MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

SEPTEMBER 2016

VOLUME I

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

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Montreal Protocol
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UNEP Technology and Economic Assessment Panel

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DECISION XXVII/4 TASK FORCE UPDATE REPORT:

FURTHER INFORMATION ON ALTERNATIVES TO OZONE DEPLETING SUBSTANCES

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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.

FORWARD

The September 2016 TEAP Report consists of four volumes:

Volume I. TEAP Decision XXVII/4 Task Force Update Report: Further Information on Alternatives to Ozone-depleting Substances

Volume II. TEAP Decision Ex. III/1 Working Group Report: Climate Benefits and Costs of Reducing Hydrofluorocarbons under the Dubai Pathway

Volume III. TEAP 2016 Final CUN Assessment Report

Volume IV. TEAP/SAP Decision XXVII/7 Report: Investigation of Carbon Tetrachloride Discrepancies

This is Volume I.

Preface

This report is a follow up to the June 2016 TEAP XXVII/4 Task Force Report, submitted to the OEWG-38 Meeting of the Parties in Vienna, July 2016.

This September 2016 TEAP XXVII/4 Task Force update report is being submitted by the TEAP to the 28th Meeting of the Parties to the Montreal Protocol, Kigali, October 2016.

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Executive summary

ES1. Introduction

- Decision XXVII/4 requested TEAP to provide an update 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 held two Open-ended Working Group (OEWG) meetings this year, TEAP had taken the approach to provide three total reports responding to Decision XXVII/4. TEAP provided its first March 2016 report to OEWG-37 focused on the refrigeration and air conditioning (R/AC) sector, and included updates on alternatives, results of testing on alternatives under high ambient temperature (HAT) conditions, discussion of other parameters outlined in the decision, and an extension of the mitigation scenarios to 2050. Based on comments and informal discussions on the report at OEWG-37, TEAP completed its second report for submission to OEWG-38, again focusing on the R/AC sector.
- TEAP's approach with its third and final report under Decision XXVII/4 is to provide Parties with a single reference document as much as possible for MOP-28. This final report contains much of the same information as in the first two reports with a focus on the R/AC sector, plus new chapters on foams, MDIs and aerosols. Updates and additions **in bold** are indicated at the beginning of each existing chapter or section, as appropriate.
- In particular, TEAP's final report under Decision XXVII/4 for MOP-28 provides the following:
    - A response to comments on the high ambient temperature criterion (chapter 5);
    - A response to comments related to scenarios including further information related to HFC production (Annex 4 of this report contains updated tables for total, new manufacturing, and servicing demand (in relation to Chapter 6)).
    - A new chapter (Chapter 7) responds to the decision request to provide new and updated information on the availability of alternatives for foam blowing.
    - A new chapter (Chapter 8) responds to the decision request to provide new and updated information on the availability of alternatives for MDIs and aerosols.
- This report focuses on relevant sectors, including on R/AC, foams, MDIs and aerosols sectors. The summaries of the chapters 1 to 6 from the second Task Force report submitted to OEWG-38 remain essentially the same with **any specific update or additional information indicated in bold upfront.**

ES2. Update on the status of refrigerants

- **No further updates were provided on the status of refrigerants (Chapter 2) since the Task Force June report, so the information, as summarized below, remains unchanged for this report.**
- Chapter 2 lists 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 increased safety risks of some of low-GWP refrigerants that need to be addressed.

- There are alternative refrigerants available today with negligible ODP and lower GWP, however, for some applications it can be challenging to achieve the same lifetime cost level of 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 an additional variable to the refrigerant choice also 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 to 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 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 CO_2-equivalent emissions generated during the production of energy consumed by the refrigeration, air-conditioning, and heat pump equipment. These emissions are affected by equipment's operating characteristics and the emission factor of the local electricity production. Operating characteristics include operating conditions, operating profile, system capacity, system hardware, among others, which makes a comparison difficult in many instances. The indirect contribution is the dominant contributor in very low to no leakage or “tight systems”.

ES3. Update on R/AC alternative refrigerants and technologies

- **Based on comments from Parties on TEAP’s report to OEWG-38, this chapter provides further updates on refrigerant alternatives and new technologies, where these are currently in use. It also updates information on how standards are being developed, to address issues such as safety.**

- HC-600a and HFC-134a continue to be the primary refrigerant options for production of new domestic refrigeration appliances. It is projected that, by 2020, about 75% of new refrigerator production will use HC-600a, most of the rest will use HFC-134a, and a small share may apply unsaturated HFC refrigerants such as HFO-1234yf.

- In supermarkets, blends such as R-448A, R-449-A, R-449B, R-450A, and R-513A are now beginning to grow in use, starting with Europe and the United States. The same holds true for condensing units and self-contained equipment. In the self-contained equipment category, early trials with HFO-1234yf and HFO-1234ze have started. The use of R-407A and R-407F continues to grow further in many parts of the world.
- Refrigerants such as R-744 are increasingly being used in supermarket systems worldwide – both in cascaded systems (R-744 for low temperature cascaded with a second refrigerant such as HFC-134a or similar and R-717 in limited cases) and in transcritical systems. Transcritical systems are being researched extensively to reduce their energy penalty at high ambient conditions through the use of component and system technologies such as ejector, adiabatic condensing, sub-cooling and parallel compression.
- In industrial refrigeration the major trend, which also is a major challenge, is the focus on refrigerant charge reduction. The market for heat pumps is increasing rapidly. Industrial heat pumps use heat that is considered waste in other parts of production processes.
- In transport refrigeration, R-452A has been introduced during 2015 as a customer option on new truck and trailer refrigeration units. R-404A remains widely available. Activities are ongoing to assess R-744 and other non-flammable (class A1) lower GWP solutions such as R-448A and R-449A. R-513A, R-513B, and R-456A are being considered as future drop-in solutions for HFC-134a. Flammable (A3) and lower flammable (A2L) refrigerant research is continuing, aiming at producing publicly available and technically sound references to support code and standard activities.
- For air-to-air air conditioners and heat pumps, the most substantial recent developments are related to the increased rate of substitution of HCFC-22 and the greater consideration of use of medium and low GWP alternatives. Some manufacturers are adopting HCs and there is also uptake of HFC-32.
- For space heating and water heating heat pumps, legislation on minimum energy efficiency has entered into force in Europe, Japan and the USA, and has decreased the number of air to water heat pumps that can be placed on the market.
- In chillers, after years of research and screening tests, an array of choices is emerging and some commercialisation has begun. Emerging refrigerants are: HCFO-1233zd, HFC-32, R-452B, R-513A, R-514A, HFO-1234yf and HFO-1234ze(E).
- In mobile air conditioners (MACs), the penetration of HFO-1234yf for new vehicles has continued and has spread to many additional models, primarily in non-Article 5 countries, but is still far from complete. In addition, development of R-744 MACs has continued and commercialisation appears imminent. Other alternatives - including hydrocarbons, HFC-152a and additional HFC/HFO blends R-444A and R-445A - have not received much additional consideration and appear unlikely to be chosen for new vehicles in the near future.
- Vapour compression technology has been the primary technology for all R/AC applications in the last 100 years. Technologies that do not employ vapour compression technology are called Not-In-Kind technologies (NIK), of which, during past years, several have been under development. Some studies have classified the development status of those technologies as: (1) most promising (membrane heat pump, thermo-elastic); (2) very promising (evaporative liquid desiccant A/C, magneto-caloric, Vuilleumier heat pump); (3) moderately promising (evaporative cooling, thermo-electric, ground-coupled solid desiccant A/C, absorption heat pump,

duplex-Stirling heat pump, thermo-acoustic, adsorption heat pump, thermo-tunneling); and (4) least promising (stand-alone solid desiccant A/C, stand-alone liquid desiccant A/C, ejector heat pump, Brayton heat pump).

ES4. Alternatives to refrigeration systems on fishing vessels

- **Where it concerns fishing vessels refrigeration systems and possible alternatives, some minor updates on the rating of different refrigerant options have been made (see Chapter 4 and Annex 2), following discussions held at OEWG-38.**
- 70% of the global fishing fleet continues to use HCFC-22 as its main refrigerant. Therefore the main challenge for the industry is to find a feasible transition from HCFC-22 to low-GWP alternatives. Considering that 70% of the global fishing fleet is based in Asia/Pacific, this challenge becomes even more important for Asia/Pacific countries and specifically for the Pacific Island region, whose economy is heavily dependent on their fishing industry. For this reason, particular attention was paid to the situation in this region.
- Based on several parameters (age of vessels, availability of alternatives, technical and economic feasibility of conversions, meeting regulatory requirements of product importer), the transition from HCFC-22 to low-GWP alternatives can be implemented following four different options:

  Option 1 – Non-halocarbon refrigerants (i.e., R-717 and R-744);

  Option 2 - Refrigerant replacement with plant adjustments;

  Option 3 – Refrigerant drop-in; and

  Option 4 - Maintaining HCFC-22 systems.

