	977	1133	1312	1522
		R-404A + R-507	8299	13065	9645	4983	1535	57	0	0	0
		Low GWP	0	0	1442	6096	11492	15270	17702	20521	23790
	Industrial	HFC-134a	714	716	730	749	772	808	864	942	1042
		R-404A + R-507	258	323	338	277	159	126	162	156	123
		Low GWP	4237	5014	6256	7850	9749	11896	14208	16698	19541
	Transport	HFC-134a	177	156	160	207	292	364	423	490	568
		R-404A + R-507	598	802	783	531	209	23	0	0	0
		Low GWP	0	0	120	396	744	1027	1218	1413	1637
	SAC	HFC-134a	645	1350	1422	994	226	0	0	0	0
		R-410A	5225	15599	26146	26474	14768	1761	0	0	0
		R-407C	3682	10489	15381	14906	8041	2012	0	0	0
		Low GWP	0	0	1561	16110	41296	68930	88228	102281	118572
	MAC	HFC-134a	51942	50737	43852	29702	12514	1943	0	0	0
		Low GWP	0	0	5939	21730	42287	60179	72017	83487	96785

Table A6-4: Demand in ktonnes CO_2-eq.for new manufacturing plus servicing (total demand) for non-Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	2438	1887	1244	1240	1120	1298	1505	1745	2022
		HC-600a	7	8	11	16	23	27	31	36	42
	Commercial	HFC-134a	2933	3084	3120	3113	2735	2617	3034	3517	4077
		R-404A + R-507	60388	63498	46975	29512	22379	21555	24988	28968	33582
		Low GWP	0	0	1312	2764	4196	5519	6398	7417	8598
	Industrial	HFC-134a	1353	1447	1492	1544	1603	1746	1930	2159	2437
		R-404A + R-507	2375	2926	1935	1491	858	761	849	800	700
		Low GWP	1	2	103	99	63	55	38	35	41
	Transport	HFC-134a	289	277	393	483	629	761	882	1023	1186
		R-404A + R-507	4634	6066	3614	3283	2780	2468	2316	2140	1936
		Low GWP	0	0	167	227	304	394	498	619	759
	SAC	HFC-134a	5241	5808	1848	1293	294	0	0	0	0
		R-410A	75619	148520	180922	218882	252133	291774	338246	392120	454575
		R-407C	18135	43419	42399	49165	50816	53328	56522	60225	64518
		Low GWP	0	0	1315	2040	2855	3801	4897	6167	7640
	MAC	HFC-134a	90571	88867	62952	49554	35762	31934	37020	42916	49752
		Low GWP	0	0	18	33	50	64	74	86	99
nA5 MIT-3	Domestic	HFC-134a	2438	1887	2	2	1	0	0	0	0
		HC-600a	7	8	30	35	40	47	54	63	73
	Commercial	HFC-134a	2933	3084	3120	3113	2735	2617	3034	3517	4077
		R-404A + R-507	60388	63498	40703	16597	2999	0	0	0	0
		Low GWP	0	0	1788	3745	5669	7156	8296	9617	11149
	Industrial	HFC-134a	1353	1447	1492	1544	1603	1746	1930	2159	2437
		R-404A + R-507	2375	2926	1267	862	478	347	393	298	143
		Low GWP	1	2	154	146	92	86	72	74	83
	Transport	HFC-134a	289	277	393	483	629	761	882	1023	1186
		R-404A + R-507	4634	6066	2876	1908	638	0	0	0	0
		Low GWP	0	0	223	331	467	582	675	782	907
	SAC	HFC-134a	5241	5808	1848	1293	294	0	0	0	0
		R-410A	75619	148520	42886	30396	7923	0	0	0	0
		R-407C	18135	43419	22525	17949	6828	0	0	0	0
		Low GWP	0	0	27754	38866	51190	63066	73111	84756	98255
	MAC	HFC-134a	90571	88867	54432	33712	11367	0	0	0	0
		Low GWP	0	0	25	45	69	88	102	119	138
nA5 MIT-5	Domestic	HFC-134a	2438	1887	1244	2	1	1	1	0	0
		HC-600a	7	8	11	35	40	47	54	63	73
	Commercial	HFC-134a	2933	3084	3120	3113	2735	2617	3034	3517	4077
		R-404A + R-507	60388	63498	46975	19659	6060	227	0	0	0
		Low GWP	0	0	1407	3745	5669	7156	8296	9617	11149
	Industrial	HFC-134a	1353	1447	1492	1544	1603	1746	1930	2159	2437
		R-404A + R-507	2375	2926	1935	1012	627	496	638	613	483
		Low GWP	1	2	103	135	81	75	54	50	58
	Transport	HFC-134a	289	277	393	483	629	761	882	1023	1186
		R-404A + R-507	4634	6066	3437	2092	822	92	0	0	0
		Low GWP	0	0	180	317	453	575	675	782	907
	SAC	HFC-134a	5241	5808	1848	1293	294	0	0	0	0
		R-410A	75619	148520	180922	50829	28354	9915	0	0	0
		R-407C	18135	43419	42399	24148	13027	3260	0	0	0
		Low GWP	0	0	2631	34771	47095	60914	73111	84756	98255
	MAC	HFC-134a	90571	88867	62952	38613	16269	2526	0	0	0
		Low GWP	0	0	18	41	65	86	102	119	138

Table A6-5 Demand in ktonnes CO_2-eq. for new manufacturing only for non-Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	2434	1883	1241	1238	1119	1297	1503	1743	2021
		HC-600a	7	8	11	16	23	27	31	36	42
	Commercial	HFC-134a	2635	2321	865	1002	1162	1347	1562	1810	2099
		R-404A + R-507	27645	11962	8932	7063	8187	9491	11003	12756	14787
		Low GWP	0	0	974	1380	1600	1855	2150	2492	2889
	Industrial	HFC-134a	424	516	543	570	600	695	806	934	1083
		R-404A + R-507	1359	1653	604	383	65	75	87	101	117
		Low GWP	1	1	88	58	11	13	15	18	21
	Transport	HFC-134a	58	74	184	214	248	287	333	386	448
		R-404A + R-507	2278	2907	350	516	598	693	803	931	1079
		Low GWP	0	0	145	159	185	214	248	288	334
	SAC	HFC-134a	4403	4053	0	0	0	0	0	0	0
		R-410A	65586	118570	130720	151541	175677	203658	236095	273699	317293
		R-407C	12171	26428	17481	20007	23194	26888	31170	36135	41890
		Low GWP	0	0	1081	1277	1481	1717	1990	2307	2675
	MAC	HFC-134a	23046	22908	5944	7059	8183	9486	10997	12749	14780
		Low GWP	0	0	12	14	16	19	22	25	30
nA5 MIT-3	Domestic	HFC-134a	2434	1883	0	0	0	0	0	0	0
		HC-600a	7	8	30	35	40	47	54	63	73
	Commercial	HFC-134a	2635	2321	865	1002	1162	1347	1562	1810	2099
		R-404A + R-507	27645	11962	3906	0	0	0	0	0	0
		Low GWP	0	0	1356	1916	2221	2575	2985	3461	4012
	Industrial	HFC-134a	424	516	543	570	600	695	806	934	1083
		R-404A + R-507	1359	1653	17	0	0	0	0	0	0
		Low GWP	1	1	132	87	16	19	22	26	30
	Transport	HFC-134a	58	74	184	214	248	287	333	386	448
		R-404A + R-507	2278	2907	0	0	0	0	0	0	0
		Low GWP	0	0	180	199	230	267	309	359	416
	SAC	HFC-134a	4403	4053	0	0	0	0	0	0	0
		R-410A	65586	118570	2434	0	0	0	0	0	0
		R-407C	12171	26428	543	0	0	0	0	0	0
		Low GWP	0	0	25344	29938	34707	40234	46643	54072	62684
	MAC	HFC-134a	23046	22908	0	0	0	0	0	0	0
		Low GWP	0	0	17	20	23	26	30	35	41
nA5 MIT-5	Domestic	HFC-134a	2434	1883	1241	0	0	0	0	0	0
		HC-600a	7	8	11	35	40	47	54	63	73
	Commercial	HFC-134a	2635	2321	865	1002	1162	1347	1562	1810	2099
		R-404A + R-507	27645	11962	8932	0	0	0	0	0	0
		Low GWP	0	0	974	1916	2221	2575	2985	3461	4012
	Industrial	HFC-134a	424	516	543	570	600	695	806	934	1083
		R-404A + R-507	1359	1653	604	0	0	0	0	0	0
		Low GWP	1	1	88	87	16	19	22	26	30
	Transport	HFC-134a	58	74	184	214	248	287	333	386	448
		R-404A + R-507	2278	2907	350	0	0	0	0	0	0
		Low GWP	0	0	145	199	230	267	309	359	416
	SAC	HFC-134a	4403	4053	0	0	0	0	0	0	0
		R-410A	65586	118570	130720	0	0	0	0	0	0
		R-407C	12171	26428	17481	0	0	0	0	0	0
		Low GWP	0	0	2163	29938	34707	40234	46643	54072	62684
	MAC	HFC-134a	23046	22908	5944	0	0	0	0	0	0
		Low GWP	0	0	12	20	23	26	30	35	41

Table A6-6: Demand in ktonnes CO_2-eq. for servicing only for non-Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
nA5 BAU	Domestic	HFC-134a	4	4	3	2	1	1	2	2	1
		HC-600a	0	0	0	0	0	0	0	0	0
	Commercial	HFC-134a	298	763	2255	2111	1573	1270	1472	1707	1978
		R-404A + R-507	32743	51536	38043	22449	14192	12064	13985	16212	18795
		Low GWP	0	0	338	1384	2596	3664	4248	4925	5709
	Industrial	HFC-134a	929	931	949	974	1003	1051	1124	1225	1354
		R-404A + R-507	1016	1273	1331	1108	793	686	762	699	583
		Low GWP	0	1	15	41	52	42	23	17	20
	Transport	HFC-134a	231	203	209	269	381	474	549	637	738
		R-404A + R-507	2356	3159	3264	2767	2182	1775	1513	1209	857