ES5. Suitability of alternatives under high ambient temperature (HAT) conditions

- **No further updated information was available related to the testing programs on alternatives under high ambient temperature conditions, so the information remains unchanged in this chapter. Within the discussion of high ambient temperature design considerations (section 5.1) a limited review is provided of the proposal under discussion by parties to define high ambient temperature countries.**
- Chapter 5 updates information on three research projects (where more projects will currently be ongoing) 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 ORNL and that for the reports from AREP-II analysed here 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 or exceed 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 and A3 alternatives at installation, servicing and decommissioning at HAT conditions.

ES6. BAU and mitigation demand scenarios for R/AC

- **This chapter contains the same scenarios as the second version of the TEAP XXVII/4 Task Force Report (June 2016), based on the same existing regulations considered in that report. The chapter also contains the following changes and additions:**
    - **Additional information on the production of various HFCs important for the R/AC foam blowing, fire protection, MDIs and aerosols sectors.**
    - **A comparison of estimated HFC production with the global calculated HFC demand for the R/AC and other sectors;**
    - **Related to this chapter, Annex 4 of this report contains updated tables for total, new manufacturing, and servicing demand.**
- These scenarios (for the R/AC sector only) were cross-checked against current estimated HFC production data. The most recent estimates for the 2015 global production of the four main HFCs[1] are presented in the table below (some revisions were made in this September report); it shows a combined total for the four main HFCs of about 525 ktonnes.

Chemical	Best estimate for global HFC production in year 2015 (ktonnes)
HFC-32	94
HFC-125	130
HFC-134a	273
HFC-143a	28
Total	*525*

- The other HFCs used are mainly HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc at an estimated global 2015 production of about 90 ktonnes. For another HFC, HFC-236fa, estimates for Article 5 production are available at about 0.3 ktonnes in 2015. In climate terms, the total global 2015 production of all HFCs amounts to about 1,200 Mt CO_2-eq.
- 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 regulation in 2015 for specific sectors and sub-sectors. The mitigation scenarios remain the same as in the September 2015 XXVI/9 report as follows:

[1] These are the four main HFCs currently used in the R/AC (including MACs) sector; HFC-134a is also used as a foam blowing agent, in MDIs and technical aerosols.

- 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)

- The global calculated bottom-up demand for the R/AC sectors in 2015 amounts to 473 ktonnes (of which 220 ktonnes in non-Article 5, 273 ktonnes in Article 5 Parties). Compared to the total of 510 ktonnes it would imply that the demand from other sectors than R/AC would amount to about 37 ktonnes (this would mainly, but not only, concern HFC-134a, used as a foam blowing agent and used in MDIs and aerosols, as well as some minor use of the other HFCs in other sectors).
- 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;
  - The increase in total demand for the four main HFCs currently used in R/AC is due primarily to the growth in demand in the stationary AC sub-sector and secondly, to the growth in demand in the commercial refrigeration sub-sector. As mentioned, total global R/AC demand is in the order of 525 ktonnes for the year 2015 for the four main HFCs.
- *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 Parties over the period 2020-2030 was previously estimated in the different scenarios as follows (assuming a 6 years transition):
  - 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 Parties. The *total* integrated HFC demand for the R/AC sector in Article 5 Parties over 2020-2040 is as follows (assuming a 6 years transition):
  - 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 the R/AC manufacturing with high-GWP refrigerants is phased out, 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 shows the impact of persisting servicing needs as a result.
- *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. An 18 years conversion period has been studied for the MIT-3 scenario (costs have not been further addressed compared to what was available in the XXVI/9 TF report). Whereas the 6 and 12 years conversion periods result in a demand decrease starting after 2020-2024, the 18 years conversion period yields a 10% increase in demand first, until the year 2030, then starts to decrease and reaches the 2020 demand value again in the year 2037. For the 18 years conversion period there is still some high GWP servicing demand after 2050. The demand for the period 2020-2050 for a 6 years conversion period is about 15,800 Mt CO_2-eq., increases to 20,500 Mt CO_2-eq. for a 12 years, and to 27,000 Mt CO_2-eq. for an 18 years conversion period. The latter implies a 70% increase in demand compared to demand for a 6 years conversion period.
- 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. in 2035).
    - For each separate Article 5 Party 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.

ES7. Foam blowing agents

- **This is a new chapter in this final update version of the Task Force report. It presents new information on alternative blowing agents compared to the XXV/5 report in 2014 for the various types of foam, specified for the various application sectors. It also gives detailed information on the consumption of blowing agents in BAU and mitigation scenarios for both non-Article 5 and Article 5 parties in this sector.**
- The foams sector continues to make significant strides in addressing the phase out of ozone depleting materials, while the industry as a whole continues to grow with estimated longer term growth rates of approximately 3 % per year in Article 5 and 1.5% per year in non- Article 5 parties. Growth is driven by the opportunity for energy savings in buildings and in some Article 5 parties to improve food handling and reduce waste through cold chain improvements.

- Hydrocarbons have been a major part of Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) reduction for large parts of the foam sectors, however national and regional regulations regarding ODP and GWP, codes and standards related to thermal performance and energy consumption, fire safety, and volatile organic compound (VOC) emissions are currently driving the choice of blowing agents used by foam manufacturers.
- Thermal performance of foams is often an essential attribute, and in these cases the choice of blowing agent is an important consideration to long term performance. Transitions to new blowing agents may require significant reformulation and in some cases equipment modifications. This is particularly true when moving from non-flammable to flammable blowing agents. Fire safety concerns for small and medium enterprises (SMEs) is a particular concern, however, less flammable hydrofluoroolefins (HFOs) and hydrochlorofluoroolefins (HCFOs) are expensive and some Article 5 foam manufacturers may wait for advice and direction on how to transition directly from HCFCs to low GWP alternatives.
- HFO/HCFOs (HFO-1234ze(E), HCFO-1233zd(E), HFO-1336mzz(Z) are becoming increasingly available either commercially or in development quantities with additional capacity under construction. In many cases these may be used in blends (such as HCs, and methyl formate) to reduce cost and balance performance (such as thermal performance, flammability, and fire performance). Reformulation efforts are still ongoing however and in some areas, as in use for one component spray polyurethane foam, shelf life stability is a particular challenge.
- Successful transition to low GWP technologies in non-Article 5 parties in the coming years, and availability of these technologies are likely key factors for Article 5 parties to avoid transitioning to high GWP HFCs as part of a phase out of HCFCs.

ES8. Metered Dose Inhalers (MDIs) and aerosols

- **This is a new chapter in this final (update) version of this Task Force report (update of the chapter in the XXVI/9 TF report, September 2015). It presents some brief background on all aerosols technologies, an update of information on alternatives, and BAU scenarios for the HFC demand for 2015-2050 in metered dose inhalers (MDIs). It also deals with aerosols, including non-MDI medical, consumer and technical aerosols.**

***Metered dose inhalers*:**

- Inhaled therapy is essential for the treatment of asthma and chronic obstructive pulmonary disease (COPD). There are two main types of inhalers for the delivery of respiratory drugs: the metered dose inhaler (MDI) and the dry powder inhaler (DPI). HFC MDI and DPI alternatives are available for all key classes of drugs used in the treatment of asthma and COPD. Under a business as usual scenario, for the period 2015 to 2050, *total cumulative* HFC demand in MDI manufacture is estimated as 638 ktonnes (594.5 ktonnes HFC-134a; 43.5 ktonnes HFC- 227ea). This corresponds to direct HFC emissions with a warming impact of approximately 990 Mt CO_2-eq., which would be significantly less than the direct emissions warming impact of CFC MDIs had they not been replaced. Direct emissions from MDIs manufactured in Article 5 Parties are estimated to contribute a warming impact of 506 Mt CO_2-eq., and non-Article 5 Parties 483 Mt CO_2-eq. over the period.
- At present, it is not yet technically or economically feasible to avoid HFC MDIs completely in this sector because there are economic impediments in switching from

HFC MDIs to multi-dose DPIs for salbutamol, and because a minority of patients cannot use available alternatives to HFC MDIs.