		Low GWP	0	0	22	68	119	180	250	331	425
	SAC	HFC-134a	838	1755	1848	1293	294	0	0	0	0
		R-410A	10033	29950	50202	67341	76456	88116	102151	118421	137282
		R-407C	5964	16991	24918	29158	27622	26440	25352	24090	22628
		Low GWP	0	0	234	763	1374	2084	2907	3860	4965
	MAC	HFC-134a	67525	65959	57008	42495	27579	22448	26023	30167	34972
		Low GWP	0	0	6	19	34	45	52	61	69
nA5 MIT-3	Domestic	HFC-134a	4	4	2	2	1	0	0	0	0
		HC-600a	0	0	0	0	0	0	0	0	0
	Commercial	HFC-134a	298	763	2255	2111	1573	1270	1472	1707	1978
		R-404A + R-507	32743	51536	36797	16597	2999	0	0	0	0
		Low GWP	0	0	432	1829	3448	4581	5311	6156	7137
	Industrial	HFC-134a	929	931	949	974	1003	1051	1124	1225	1354
		R-404A + R-507	1016	1273	1250	862	478	347	393	298	143
		Low GWP	0	1	22	59	76	67	50	48	53
	Transport	HFC-134a	231	203	209	269	381	474	549	637	738
		R-404A + R-507	2356	3159	2876	1908	638	0	0	0	0
		Low GWP	0	0	43	132	237	315	366	423	491
	SAC	HFC-134a	838	1755	1848	1293	294	0	0	0	0
		R-410A	10033	29950	40452	30396	7923	0	0	0	0
		R-407C	5964	16991	21982	17949	6828	0	0	0	0
		Low GWP	0	0	2410	8928	16483	22832	26468	30684	35571
	MAC	HFC-134a	67525	65959	54432	33712	11367	0	0	0	0
		Low GWP	0	0	8	25	46	62	72	84	97
nA5 MIT-5	Domestic	HFC-134a	4	4	3	2	1	1	1	0	0
		HC-600a	0	0	0	0	0	0	0	0	0
	Commercial	HFC-134a	298	763	2255	2111	1573	1270	1472	1707	1978
		R-404A + R-507	32743	51536	38043	19659	6060	227	0	0	0
		Low GWP	0	0	433	1829	3448	4581	5311	6156	7137
	Industrial	HFC-134a	929	931	949	974	1003	1051	1124	1225	1354
		R-404A + R-507	1016	1273	1331	1012	627	496	638	613	483
		Low GWP	0	1	15	48	65	56	32	24	28
	Transport	HFC-134a	231	203	209	269	381	474	549	637	738
		R-404A + R-507	2356	3159	3087	2092	822	92	0	0	0
		Low GWP	0	0	35	118	223	308	366	423	491
	SAC	HFC-134a	838	1755	1848	1293	294	0	0	0	0
		R-410A	10033	29950	50202	50829	28354	9915	0	0	0
		R-407C	5964	16991	24918	24148	13027	3260	0	0	0
		Low GWP	0	0	468	4833	12388	20680	26468	30684	35571
	MAC	HFC-134a	67525	65959	57008	38613	16269	2526	0	0	0
		Low GWP	0	0	6	21	42	60	72	84	97

Table A6-7: Demand in tonnes for servicing and new manufacturing (total demand) for Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	12941	13329	15333	18242	21634	26893	33468	41682	51935
		HC-600a	3083	5747	10141	15684	23446	29496	36965	46197	57613
	Commercial	HFC-134a	2743	5089	9356	11910	15018	18781	23404	29166	36346
		R-404A + R-507	11343	31391	55505	97823	148283	198343	255658	320891	399889
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	720	1320	2255	3730	6074	8301	10829	13737	17118
		R-404A + R-507	599	3132	6266	10969	15212	20001	25495	31870	39332
		Low GWP	19347	23571	28991	36291	46469	56461	67842	81380	97596
	Transport	HFC-134a	544	1075	1982	2608	3104	3798	4521	5424	6697
		R-404A + R-507	1143	1881	2192	3135	4195	5235	6592	8316	10393
		Low GWP	0	0	0	0	0	0	0	0	0
	SAC	HFC-134a	1091	2315	4556	5849	7087	8173	8961	9609	10338
		R-410A	40975	106661	192770	284682	364845	427266	479588	524488	566180
		R-407C	16543	55278	101216	174433	285500	372998	457406	532391	587361
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	36354	51396	66680	84928	108190	138081	176230	224919	287060
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	12941	13329	12953	1296	549	333	94	0	0
		HC-600a	3083	5747	12521	32630	44531	56056	70339	87879	109548
	Commercial	HFC-134a	2743	5089	9356	11910	15018	18781	23404	29166	36346
		R-404A + R-507	11343	31391	50015	30001	9356	1285	0	0	0
		Low GWP	0	0	5490	67822	140098	197058	255658	320891	399889
	Industrial	HFC-134a	720	1320	2255	3730	6074	8301	10829	13737	17118
		R-404A + R-507	599	3132	5774	4392	2883	1131	1412	3306	5077
		Low GWP	19347	23571	29484	42868	58798	75331	91924	109944	131850
	Transport	HFC-134a	544	1075	1982	2608	3104	3798	4521	5424	6697
		R-404A + R-507	1143	1881	1976	1265	928	554	164	0	0
		Low GWP	0	0	216	1871	3267	4680	6428	8316	10393
	SAC	HFC-134a	1091	2315	4556	5849	7087	8173	8961	9609	10338
		R-410A	40975	106661	170273	65015	18972	13467	4267	0	0
		R-407C	16543	55278	92804	58029	20684	13059	4411	0	0
		Low GWP	0	0	30909	336071	610690	773737	928316	1056879	1153541
	MAC	HFC-134a	36354	51396	59636	22153	6375	0	0	0	0
		Low GWP	0	0	7044	62775	101815	138081	176230	224919	287060
A5 MIT-5	Domestic	HFC-134a	12941	13329	15333	15442	1541	636	389	111	0
		HC-600a	3083	5747	10141	18484	43539	55752	70044	87768	109548
	Commercial	HFC-134a	2743	5089	9356	11910	15018	18781	23404	29166	36346
		R-404A + R-507	11343	31391	55505	88798	45752	23639	7810	0	0
		Low GWP	0	0	0	9024	102531	174704	247847	320891	399889
	Industrial	HFC-134a	720	1320	2255	3730	6074	8301	10829	13737	17118
		R-404A + R-507	599	3132	6266	10200	7134	5289	2973	3306	5077
		Low GWP	19347	23571	28991	37060	54546	71173	90363	109944	131850
	Transport	HFC-134a	544	1075	1982	2608	3104	3798	4521	5424	6697
		R-404A + R-507	1143	1881	2192	2860	1577	1066	662	209	0
		Low GWP	0	0	0	275	2618	4169	5930	8108	10393
	SAC	HFC-134a	1091	2315	4556	5849	7087	8173	8961	9609	10338
		R-410A	40975	106661	192770	254067	104162	83830	55193	16085	0
		R-407C	16543	55278	101216	160942	108166	30160	21180	7194	0
		Low GWP	0	0	0	44105	438017	686274	860621	1033601	1153541
	MAC	HFC-134a	36354	51396	66680	76006	28027	4843	0	0	0
		Low GWP	0	0	0	8922	80163	133238	176230	224919	287060

Table A6-8: Demand in tonnes for new manufacturing only for Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	11234	12812	14610	17323	20540	25597	31899	39751	49537
		HC-600a	2622	5557	9740	14957	22252	27730	34557	43064	53666
	Commercial	HFC-134a	2617	4779	8726	10874	13551	16887	21045	26225	32682
		R-404A + R-507	9216	20804	31030	52412	76790	95695	119253	148611	185196
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	406	650	1040	1663	2661	3191	3827	4590	5504
		R-404A + R-507	238	1613	2532	3972	4435	5319	6379	7649	9173
		Low GWP	3305	4242	5579	7566	10645	12766	15309	18358	22015
	Transport	HFC-134a	321	551	948	964	981	1223	1524	1899	2367
		R-404A + R-507	877	1241	1158	1660	2290	2853	3556	4431	5522
		Low GWP	0	0	0	0	0	0	0	0	0
	SAC	HFC-134a	862	1587	2923	3072	3229	3478	3747	4036	4348
		R-410A	34583	82577	134702	178540	206625	222594	239796	258329	278294
		R-407C	6107	26645	43128	69810	112998	121731	131139	141274	152192
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	25061	32577	40822	52100	66495	84866	108313	138238	176430
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	11234	12812	12238	580	0	0	0	0	0
		HC-600a	2622	5557	12112	31700	42792	53327	66455	82815	103203
	Commercial	HFC-134a	2617	4779	8726	10874	13551	16887	21045	26225	32682
		R-404A + R-507	9216	20804	26172	4495	0	0	0	0	0
		Low GWP	0	0	4858	47916	76790	95695	119253	148611	185196
	Industrial	HFC-134a	406	650	1040	1663	2661	3191	3827	4590	5504
		R-404A + R-507	238	1613	2132	230	0	0	0	0	0
		Low GWP	3305	4242	5979	11308	15080	18085	21687	26007	31188