Aerosols:

- Aerosols can be divided into three categories: consumer aerosols; technical aerosols; and non-MDI medical aerosols. Technically and economically feasible alternatives to ozone-depleting propellants and solvents (CFCs and HCFCs) are available for aerosols. A significant proportion of aerosol propellants have migrated to flammable hydrocarbons and dimethyl ether (DME), which dominate in the consumer aerosol market. Non-flammable and non-toxic HFCs are used in aerosols when flammability or toxicity is a consideration. HFCs are also used where emissions of volatile organic compounds (VOCs) are controlled.

- Based on preliminary data, global HFC demand for aerosols is estimated as 44,000 tonnes for 2015, with 15,000 tonnes HFC-134a and 29,000 tonnes HFC-152a. This corresponds to a warming impact from direct emissions of 25,500 kt CO_2-eq. Consumer aerosols were the largest category (84 per cent), with technical aerosols (14 per cent) and non-MDI medical aerosols (2 per cent) making up the remainder. The majority of consumer aerosols used HFC-152a propellant (74 per cent) and the remainder HFC-134a. The majority of technical aerosols used HFC-134a propellant (80 per cent) and the remainder HFC-152a. The majority of non-MDI medical aerosols used HFC-134a propellant (90 per cent).

- One possible BAU scenario for global HFC demand (HFC-134a and HFC-152a) in aerosols is presented for the period from 2015 to 2050. The *total cumulative* HFC demand in aerosols is estimated as 2,300 ktonnes (350 ktonnes HFC-134a; 1,950 ktonnes HFC-152a). This corresponds to direct emissions with a warming impact of approximately 740 Mt CO_2-eq. Direct emissions from aerosols manufactured in Article 5 Parties are estimated to contribute a warming impact of 300 Mt CO_2-eq., and non-Article 5 parties 440 Mt CO_2-eq., over the period. Production is expected to expand in Article 5 parties.

- HFC consumption in the Aerosols sector is currently ranked as the third largest after the refrigeration and air conditioning and foams sectors, where aerosols are a totally emissive use. There would be environmental benefits in selecting more climate-friendly options. In many cases, current HFC propellants and solvents can be substituted with lower GWP options, and by NIK alternatives where they are suited for the purpose. In some markets or for some products there may be challenges in adopting lower GWP options, which may not always be feasible.

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 held 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. A resumed OEWG-37 meeting was held 15-16 July. TEAP provided its response to Decision XXVII/4 in three parts: a first report submitted to OEWG-37 primarily focused on the R/AC sector; a second report submitted to OEWG-38 addresses comments received at OEWG-37 with the focus remaining on the R/AC sector. This third and final report provides updates related to the other sectors including MDIs and aerosols, where updated information was available to the TEAP, as well as responding to comments on the second report from Parties at OEWG-38, for consideration by parties at 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:

- Radim Cermak (CZ, member RTOC)
- 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)
- Petter Nekså (Norway, member RTOC)
- Keiichi Ohnishi (Japan, co-chair MCTOC)
- Alaa A. Olama (Egypt, member RTOC)
- Alexander C. Pachai (Denmark, 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, co-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 second report. The factors considered include:

- The relatively short period between the delivery of the final XXVI/9 Report (September 2015) and the preparation of the first report to OEWG-37, second XXVII/4 Report to be submitted for OEWG-38, and final update report to be submitted to MOP-28.

- 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, TEAP has taken an approach of providing a response to Decision XXVII/4 as follows:

- For OEWG-37, TEAP provided a 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 provided a second Task Force report that incorporated updates to the R/AC sector information only based on discussions at OEWG-37, and responded to other parts of the decision, including information on alternatives to refrigeration systems on fishing vessels.
- For MOP-28, TEAP is providing this Task Force update report, following discussions during OEWG-38. This will also include update chapters on foam alternatives (and scenarios), fire protection and medical and technical aerosols.

The chapter layout of this September 2016 TEAP Decision XXVII/4 Task Force update report is as follows:

Executive Summary

Chapter 1 - Introduction

Chapter 2 - Update on the status of refrigerants

Chapter 3 - Update on R/AC alternative refrigerants and technologies

Chapter 4 - Alternatives to refrigeration systems on fishing vessels

Chapter 5 - Suitability of alternatives under high ambient temperature (HAT) conditions

Chapter 6 - BAU and MIT scenarios for A5/non-A5 countries for 1990-2050: R/AC

Chapter 7- Foam blowing agents

Chapter 8 - Update on alternatives and BAU scenarios for 2015-2050: MDIs and aerosols

Annex 1 - Summary of informal discussion on the TEAP Decision XXVII/4 Task Force Report for OEWG-37

Annex 2 - Background information about refrigeration in the fishing industry

Annex 3 - EU (F-gas, MAC Directive), USA (EPA SNAP Program) and Japan regulatory prohibition

Annex 4 - Updated tables for total, new, manufacturing, and servicing demand

2 Update of the status on refrigerants

This chapter essentially contains the same information as the June 2016 version of the XXVII/4 Task Force report. No new refrigerants or blends have been added to the tables. Comments related to interest in including the current status of commercialization of the newer refrigerants were not addressed because either the information was not consistently available or was not able to be substantiated within the time period available to the Task Force to complete this final report.

2.1 Introduction

This chapter in the first report provided 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 included:

- A total 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, as well as increased safety risks of some of low-GWP refrigerants that need to be addressed.
- 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 on the methods of assessing the energy efficiency related to the use of a refrigerant.
- A discussion on the new refrigerants research and development, including challenges regarding costs and size is included. 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, testing, development and commercialization will decrease the number of viable candidates and that market experience will likely further narrow down the number of viable lower GWP candidates in the future.

For ease of reference, the names of the four largest 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).

The results of the above programs' testing of alternatives at high ambient temperature (HAT) conditions are further discussed in Chapter 5. 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. Results will be published when available.

The fluids participating in the four programmes named above and the refrigerants proposed under ASHRAE (ASHRAE, 2015), are presented in Table 2-3 for pure fluids and in Table 2-4 for blends with publicly known compositions. For ease of reference, key properties for selected commonly used refrigerants are given in Table 2-5 and Table 2-6.

The fluids which composition is not yet public are (with the 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 2-3: 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
HCFO-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
HFO-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
HFO-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
HFO-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 2-4: 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: Phase 1	Participation in AREP program: Phase 2	High ambient programmes for HCFC-22 and R-410A alternatives: PRAHA	High ambient programmes for HCFC-22 and R-410A alternatives: EGYPRA	High ambient programmes for HCFC-22 and R-410A alternatives: US DoE	Composition	Molecular Weight	Bubble point/dew or Normal boiling point (°C)	GWP 100 Year (IPCC5)	GWP 100 Year (RTOC)
R-514A**	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	HFC-134a	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 2-5: 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 2-6: 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 2-3 through 2-6 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 2-3 and 2-4, refrigerant designations, safety classes and compositions are taken from the AHRI AREP program where available, otherwise from ASHRAE 34 public review (ASHRAE, 2015).

- All other data in Tables 2-3 through 2-6 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 30 m^2 room as an example, the safety standard, in this case IEC 6335-2-40, allows 0.413 kg 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. It also requires a higher level of optimising to account for the low charge limitation 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, lower 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, R-717, R-744). The list also includes blends, which, in addition to the listed single-component candidates, comprise the so-called hydrofluoroolefins (unsaturated HFCs) such as HFO-1234yf and HFO-1234ze(E), along with traditional (saturated) HFC refrigerants to achieve the desired attributes of the blend, e.g., low GWP, lower 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 chemicals 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 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 uses a “gate” or decision point placed just in-front of each major investment, so that management can decide 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 (with a research acronym) released for small scale testing in industry test programs;
- 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);
- Submission and acceptance under pertinent government regulations (e.g., REACH or SNAP);
- 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. 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. An issue for the new mixtures is that many contain one of the two new molecules, HFO-1234yf or HFO-1234ze(E), which may have had only limited production until recently.

Once the fluid is launched in the market, companies will invest 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. Market shares obtained in the early phase tends to be relatively easy to sustain, which is 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 HFO-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 and it is also applied in one-component foam and some aerosol propellant 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 HCFO-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; and 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 include 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 and opportunities 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 5 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 are changed.
- 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 challenges in assessing the climate impact including the difficulties of obtaining reliable and accurate data on system leakage rates and determining the carbon emissions generated, now and in the future, and in producing the energy necessary to power the R/AC and HP system.