	Transport	HFC-134a	321	551	948	964	981	1223	1524	1899	2367
		R-404A + R-507	877	1241	956	110	0	0	0	0	0
		Low GWP	0	0	203	1551	2290	2853	3556	4431	5522
	SAC	HFC-134a	862	1587	2923	3072	3229	3478	3747	4036	4348
		R-410A	34583	82577	113983	10182	0	0	0	0	0
		R-407C	6107	26645	36495	3981	0	0	0	0	0
		Low GWP	0	0	27353	234187	319623	344324	370935	399603	430485
	MAC	HFC-134a	25061	32577	34293	2481	0	0	0	0	0
		Low GWP	0	0	6529	49619	66495	84866	108313	138238	176430
A5 MIT-5	Domestic	HFC-134a	11234	12812	14610	14533	688	0	0	0	0
		HC-600a	2622	5557	9740	17747	42104	53327	66455	82815	103203
	Commercial	HFC-134a	2617	4779	8726	10874	13551	16887	21045	26225	32682
		R-404A + R-507	9216	20804	31030	44426	5149	0	0	0	0
		Low GWP	0	0	0	7986	71642	95695	119253	148611	185196
	Industrial	HFC-134a	406	650	1040	1663	2661	3191	3827	4590	5504
		R-404A + R-507	238	1613	2532	3348	0	0	0	0	0
		Low GWP	3305	4242	5579	8190	15080	18085	21687	26007	31188
	Transport	HFC-134a	321	551	948	964	981	1223	1524	1899	2367
		R-404A + R-507	877	1241	1158	1402	137	0	0	0	0
		Low GWP	0	0	0	258	2152	2853	3556	4431	5522
	SAC	HFC-134a	862	1587	2923	3072	3229	3478	3747	4036	4348
		R-410A	34583	82577	134702	150481	9255	0	0	0	0
		R-407C	6107	26645	43128	58838	5061	0	0	0	0
		Low GWP	0	0	0	39031	305306	344324	370935	399603	430485
	MAC	HFC-134a	25061	32577	40822	43830	3166	0	0	0	0
		Low GWP	0	0	0	8270	63328	84866	108313	138238	176430

Table: A6-9 Demand in tonnes for servicing only for Article 5 Parties for the period 2010-2050 for the six major sub-sectors and for the BAU, MIT-3 and MIT-5 scenarios

In tonnes (servicing)											
			2010	2015	2020	2025	2030	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	1707	517	723	919	1094	1296	1569	1931	2398
		HC-600a	461	190	401	727	1194	1766	2408	3133	3947
	Commercial	HFC-134a	126	310	630	1036	1467	1894	2359	2941	3664
		R-404A + R-507	2127	10587	24475	45411	71493	102648	136405	172280	214693
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	314	670	1215	2067	3413	5110	7002	9147	11614
		R-404A + R-507	361	1519	3734	6997	10777	14682	19116	24221	30159
		Low GWP	16042	19329	23412	28725	35824	43695	52533	63022	75581
	Transport	HFC-134a	223	524	1034	1644	2123	2575	2997	3525	4330
		R-404A + R-507	266	640	1034	1475	1905	2382	3036	3885	4871
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	229	728	1633	2777	3858	4695	5214	5573	5990
		R-410A	6392	24084	58068	106142	158220	204672	239792	266159	287886
		R-407C	10436	28633	58088	104623	172502	251267	326267	391117	435169
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	11293	18819	25858	32828	41695	53215	67917	86681	110630
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	1707	517	715	716	549	333	94	0	0
		HC-600a	461	190	409	930	1739	2729	3884	5064	6345
	Commercial	HFC-134a	126	310	630	1036	1467	1894	2359	2941	3664
		R-404A + R-507	2127	10587	23843	25506	9356	1285	0	0	0
		Low GWP	0	0	632	19906	63308	101363	136405	172280	214693
	Industrial	HFC-134a	314	670	1215	2067	3413	5110	7002	9147	11614
		R-404A + R-507	361	1519	3642	4162	2883	1131	1412	3306	5077
		Low GWP	16042	19329	23505	31560	43718	57246	70237	83937	100662
	Transport	HFC-134a	223	556	1217	2073	2825	2825	2825	2825	2825
		R-404A + R-507	266	684	1159	962	0	0	0	0	0
		Low GWP	0	0	33	853	2535	2535	2535	2535	2535
	SAC	HFC-134a	229	728	1633	2777	3858	4695	5214	5573	5990
		R-410A	6392	24084	56290	54833	18972	13467	4267	0	0
		R-407C	10436	28633	56309	54048	20684	13059	4411	0	0
		Low GWP	0	0	3556	101884	291067	429413	557381	657276	723056
	MAC	HFC-134a	11293	18819	25343	19672	6375	0	0	0	0
		Low GWP	0	0	515	13156	35320	53215	67917	86681	110630
A5 MIT-5	Domestic	HFC-134a	1707	517	723	909	853	636	389	111	0
		HC-600a	461	190	401	737	1435	2425	3589	4953	6345
	Commercial	HFC-134a	126	310	630	1036	1467	1894	2359	2941	3664
		R-404A + R-507	2127	10587	24475	44372	40603	23639	7810	0	0
		Low GWP	0	0	0	1038	30889	79009	128594	172280	214693
	Industrial	HFC-134a	314	670	1215	2067	3413	5110	7002	9147	11614
		R-404A + R-507	361	1519	3734	6852	7134	5289	2973	3306	5077
		Low GWP	16042	19329	23412	28870	39466	53088	68676	83937	100662
	Transport	HFC-134a	223	524	1034	1644	2123	2575	2997	3525	4330
		R-404A + R-507	266	640	1034	1458	1440	1066	662	209	0
		Low GWP	0	0	0	17	466	1316	2374	3677	4871
	Industrial	HFC-134a	229	728	1633	2777	3858	4695	5214	5573	5990
		R-410A	6392	24084	58068	103586	94907	83830	55193	16085	0
		R-407C	10436	28633	58088	102104	103105	30160	21180	7194	0
		Low GWP	0	0	0	5074	132711	341950	489686	633998	723056
	MAC	HFC-134a	11293	18819	25858	32176	24861	4843	0	0	0
		Low GWP	0	0	0	652	16835	48372	67917	86681	110630

Table A6-10: Demand in ktonnes CO_2-eq. for new manufacturing plus servicing (total demand) for Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	16823	17327	19933	23715	28125	34960	43509	54186	67516
		HC-600a	62	115	203	314	469	590	739	924	1152
	Commercial	HFC-134a	3566	6615	12162	15484	19524	24415	30425	37915	47250
		R-404A + R-507	44723	123759	218844	385658	584559	781886	1007810	1264957	1576367
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	937	1716	2931	4849	7896	10792	14078	17858	22253
		R-404A + R-507	2359	12341	24689	43217	59936	78802	100448	125566	154966
		Low GWP	1	1	3	5	9	11	13	16	19
	Transport	HFC-134a	707	1398	2577	3390	4035	4938	5877	7051	8706
		R-404A + R-507	4502	7411	8635	12354	16530	20625	25937	32766	40950
		Low GWP	0	0	0	0	0	0	0	0	0
	SAC	HFC-134a	1418	3009	5923	7603	9213	10624	11649	12492	13440
		R-410A	78671	204789	370118	546589	700502	820350	920809	1007017	1087066
		R-407C	26799	89550	163971	282581	462511	604256	740997	862474	951525
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	47261	66815	86684	110406	140647	179505	229099	292395	373178
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	16823	17327	16839	1685	714	432	122	0	0
		HC-600a	62	115	250	653	891	1121	1407	1758	2191
	Commercial	HFC-134a	3566	6615	12162	15484	19524	24415	30425	37915	47250
		R-404A + R-507	44723	123759	197206	118371	32484	5078	0	0	0
		Low GWP	0	0	1647	20347	42029	59117	76697	96267	119967
	Industrial	HFC-134a	937	1716	2931	4849	7896	10792	14078	17858	22253
		R-404A + R-507	2359	12341	22749	17303	11359	4454	5564	13024	20005
		Low GWP	1	1	150	1078	3707	5672	7238	8585	10295
	Transport	HFC-134a	707	1398	2577	3390	4035	4938	5877	7051	8706
		R-404A + R-507	4502	7411	7785	4984	3657	2184	646	0	0
		Low GWP	0	0	68	648	980	1404	1928	2495	3118
	SAC	HFC-134a	1418	3009	5923	7603	9213	10624	11649	12492	13440
		R-410A	78671	204789	326924	124828	36425	25856	8192	0	0
		R-407C	26799	89550	150343	94007	33508	21156	7146	0	0
		Low GWP	0	0	9273	100821	183207	232121	278495	317064	346062
	MAC	HFC-134a	47261	66815	77527	28799	8288	0	0	0	0
		Low GWP	0	0	7	63	102	138	176	225	287
A5 MIT-5	Domestic	HFC-134a	16823	17327	19933	20074	2003	827	506	144	0