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

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 (R/AC and HP) equipment. The indirect contribution accounts for the CO_2-equivalent emissions generated during the production of the energy consumed by the R/AC and 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 measure 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 R/AC and heat pump systems during their 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 2-7 below). This taxonomy is based on fixed GWP values.

Table 2-7 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 2-7: 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 2-8, 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 2-8: 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 is in class B2L.

2.9 Environmentally sustainable and environmentally sound

The alternatives described under “low” or “lower” GWP here aim at satisfying a criterion of “environmentally sustainable” or “environmentally sound” (as this classification was used in Decision XXVI/9, taken in 2014).

“By environmental sustainability we mean meeting current human needs without undermining the capacity of the environment to provide for those needs over the long term.” (http://www.unmillenniumproject.org/documents/EnvironSust_summary.pdf).

None of the substances proposed as refrigerants are without potentially adverse impacts to the environment if the emissions are large enough (with the exception of water and air, neither of which can be widely applied). A good example is R-744 (CO_2) which has no ODP and a very low GWP, however its emissions related to energy production are the primary contributor to global warming. What the environment and humanity is able or willing to handle is a policy decision, and so is the fraction of the environmental load allowed to be related to refrigerant emissions. One option to consider might be setting certain limits on direct refrigerant emissions relative to the IPCC 2050 scenarios. One could propose that a maximum of 1% of total GHG emissions could be an acceptable contribution of refrigerants and foam blowing agents. However, even with this type of policy approach the question remains of how emissions should be distributed between various application sectors within this very “broad” industry. Further, determining how much GHGs (HFCs) could be produced, and over what time frame, and how banks of these chemicals would be addressed such that the emissions through 2050 met this criterion, would involve establishing highly uncertain assumptions (e.g., leak rates) which could be very different between those various applications.

The following definition for ”environmentally sound” is often used: “*An environmentally sound product or manufacturing process is a product or process that, from beginning to end, is in essential harmony with its environment and the associated ecological factors”* (http://www.businessdictionary.com/definition/environmentally-sound.html)

Article 10, paragraph (c) of the Kyoto Protocol (as decided in 1997) reiterated that all Parties shall: “co-operate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies.”

The IPCC in its AR5 report (IPCC, 2014) describes barriers for the spread of environmentally sound technologies (ESTs), as follows: “The spread of proven environmentally sound technologies that would diffuse through commercial transactions may be limited because of existing barriers. Barriers to the transfer of environmentally sound technologies arise at each stage of the process. These vary according to the specific context, for example from sector to sector and can manifest themselves differently in developed countries, developing countries and countries with economies in transition.” The IPCC report provides an extensive overview of the most important barriers in developed, developing and transition economies that could impede the transfer of environmentally sound technologies to mitigate and adapt to climate change. Governments can promote technology transfer by reducing these barriers.

2.10 References

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3 Update on R/AC alternative refrigerants and technologies

This chapter has been slightly updated in various sections. It updates information on the current development of standards (section 3.11), addressing issues such as safety, within the R/AC sector.

3.1 Domestic Appliances

HC-600a and HFC-134a continue to be the primary refrigerant options for production of new equipment. It is projected that, by 2020, about 75% of new refrigerator production will use HC-600a, most of the rest will use HFC-134a, and a small share may apply unsaturated HFC refrigerants such as HFO-1234yf.

Globally, the activity undertaken so far on HFO-1234yf in domestic refrigerator applications remains very limited and is not being pursued with high priority, due to cost implications. The use of HFO-1234yf in a domestic freezer has been tested as a proof of concept.

The Association of Home Appliance Manufacturers (AHAM) of North America has recently announced a voluntary goal to phase down HFC-134a in household refrigerators and freezers after 2024. It is not yet clear whether manufacturers will choose HC-600a (class A2) or HFO-1234yf (class A2L) as both are flammable and still have to adhere to current and emerging safety and energy efficiency standards.

In the proposed USA Significant New Alternatives Policy (SNAP) listing of 18 April 2016, HFC-134a in domestic appliances is listed as undesirable as of 1/1/2021. The EU F-gas regulation 517/2014 prohibits the use of HFC-134a in domestic appliances as of 1/1/2015. This implies that the whole sector has been converted to a low GWP refrigerant (defined as GWP<150 in Regulation 517/2014) and HFC-134a can no longer be used, including in the insulation foams of this equipment.

The heat pump clothes (laundry) dryer (HPCD) sales using HFC-134a are rapidly growing in the EU. HPCDs using R-407C and HC-290 have also been introduced. New research with R-744 shows significant efficiency gain may be possible. Alternative refrigerant solutions that are being explored include HC-600a and low GWP HFOs.

3.2 Commercial Refrigeration

While the F-gas regulation 517/2014 is now effective in Europe, in the United States, the Environmental Protection Agency (EPA), as already mentioned above, published a final rule for change of status of refrigerants in several applications under its SNAP program. Of significance were three changes of status: (1) for supermarket systems, (2) for condensing units and (3) one for self-contained coolers and freezers. In all of these applications, the high GWP HFC blend R-404A is not allowed in new equipment starting in January 1, 2017 for supermarkets, January 1, 2018 for condensing units and January 1, 2019 or 2020 for certain self-contained systems. Canada has signalled its intention to do something similar, and the US state of California is looking to the European F-gas regulation for its regulation. These are examples of governments that have started down the path of not allowing high GWP HFC refrigerants or HFC based blends in new equipment.

Lower GWP refrigerants and HFC blends (both class A1 and class A2L) are also being approved for use in various equipment types. The recent impact of these developments is summarized below for various refrigerants as relevant to commercial refrigeration equipment.

In supermarkets, blends such as R-448A, R-449-A, R-449B, R-450A, and R-513A are now beginning to grow in use, starting with Europe and the US. Component manufacturers (compressors, valves, controls etc.,) are releasing new products and approving existing products for use with these new refrigerants which range from half to a third of the GWP of the refrigerants that they are replacing.

The same holds true for condensing units and self-contained equipment. In the self-contained equipment category, early trials with HFO-1234yf and HFO-1234ze(E) have begun as well. The use of R-407A and R-407F has been considered. R-407F is used as a substitute for R-404A (GWP=3922) in refurbishment of existing systems. This is seen predominantly in the EU where a servicing ban of systems operating with refrigerants exhibiting a GWP >2500 enters into force on 1 January 2020.

Refrigerants such as R-744 are increasingly being used in supermarket systems worldwide – both in cascaded systems (R-744 for low temperature cascaded with a second refrigerant like HFC-134a or similar and R-717 in limited cases) and in transcritical systems. Transcritical systems are being researched extensively to reduce their energy penalty at high ambient conditions through the use of component and system technologies such as ejector, adiabatic condensing, sub-cooling and parallel compression. R-744 is also beginning to see its use in walk-in applications with condensing units. Self-contained systems are increasingly moving from R-404A, HCFC-22 and HFC-134a to HC-290 or R-744. Charge limits continue to limit the size of the equipment possible with the hydrocarbon refrigerant.

3.3 Industrial Systems

In the time since the release of the 2014 RTOC Assessment report, a number of overarching trends have been identified and are expected to be included in the 2018 Assessment report. The biggest trend in industrial refrigeration, which also forms an extensive challenge, is the constant focus on refrigerant charge reduction. Another big trend in the market is the heat pump market development. Industrial heat pumps use heat that is considered waste in other parts of production processes. An example is the dairy sector, where milk is both cooled and heated in different sequences. The pasteurization process requires temperatures around 70 to 80°C. Different technologies are used to achieve these temperatures.

For industrial processes, high temperature heat pumps are required, with temperatures to be produced of up to about 100 °C, sometimes even up to 180°C. Water Vapour Recompression (VRC, process recovering low heat steam at low pressure and compressing it to a high pressure and high temperature) is gaining a lot of attention.

In some Parties, industrial refrigeration systems have been widely based on HCFC-22. Also in Article 5 Parties, the trend is now to abandon it and look for drop-in alternatives or for new refrigerant solutions.

District energy concepts (District Heating combined with District Cooling, «DC») are growing all over the world including in Article 5 countries. In Europe, the two countries where the DC concept is most applied are France and Sweden. There is now more emphasis on applying DC in the Middle East post the 2014 assessment since it has the largest DC growth potential in the world. Recently the Multilateral Fund Executive Committee approved demonstration projects in the area. Implementing agencies UNIDO/UNEP are preparing demonstration projects in Egypt, Kuwait and Colombia to help establish “New Technologies”, legislation and benefits of DC for these areas. DC can be driven by vapour compression or absorption chillers (which fits into NIK) but in any case it requires significant investments in infrastructure. Based on the financial assessment of the investments and operation costs DC can be implemented in new buildings or new buildings networks.