		HC-600a	62	115	203	370	871	1115	1401	1755	2191
	Commercial	HFC-134a	3566	6615	12162	15484	19524	24415	30425	37915	47250
		R-404A + R-507	44723	123759	218844	350091	180501	93204	30793	0	0
		Low GWP	0	0	0	2707	30759	52411	74354	96267	119967
	Industrial	HFC-134a	937	1716	2931	4849	7896	10792	14078	17858	22253
		R-404A + R-507	2359	12341	24689	40190	28109	20839	11712	13024	20005
		Low GWP	1	1	3	235	2432	4424	6770	8585	10295
	Transport	HFC-134a	707	1398	2577	3390	4035	4938	5877	7051	8706
		R-404A + R-507	4502	7411	8635	11269	6214	4200	2610	822	0
		Low GWP	0	0	0	83	785	1251	1779	2432	3118
	SAC	HFC-134a	1418	3009	5923	7603	9213	10624	11649	12492	13440
		R-410A	78671	204789	370118	487808	199992	160953	105970	30882	0
		R-407C	26799	89550	163971	260727	175229	48859	34312	11654	0
		Low GWP	0	0	0	13232	131405	205882	258186	310080	346062
	MAC	HFC-134a	47261	66815	86684	98808	36435	6296	0	0	0
		Low GWP	0	0	0	9	80	133	176	225	287

Table A6-11: Demand in ktonnes CO_2-eq. for new manufacturing only for Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	14993	16655	18993	22520	26702	33276	41468	51677	64399
		HC-600a	52	111	195	299	445	555	691	861	1073
	Commercial	HFC-134a	3402	6213	11344	14136	17617	21953	27358	34093	42486
		R-404A + R-507	36328	81998	122316	206575	302644	377150	469997	585702	729891
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	528	845	1352	2162	3460	4149	4975	5966	7155
		R-404A + R-507	937	6354	9976	15650	17476	20957	25131	30138	36141
		Low GWP	0	1	1	2	4	5	6	8	9
	Transport	HFC-134a	417	717	1232	1254	1276	1590	1981	2469	3077
		R-404A + R-507	3455	4891	4564	6542	9022	11243	14010	17460	21758
		Low GWP	0	0	0	0	0	0	0	0	0
	SAC	HFC-134a	1121	2063	3800	3993	4197	4521	4871	5247	5653
		R-410A	66400	158547	258628	342797	396720	427380	460409	495991	534324
		R-407C	9893	43164	69868	113092	183057	197204	212445	228863	246551
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	32579	42350	53069	67730	86443	110326	140807	179709	229359
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	14604	16655	15910	754	0	0	0	0	0
		HC-600a	52	111	242	634	856	1067	1329	1656	2064
	Commercial	HFC-134a	3402	6213	11344	14136	17617	21953	27358	34093	42486
		R-404A + R-507	36328	81998	103166	17714	0	0	0	0	0
		Low GWP	0	0	1457	14375	23037	28708	35776	44583	55559
	Industrial	HFC-134a	528	845	1352	2162	3460	4149	4975	5966	7155
		R-404A + R-507	937	6354	8401	908	0	0	0	0	0
		Low GWP	0	1	1221	1125	1335	1601	1920	2302	2761
	Transport	HFC-134a	417	717	1232	1254	1276	1590	1981	2469	3077
		R-404A + R-507	3455	4891	3766	432	0	0	0	0	0
		Low GWP	0	0	61	465	687	856	1067	1329	1657
	SAC	HFC-134a	1121	2063	3800	3993	4197	4521	4871	5247	5653
		R-410A	66400	158547	218847	19549	0	0	0	0	0
		R-407C	9893	43164	59121	6449	0	0	0	0	0
		Low GWP	0	0	8206	70256	95887	103297	111281	119881	129146
	MAC	HFC-134a	32579	42350	44581	3225	0	0	0	0	0
		Low GWP	0	0	7	50	66	85	108	138	176
A5 MIT-5	Domestic	HFC-134a	14604	16655	18994	18893	894	0	0	0	0
		HC-600a	52	111	195	355	842	1067	1329	1656	2064
	Commercial	HFC-134a	3402	6213	11344	14136	17617	21953	27358	34093	42486
		R-404A + R-507	36328	81998	122316	175098	20289	0	0	0	0
		Low GWP	0	0	0	2396	21493	28708	35776	44583	55559
	Industrial	HFC-134a	528	845	1352	2162	3460	4149	4975	5966	7155
		R-404A + R-507	937	6354	9976	13193	0	0	0	0	0
		Low GWP	0	1	1	190	1335	1601	1920	2302	2761
	Transport	HFC-134a	417	717	1232	1254	1276	1590	1981	2469	3077