3.4 Transport refrigeration

R-452A has been introduced during 2015 as a customer option on new truck and trailer refrigeration units (it is a blend consisting of HFC-32, HFC-125 and HFO-1234yf). R-404A continues to be offered as well for its wide availability. R-452A has similar cooling capacity, fuel efficiency, reliability and refrigerant charge as R-404A, but it offers a 45% GWP reduction. The features supporting R-452A in transport refrigeration include non-flammability and low compressor discharge temperatures. By January 2016, one manufacturer has sold 1500+ units with R-452A already. The close property match of R-452A to R-404A gives customers the option to retrofit their existing fleets. The conversion does not require component changes and it can be carried out in the field during the life of the product.

In addition, activities are ongoing to assess R-744 and other non-flammable (A1) lower GWP solutions such as R-448A and R-449A. The blends R-513A, R-513B, and R-456A are being considered as future drop-in solutions for HFC-134a that is utilized in some refrigerated vans and a large number of marine containers. These blends have approximately 50% of the GWP of HFC-134a. R&D is ongoing, but no products have been released so far based on these refrigerants blends.

Flammable (A3) and lower flammable (A2L) refrigerant research has continued, aiming at producing publicly available and technically sound references to support code and standard activities with regard to transport systems. König and Bararu (2014) have shown that frequency of hazard and probabilities of fatalities for the global reefer container fleet would be below 10^{-6} (one in a million) if adequate design changes were in place and best practice guidelines were established. In February 2016, the first meeting took place to develop the International Organisation for Standardisation (ISO) 20854 safety standard for refrigerating systems using flammable (A2) and lower flammable (A2L) refrigerants in marine containers. The feasibility of using HC-290 in trucks has been demonstrated in a demo unit in South Africa and was presented at the MOP-27 in Dubai in 2015. The benefits are an improved energy performance and lower life cycle CO_2 emissions. The project included a risk assessment, careful components selection, and leak simulation tests.

An energy optimization of a cryogenic system has entered a commercial testing phase in the United Kingdom (UK). The system uses liquid nitrogen to provide cooling through its expansion and to power a Dearman engine supplying a vapour compression cycle. A second generation machine is being developed but this has not yet reached a commercially viable stage.

A UK supermarket chain continues carrying out trials of an R-744 refrigerated trailer since 2013. They revealed that they have subsequently acquired a second R-744 trailer that can operate at different temperatures and this will be joined by a third in 2016.

Since 2012, companies shipping and leasing reefer containers have continued to trial R-744 units from the same manufacturer. R-744 systems have been installed in reefer containers in UK for commercial use. Training for service and repair is available.

The German and French railways have continued to look at air cycle systems as alternatives to vapor compression systems. In March 2015 DB (Deutsche Bahn) has equipped a first and in May 2016 a second multiple unit (Intercity-Express (ICE)) train with an improved air cycle system and set up an 2 year extensive field data measurement program, while Société Nationale des Chemins de Fer (SNCF) has set up a 24-months demonstration program in a regional train.

3.5 Air-to-air air conditioners and heat pumps

Air conditioners, including reversible air heating heat pumps (generally defined as “reversible heat pumps”), range in size from 1 kW to 750 kW although the majority are less than 70 kW. The most popular are non-ducted single splits, which are produced in excess of 100 million units per year. Whilst nearly all air conditioners manufactured prior to 2000 used HCFC-22, all products sold within non-Article 5 Parties now use non-ODS refrigerants, albeit largely without the use of low-GWP alternatives. For most products, R-410A is used. Whilst the production of air conditioners using HCFC-22 remains the dominant option within Article 5 Parties there is a substantial shift in many countries to move to HFCs and HCs, approximately one half of all units produced globally use non-ODP refrigerants. Nevertheless, the majority of the installed unit population still uses HCFC-22; an estimated two-thirds of a billion HCFC-22 air conditioners are operating worldwide, representing approximately one million tonnes of HCFC-22.

The most substantial recent developments are related to the increased rate of substitution of HCFC-22 and the greater consideration of use of medium and low GWP alternatives. Previously, medium and low GWP alternatives were not being given major consideration (except HCs such as HC-290) whereas now additional manufacturers are adopting HCs and there is also uptake of HFC-32, especially in Japan where in 2014 100% of residential split air conditioner production was switched to HFC-32. Several enterprises – in Japan, and recently in other Parties as well, – are promoting and selling air conditioners using HFC-32 outside of Japan. Many enterprises are also considering and evaluating new HFC/HFO blends, such as mixtures of various compositions of HFC-32, HFC-125, HFC-134a, HFO-1234yf and HFO-1234ze(E). Broad testing has been carried out of these mixtures within various collaborative industry projects and the results are being made available on a regular basis. Whilst R-744 remains to be applied in larger types of systems within more temperature climates, there has not been any significant shift in increasing adoption of the technology.

China has completed the conversion of 18 production lines to HC-290 as part of their HPMP and portable units are being sold widely. In India, at least one plant has produced several hundred thousand HC-290 split air conditioners. There is also additional information relating to different alternatives performance under high ambient conditions. Nevertheless, some enterprises within the Middle East still see R-407C and HFC-134a as favourable alternatives to HCFC-22.

In light of the fact that almost all medium and low GWP alternatives are flammable there has been some developments on new requirements for safety standards (particularly for increasing refrigerant charge size), by the working groups addressing A2, A2L and A3 refrigerants at both IEC and ISO level. Nevertheless, significant progress is still needed in order to have a technology neutral assessment (enabling flexibility and better cost estimates). Due to the complexities of the process it is unclear by when amendments will be finally published.

3.6 Water heating heat pumps

In Europe, Japan and the US, the legislation on minimum energy efficiency for space heating and water heating heat pumps became active and has limited the number of air to water heat pumps that can be placed on the market.

For space heating heat pumps in the EU, the minimum energy efficiency was set as a primary energy efficiency based on seasonal efficiency, placed in an average European climate with a design temperature at -10°C, including standby losses. From September 2015 on, all space heating heat pumps shall have a primary energy efficiency of 100%. For low temperature space heating heat pumps it shall be 115%. This results in a seasonal coefficient of performance (SCOP) of respectively 2.5 and 2.875. From September 2017 onwards, the values shall be 110% (SCOP of 2.75) and 125% (SCOP of 3.125). The seasonal efficiency is based on a specific temperature pattern and includes standby energy losses. For water heating heat pumps the requirements are less restrictive except for larger systems where the requirements will have restrictions as of September 2018. For the moment, there is no drastic impact on the refrigerant currently used.

HFC-32 has been just introduced by one manufacturer in Japan as the refrigerant for water heating systems (mainly R-744 products are sold in the market). Unlike R-744, which can produce hot water with temperatures up to 90°C, the temperature of the water is limited to 65°C. The main purpose is to offer a cost competitive and high energy efficiency solution for families with lifestyles suited to operations of this system.

3.7 Chillers

The components, refrigeration cycles used, systems, and application of chillers remains largely unchanged from the 2014 RTOC Assessment Report or since 1980 for that matter with exception of increased use of variable-speed drives. Vapour compression technology dominates all chiller types, and there has been little progress towards commercialisation of magnetic refrigeration based chillers and other not-in-kind technologies. However, absorption chillers are, and will continue to be, part of the global mix of chillers. In all regions, there is a demand for higher performance chillers and the systems that use them, at both full and partial load. Some manufacturers are offering newly designed compressors, have expanded the use of variable speed drives and permanent magnet motors, and are using more sophisticated control systems. Manufacturers, consumers, and regulators alike have had an ongoing interest in low GWP refrigerants with high thermodynamic efficiency. The slow movement to new refrigerants reflects the high cost of product development and tooling changes, as well as the uncertainty in the supply of new refrigerants by chemical producers who also face huge investments and regulatory hurdles. None-the-less, chiller manufacturers seem to be gravitating to lower GWP alternative refrigerants, and have introduced a number of new products that use them.

The 2014 RTOC Assessment Report gave a complete discussion of the trade-offs and research efforts associated with use of lower GWP refrigerants. As noted in the report, in order to be acceptable, new refrigerants should result in products with energy efficiencies that are equal to or better than the refrigerants replaced. Secondly, the global warming effects from chillers are dominated by the energy-related component from their power consumption. Total Equivalent Warming Impact (TEWI) and Life Cycle Climate Performance (LCCP) models typically show that more than 95% of the climate effect is due to energy consumption. The direct global warming effects from refrigerant emissions are significantly smaller since direct emissions have been significantly reduced in recent years through lower charge systems, low-leak designs, manufacturing and testing improvements, and improved service practices.