		R-404A + R-507	3455	4891	4564	5524	542	0	0	0	0
		Low GWP	0	0	0	78	646	856	1067	1329	1657
	SAC	HFC-134a	1121	2063	3800	3993	4197	4521	4871	5247	5653
		R-410A	66400	158547	258628	288923	19076	0	0	0	0
		R-407C	9893	43164	69868	95318	8802	0	0	0	0
		Low GWP	0	0	0	11709	91276	103297	111281	119881	129146
	MAC	HFC-134a	32579	42350	53069	56980	4116	0	0	0	0
		Low GWP	0	0	0	8	63	85	108	138	176

Table A6-12: Demand in ktonnes CO_2-eq. for servicing only for Article 5 Parties for the period 2010-2050 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	2035	2040	2045	2050
A5 BAU	Domestic	HFC-134a	1830	672	940	1195	1423	1684	2041	2509	3117
		HC-600a	10	4	8	15	24	35	48	63	79
	Commercial	HFC-134a	164	402	818	1348	1907	2462	3067	3822	4764
		R-404A + R-507	8395	41761	96528	179083	281915	404736	537813	679255	846476
		Low GWP	0	0	0	0	0	0	0	0	0
	Industrial	HFC-134a	409	871	1579	2687	4436	6643	9103	11892	15098
		R-404A + R-507	1422	5987	14713	27567	42460	57845	75317	95428	118825
		Low GWP	1	0	2	3	5	6	7	8	10
	Transport	HFC-134a	290	681	1345	2136	2759	3348	3896	4582	5629
		R-404A + R-507	1047	2520	4071	5812	7508	9382	11927	15306	19192
		Low GWP	0	0	0	0	0	0	0	0	0
	SAC	HFC-134a	297	946	2123	3610	5016	6103	6778	7245	7787
		R-410A	12271	46242	111490	203792	303782	392970	460400	511026	552742
		R-407C	16906	46386	94103	169489	279454	407052	528552	633611	704974
		Low GWP	0	0	0	0	0	0	0	0	0
	MAC	HFC-134a	14682	24465	33615	42676	54204	69179	88292	112686	143819
		Low GWP	0	0	0	0	0	0	0	0	0
A5 MIT-3	Domestic	HFC-134a	2219	672	929	931	714	432	122	0	0
		HC-600a	10	4	8	19	35	54	78	102	127
	Commercial	HFC-134a	164	402	818	1348	1907	2462	3067	3822	4764
		R-404A + R-507	8395	41761	94040	100657	32484	5078	0	0	0
		Low GWP	0	0	190	5972	18992	30409	40921	51684	64408
	Industrial	HFC-134a	409	871	1579	2687	4436	6643	9103	11892	15098
		R-404A + R-507	1422	5987	14348	16395	11359	4454	5564	13024	20005
		Low GWP	1	0	-1071	-47	2372	4071	5318	6283	7534
	Transport	HFC-134a	290	681	1345	2136	2759	3348	3896	4582	5629
		R-404A + R-507	1047	2520	4019	4552	3657	2184	646	0	0
		Low GWP	0	0	7	183	293	548	861	1166	1461
	SAC	HFC-134a	297	946	2123	3610	5016	6103	6778	7245	7787
		R-410A	12271	46242	108077	105279	36425	25856	8192	0	0
		R-407C	16906	46386	91222	87558	33508	21156	7146	0	0
		Low GWP	0	0	1067	30565	87320	128824	167214	197183	216916
	MAC	HFC-134a	14682	24465	32946	25574	8288	0	0	0	0
		Low GWP	0	0	0	13	36	53	68	87	111
A5 MIT-5	Domestic	HFC-134a	2219	672	939	1181	1109	827	506	144	0
		HC-600a	10	4	8	15	29	48	72	99	127
	Commercial	HFC-134a	164	402	818	1348	1907	2462	3067	3822	4764
		R-404A + R-507	8395	41761	96528	174993	160212	93204	30793	0	0
		Low GWP	0	0	0	311	9266	23703	38578	51684	64408
	Industrial	HFC-134a	409	871	1579	2687	4436	6643	9103	11892	15098
		R-404A + R-507	1422	5987	14713	26997	28109	20839	11712	13024	20005
		Low GWP	1	0	2	45	1097	2823	4850	6283	7534
	Transport	HFC-134a	290	681	1345	2136	2759	3348	3896	4582	5629
		R-404A + R-507	1047	2520	4071	5745	5672	4200	2610	822	0
		Low GWP	0	0	0	5	139	395	712	1103	1461
	SAC	HFC-134a	297	946	2123	3610	5016	6103	6778	7245	7787
		R-410A	12271	46242	111490	198885	180916	160953	105970	30882	0
		R-407C	16906	46386	94103	165409	166427	48859	34312	11654	0
		Low GWP	0	0	0	1523	40129	102585	146905	190199	216916
	MAC	HFC-134a	14682	24465	33615	41828	32319	6296	0	0	0
		Low GWP	0	0	0	1	17	48	68	87	111