Chillers have traditionally used an array of refrigerants due to the economics associated with high performance compressors as well as physical size and manufacturing constraints over the range of capacities provided by chillers. Table 9-1 of the 2014 RTOC Assessment Report gave a discussion and complete listing of all chiller types by size, compressor type, and refrigerants used.

After years of research and screening tests, an array of choices is emerging. Some commercialization has started and recent new product introductions indicate that a change has started (shown in Table 3-1).

Table 3-1 Emerging refrigerants used in Chillers

Product	Refrigerants presently in use	Emerging refrigerants
Large chillers with centrifugal compressors using low pressure refrigerants	CFC-11[2] HCFC-123 [1] HFC-245fa	HCFO-1233zd(E) R-514A
Large chillers with centrifugal compressors using medium pressure refrigerants	CFC-12[2] HFC-134a	R-513A HFO-1234yf HFO-1234ze(E)
Mid-size chillers with positive displacement (screw) compressors	CFC-12[2] HFC-134a	R-513A HFO-1234yf[3] HFO-1234ze(E)[3]
Small chillers with positive displacement (scroll or recip) compressors	HCFC-22[2] R-407C R-410A	HFC-32[3] R-452B[3]

1. *Phase-out in new equipment in 2020*
2. *Phased out but may still be used for servicing in Article 5 Parties*
3. *Classified as A2L refrigerant (lower flammable)*

The emerging refrigerants may not be the final selections. With high efficiency as a primary customer requirement, new product introductions will use refrigerants that likely preserve or improve thermodynamic efficiency with significantly reduced GWPs. A number of refrigerants are listed as safety class 2L (flammable with flame propagation speeds of 10 cm/s or less). Some Parties, notably the U.S., have not yet implemented the necessary product standards and code changes to use these refrigerants in the occupied space or in large machinery rooms without the burdensome requirements of safety class 2 or 3, highly flammable refrigerants. Even with codes and standards changes, some additional application cost may be expected. Taken together with generally higher refrigerant costs, this means that the cost of new chillers with lower GWP refrigerants is likely higher. Manufacturers typically pass along additional costs, and therefore the price is likely higher, which typically will dampen the demand as long as the existing product is not discontinued.

Regulation is taking a leading role in mandating the adoption of new refrigerants with lower GWPs. There is continued pressure for the use of lower GWP refrigerants in all Parties and industry is responding. For example, AHRI (the manufacturer's trade association in the US) and NRDC (the National Resources Defense Council, Washington, D.C.) recently agreed to discontinue sale of chillers using higher GWP refrigerants HFC-134a, R-410A and R-407C by 1/1/2025. This agreement is consistent with the emerging refrigerants listed in Table 3-1. The agreement also provides support to the US EPA's proposal to ban all 3 refrigerants from new production chillers, although the EPA proposed timeline is somewhat quicker. The time to 2025 will allow manufacturers to complete the design and implementation of full product lines, and work on cost reductions. At the same time, refrigerant producers will need to increase capacity to meet demand, and put products into the product service infrastructure. Ideally, as the product changes occur, major disruptions will be avoided.

One can also not overlook the role that zero or near-zero GWP refrigerants such as R-717, R-718, and HC-290, and absorption chillers may play. As noted in the 2014 RTOC Assessment Report, these alternatives have been available for some time, and new choices may emerge. It is impossible to predict the market mix that may emerge, especially in view of future government regulations or incentives.

As far as drop-in alternatives or retrofits are concerned, it is too early to tell if manufacturers will offer retrofit packages for use in upgrading existing chillers with the emerging lower GWP refrigerants. While technically possible, it would not be likely for several reasons. First, all compressor types are optimized for the specific refrigerant used. Substituting a different refrigerant usually results in a loss of capacity, efficiency or both. Second, the pressure ratio for fixed displacement compressors may limit the ability of the compressor to reach the appropriate pressure rise when a different refrigerant is used. A similar phenomenon is found in centrifugal compressors when changing refrigerants, but may be overcome with a change in impellers or speed when a variable speed drive is used. Third, many of the emerging refrigerants are safety class 2L. Use of a safety class 2L refrigerant to replace a safety class 1 refrigerant may require significant changes to meet the building codes and standards, as well as product standards (such as UL, listing to a product standard). These things taken together would likely discourage retrofits.

3.8 Vehicle air conditioning

Since the 2014 RTOC Assessment Report, no new alternatives have been introduced in light-duty mobile air conditioners (MACs). The penetration of HFO-1234yf for new vehicles has continued and has spread to many additional models, primarily in non-Article 5 Parties, but is still far from complete. HFC-134a continues to be used in the majority of new vehicles, especially in vehicles used in Article 5 Parties. Regulations and announcements of such - including the MAC Directive of 2006 in the EU, credit system and model year 2021 HFC-134a phase-out in the US, the Canadian consideration of bans and HFC phasedowns, and the Japanese target GWP of 150 by 2023, - continues to be primary factors influencing this trend. In addition, development of R-744 MACs has continued and appears imminent, with announcements from Mercedes-Benz to use it in new S-class and E-class models for the EU beginning in 2017, and indications that Audi A8 and Volkswagen Phaeton models will also use R-744 in 2017.

Other alternatives that were discussed in the 2014 RTOC Assessment report, - including hydrocarbons, HFC-152a and additional HFC/HFO blends R-444A and R-445A, - have not received much additional consideration and appear unlikely to be chosen for new vehicles in the near future.

The trend in electrified drivetrains continues, with hybrids and battery-electric vehicles capturing more of the market. This is important in terms of refrigerant as these vehicles will increase the desire for heat pump (heating and cooling) systems in lieu of cooling-only systems. More advanced designs integrating battery and/or electronics cooling with the passenger comfort system are likely to be introduced.

Buses still rely primarily on HFC-134a and R-407C for passenger comfort. Some vehicles using R-744 are operating, and their use, while currently nearly 90 buses in Europe, is increasing but is limited by the availability of open-type compressors. The trend to hybrid electric buses will allow hermetic or semi-hermetic compressors, making the use of R-744 more likely.

Heavy Duty trucks still rely on HFC-134a for driver comfort. Some versions are likely to introduce HFO-1234yf soon.

3.9 Not-In-Kind technologies

This chapter looks into technologies that do not employ vapour compression technology. They are called Not-In-Kind-Technologies (NIK). Vapour compression technology has been the dominant technology for all R/AC applications in the last 100 years. Nevertheless, during past years several other technologies have been developed. The development status of those technologies can be classified as:

- R&D status
- Emerging technology
- Commercially available

Recently, the U.S. Department of Energy (U.S. DoE, 2014) developed a study to characterize and evaluate alternatives to vapour-compression technology to serve future residential and commercial HVAC applications. Provided below are some of the main aspects of this study.

NIK technology classifications are divided into three groups according to their particular driving energy. Those are:

- Thermally driven.
- Electro- mechanically driven.
- Solid State driven.

Seventeen NIK technologies from these 3 groups were compared in the study to a baseline vapour compression technology, considering the following criteria:

- Energy savings potential.
- Non-energy benefits.
- Cost/complexity.

1. Heating and cooling capabilities.
2. Development status.
3. Market barriers.

Based on these criteria they were classified as i) most promising, ii) very promising, iii) moderately promising, and iv) least promising:

- Most promising: membrane heat pump, thermo-elastic;
- Very promising: evaporative liquid desiccant A/C, magneto-caloric, Vuilleumier heat pump;
- Moderately promising: evaporative cooling, thermo-electric, ground-coupled solid desiccant A/C, absorption heat pump, duplex-Stirling heat pump, thermo-acoustic, adsorption heat pump, thermo-tunneling;
- Least promising: stand-alone solid desiccant A/C, stand-alone liquid desiccant A/C, ejector heat pump, Brayton heat pump.

The present status, the development of prototypes and equipment and the expected technical progress of some NIK technologies are being discussed by RTOC and will be covered in the 2018 RTOC Assessment Report.

3.10 Developments of CO_2 technology

Applying CO_2 (R-744) as a working fluid is common in hot water and industrial heat pumps, light commercial beverage cooling and especially in supermarket refrigeration.

Due to the thermodynamic properties of CO_2, throttling losses compared to conventional low-pressure fluids are significantly higher, particularly at elevated heat rejection temperatures common at higher ambient temperatures where the energy efficiency of the CO_2 units is lower.

Introducing an internal heat exchanger can help to reduce the throttling losses. In addition, utilising the kinetic energy of the fluid flowing from the high- to the low-pressure side can save compressor work instead of dissipating it in the throttling process. Two apparatuses are able to perform such work recovery, expanders and ejectors.

Expanders uses the throttling energy to assist the compressor and are comparable with compressors with respect to cost and complexity.

Ejectors are more comparable to expansion devices, however, they use the expansion of the high-pressure fluid to entrain and compress a low-pressure fluid by means of momentum transfer between the two steams inside the ejector without moving parts. Ejectors are suitable for dedicated applications due to their high robustness, reliability and potential low cost.

As reported by Elbel and Lawrence (2016), the work recovery efficiency of CO_2 ejectors is generally in the range of 20-30%, which means that 20-30% of the normally dissipated expansion work is applied to unload the compressor by pre-compressing the suction stream from suction inlet pressure (evaporator outlet) to the separator pressure (compressor inlet). Unloading the compressor is not the only benefit of an ejector, using it to simultaneously pump additional liquid through the evaporators, i.e. overfeeding them, avoids dry-out and improves the evaporator and system performance significantly. This increases the required suction pressure of the compressor twice, firstly due to the elevated evaporation temperature (flooded evaporation) and the pre-compression of the evaporator outlet fluid.

For commercial refrigeration applications, as in supermarkets, ejector systems enabling continuously flooded evaporator operation are commercially available. There are more than 40 ejector supported CO_2 installations around the globe. The first pilot systems applying additional compressor unloading by pre-compressing of medium temperature vapour (from chilled food display cabinets) are successfully operated for several years in Switzerland (Schönenberger et al. 2014).

The multi-ejector is an add-on enhancement technology increasing the energy efficiency at high ambient temperatures to a state of the art CO_2 booster system with parallel compression. The parallel compression booster system represents a development step towards higher energy efficiency compared to the traditional booster systems with flash gas by-pass. Based on the experimental investigations in laboratories and field tests of the CO_2 supermarket systems, a seasonal energy efficiency improvement of 10% is obtained between a CO_2 booster and a similar system with parallel compression. At high ambient temperatures, another 20% improvement is achievable when adding the multi-ejector technology to a well-designed CO_2 parallel compression system. Global supermarket chains, operating CO_2 ejector supported supermarkets in Spain, have measured an annual energy saving of 25% compared to the previous HFC unit installed prior to the remodelling of the supermarket.

Utilization of heat recovery for space heating (where needed) and hot water production is an important part of the refrigeration systems and can be done with CO_2 without any large extra effort.

CO_2 ejector technology is under development for other applications such as industrial or commercial cold storage refrigeration systems, transport refrigeration systems, industrial heat pump applications, chillers, etc.

3.11 Standards in the R/AC industry

For the refrigeration, air-conditioning and heat-pump industry the two most important standardisation organisations for international standards are the International Organization for Standardisation (ISO) and the International Electro-technical Commission (IEC). In some cases, standards from nationally based organisations will be more recognised in the field (e.g., ASHRAE, UL and SAE in the United States). In these cases, efforts may be made to harmonise with ISO and IEC standards as appropriate.

ISO has published two standards of high relevance to the topic of refrigerants: (1) “ISO 817 Refrigerants - Designation and safety classification” and (2) “ISO 5149 Refrigerating systems and heat pumps - Safety and environmental requirements”. ISO 5149 is the primary standard for larger systems. IEC has published relevant application specific standards as parts of the standard “IEC 60335 Household and similar electrical appliances – Safety”, for instance “IEC 60335-2-40 Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers”. The IEC application standards are typically used for factory build systems, while the ISO 5149 is typically used for larger systems.

The safety standards covers topics such as:

- Refrigerant safety: Definitions and charge limits and definitions.
- Construction: Approval of components, piping, joints and assemblies, pressure testing and tightness requirements, safety valves and switches, setting and selection, avoidance of ignition sources for flammables.
- Installation: Machine rooms, other installation sites, ventilation.
- Maintenance: Safe practices, avoid leaking refrigerants

Some of these topics, especially the charge limits, have profound influence on which refrigerants are considered safe to use in what applications.

The text of a standard is produced by a Working Group, a sub-committee of the Technical Committee of either ISO or IEC responsible for all standards related to refrigerating systems safety. In shorthand this is ISO/TC86/SC1 or IEC/TC61D/SC61. The technical committee members are nominated representatives of national standards bodies (NSB) and the committee business is conducted by ballot, with votes cast by the head of delegation from each country on behalf of their NSB. In contrast, the members of a WG are nominated experts who do not represent a country or NSB and who do not need to be members of the TC. The WG strives to meet face-to-face, and participation of experts in the standardisation working groups is typically sponsored by the employer of the expert. Membership of the Technical Committee is open to representatives of all member countries (ISO has 161 members, while IEC has 83 members and associated members).

The international standards preparation processes comprise several defined stages requiring alternate input from NSBs and Working Group members. A committee draft is prepared by the WG and circulated to NSBs for comment. The comments received are resolved to the best of the WG’s ability in discussion, within a consensus process and the resultant draft standard is sent to the NSB’s for vote. The rules for voting are complex but clearly defined. The standard is only accepted if several criteria are met. In some cases, particularly if a large number of comments are received to the draft standard, the text will go back to the working group for review and will then be recirculated as a second draft. Once the text has been refined, the standard will be reissued as a final draft for vote by the NSB’s. If the votes meet the criteria then the text will proceed to publication. The process of updating a standard typically takes 3-5 years, although the complexity of safety standards can make the consensus driven process drag out considerably.

There is currently a strong focus on enabling climate friendly refrigerants in both ISO/TC86/SC1 or IEC/TC61. Under ISO/TC86/SC1/WG1 work is ongoing re-evaluating the charge limits for flammable refrigerants focus to date has been on the A2L safety class (e.g. the lower flammability refrigerants), however focus is increasing on the A2 and A3 safety classes (e.g. HFC-152a and the hydrocarbons).

Under IEC/TC61 there are several working groups considering flammable refrigerants:

- IEC/TC61C/WG04 considers added requirements for display cabinets to allow for larger charges of flammable refrigerants. WG04 started working in 2015 and expect the resulting change in the safety standard to be in 2018.
- IEC/SC61D/WG09 considers added requirements for domestic and light commercial air-conditioning and heat-pumps to allow for larger charges of flammable refrigerants of A2L safety class. WG09 started working in 2011 and although a committee draft for vote (CDV) will be published on 14th of October 2016, the final inclusion into the standard is expected to be in 2018-2019.
- IEC/SC61D/WG16 considers added requirements for domestic and light commercial air-conditioning and heat-pumps to allow for larger charges of flammable refrigerants of A3 safety class. The working group started working in 2015, and the work is still focusing on getting consensus on the conceptual level. A preliminary optimistic estimate for the change in the standard is 2021, but the timing is very uncertain at this early point in the process.

3.12 References

Elbel and Lawrence, 2016	Review of recent developments in advanced ejector technology. 2016. Int. J. Refrigeration, Volume 62, February 2016, pp. 1-18, ISSN 0140-7007
Schönenberger et al., 2014	Experience with ejectors implemented in a R-744 booster system operating in a supermarket. 2014. 11th IIR GL Conference, Hangzhou, China (paper 19)
U.S. DoE, 2014	Energy Savings Potential and RD&D Opportunities for Non-Vapor-Compression HVAC Technologies

4 Alternatives to refrigeration systems on fishing vessels

Where it concerns fishing vessels refrigeration systems and possible alternatives, some minor updates on the rating of different refrigerant options have been made (see Chapter 4 and Annex 2), following discussions held at OEWG-38.

4.1 Introduction

In order to respond to the following question asked within the Decision XXVII/4 of the Twenty-seventh Meeting of the Parties:

(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 :

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

a Working Group was established within the TEAP Decision XXVII/4 Task Force.

As their first action, the members of the Working Group, aiming at clarifying the problems being experienced by the fishing industry, compiled a questionnaire to be circulated to Parties in order that an understanding of their needs could be ascertained. Responses to the questionnaire as well as further investigation of worldwide fishing practices, refrigeration systems and techniques employed were considered by the Working Group in the development of this chapter (see Annex 2 for a broader description).

4.2 Considerations and options for replacement and retrofit of refrigeration systems in fishing vessels

As a summary of the analysis performed on the world fishing industry, with a particular attention on the situation in the Pacific Islands region, the following are important considerations of the options for replacement and retrofit of refrigeration systems on fishing vessels:

- 70% of the global fishing fleet continues to use HCFC-22 as its main refrigerant. Therefore the main challenge for the industry is to find a feasible transition from HCFC-22 to low-GWP alternatives.
- Considering that 70% of the global fishing fleet is based in Asia/Pacific, this challenge becomes even more important for Asia/Pacific Parties and specifically for the Pacific Island region, whose economy is heavily dependent on their fishing industry.
- Based on several parameters (age of vessels, availability of alternatives, technical and economic feasibility of conversions, meeting regulatory requirements of product importer), the transition from HCFC-22 to low-GWP alternatives can be implemented following four different options as further discussed in the following sections, with rating provided according to the degree of financial, technical and regulatory risk, and in Annex 2:
    - Option 1 – Non-halocarbon refrigerants
    - Option 2 - Refrigerant replacement with plant adjustments
    - Option 3 – Refrigerant drop-in
    - Option 4 - Maintaining HCFC-22

4.2.1 Option 1 – Non-halocarbon refrigerants R-717(Ammonia) and R-744(CO2

Current technology using ammonia (R-717), carbon dioxide (R-744) or ammonia/carbon dioxide cascade, provides solutions for almost all refrigeration applications on fishing vessels.

For replacement or retrofit of HCFC-22 refrigeration plants on existing vessels,

- CO_2 is a cost-effective option already in use,(comparable cost to HFC conversion)
- the cost and modifications mean that Ammonia is not a viable option.

For new ships, or where re-building is acceptable, both Ammonia and CO2 are viable options. However, running an ammonia plant requires skilled personnel.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
Option 1 – Non-halocarbon refrigerants				
R-717 system	Medium	Medium	High	Nil
	Requires new ship with separate machine room or rebuilding	Potential improvement in efficiency. Require competence, but inexpensive refrigerant	Highly complex relative to on-board capabilities. Additional safety risk of ammonia (lower flammable and toxic). Training required in new markets	No environmental policy risk throughout expected life of equipment.
R-717/R-744 cascade system	Medium	Medium	High	Nil
	Requires new ship with separate machine room or rebuilding	Potential improvement in efficiency. High maintenance cost due to complexity. Require competence, but inexpensive refrigerant	Highly complex relative to on-board capabilities. Additional safety risk of ammonia (lower flammable and toxic), Training required in new markets	No environmental policy risk throughout expected life of equipment.
R-744 system	Medium	Low-to-Medium	Medium	Nil
	Suitable for existing vessels with replacement of system	Potential improvement in efficiency at the expenses of complexity. Require competence, but inexpensive refrigerant	Some complexity relative to on-board capabilities. Training required in new markets	No environmental policy risk throughout expected life of equipment.

4.2.2 Option 2 – Refrigerant replacement with plant adjustments

Currently there is no immediate definitive low GWP alternative for HCFC-22, although a number of HFC blends are under investigation. Nevertheless, the situation is evolving rapidly, and viable options may emerge in the medium term. It is likely that the alternatives will be flammable in category A2 or A2L, thus requiring adequate safety considerations and precautions.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Medium	Unknown	Unknown	Unknown
Option 2 – Refrigerant replacement with plant adjustments				
Conventional refrigeration plant system operating with low-GWP HFC blend	Suitable for existing vessels with change of components and adjustments	Cost of refrigerants at present unknown Flammability must be addressed	No significant change in type of technology and components	Environmental policy risk throughout expected life of equipment unknown at present

4.2.3 Option 3 – Refrigerant drop-in

For systems with less than 10 to 15 years' service life, a retrofit using a drop-in refrigerant could be a feasible option, but no suitable low-GWP HFC alternative is yet available on the market. Nevertheless, the situation is evolving rapidly, and viable options may emerge in the medium term.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Unknown	Unknown	Unknown	Unknown
Option 3 – Refrigerant drop-in				
Conventional refrigeration plant system operating with low-GWP HFC blend	Requires improvement of refrigerant containment	Cost of refrigerants at present unknown Flammability must be addressed	No significant change in type of technology and components	Environmental policy risk throughout expected life of equipment unknown at present

4.2.4 Option 4 – Maintaining HCFC-22

The absence of suitable options for retrofit of some on-board systems equipped with HCFC-22, could require continued use of HCFC-22 in those specific systems for several years, until the end of the ship life cycle, or until a cost and environmentally effective solution becomes available. The time horizon for this type of option should be no more than 4-5 years and the target should be those on-board plants with more than 10-15 years' service life. Maintaining HCFC-22 would require the contextual execution of some actions that increase operational efficiency.

One aspect to be considered is how to meet regulatory requirement of product importers, especially when non-flagged vessels are involved.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Low	High	Low	Very high
Option 4 – Maintaining HCFC-22				
Existing plant, operating with HCFC-22, with improved containment Short term solution (max 4-5 years) May not be practical for all vessels	Requires improvement of refrigerant containment	HCFC-22 price expected to increase	No change in technology Limited supply of HCFC-22 in emergency	HFC-22 phase-out in advanced stages

4.2.5 Additional considerations

Some additional considerations with regard to replacement and retrofit of refrigerant systems in fishing vessels include the following:

- The only sector where both replacement and retrofit with low GWP alternatives re currently not possible, is the ultra-low temperature refrigeration (lower than -50°C evaporation) needed in some systems for the conservation of sashimi and sushi grade tuna.
- High Ambient Temperature issues do not pose a problem for this specific sector as refrigeration systems are generally cooled by sea water.
- Not-In-Kind technologies (defined as those refrigeration techniques which do not use vapour compression reverse cycle), even though presenting some interesting future options for application within the fishing industry, are not expected to be commercially available for the sector in the short term.

5 Suitability of alternatives under High Ambient Temperature (HAT) conditions

No further updated information was available related to the testing programs on alternatives under high ambient temperature conditions, so the information remains unchanged in this chapter. Within the discussion of high ambient temperature design considerations (section 5.1) is provided a limited review of the proposal under discussion by parties to define high ambient temperature countries.

5.1 Influence of HAT conditions on R/AC equipment design

As mentioned previously in the TF reports, HAT conditions are an important issue for the design of R/AC systems. Ambient temperatures are also used in cooling load calculation and building envelope design.

As the ambient temperature increases, refrigerant condensing temperature increases, refrigerating load increases and capacity decreases. With increasing refrigerant condensing temperature, compressor discharge pressure and temperature also increases, 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 to specify material and pipe wall thickness requirements in a system. Table 5-1 is taken from EN378-2:2008 and the equivalent ISO 5149 based on IEC 60721-2-1.

Table 5-1: 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 systems are normally designed for 35°C (T1 in ISO 5151:2010) with appropriate performance (cf. for example, under standards requirements), and this up to 43°C in some parties, the high ambient temperature condition requires a design at 46°C (T3 in ISO 5151:2010) with appropriate operation up to 52°C.

High humidity is an important issue even with lower than 35°C temperature conditions for certain Parties. This is because parties that are exposed to high humidity conditions, need higher cooling loads and thus larger capacity A/C units when considering the fresh air loads requirement when selecting air conditioning units, especially with humidity levels above 60%.

Earlier Task Force reports ((UNEP, 2015) and the June version of the XXVII/4 TF report already presented methods to assess temperature conditions using incidence of number of hours, weather profiles, cooling degree days, or bin weather data. These methods are summarized as follows.

1. "**Incidence of Ambient Temperatures**" is a design method that is based on 0.4%, 1%, 2% and 5% of the time per year --for the last 10 years-- (corresponding to 35, 88, 175 and 438 hours per year) that the temperature exceeds 35, 40 or 45^{0}C. It is currently the most used method for designing air conditioning and refrigeration, where temperature design tables exist for most cities around the world. Most experts and consultants use this method when they have to make estimates for the cooling capacity of A/C and R equipment. A few specific ways use the 0.4 % number, others use 1% or 2 %, but the 5% number (i.e., 438 hours a year above

35^{0}C). This method can really deal with high temperature design conditions, provided all data are available.

2. The "**Climate Zones**" method is based on a world map in the ASHRAE Standard 169-2013 defining various climate zones. Zones defined vary from zone A0 (extremely hot humid) down to climate zone 2B (hot dry). The definition of a climate zone is based on the criteria of Cooling Degree Days (CDD). This indicator uses daily temperature data from weather stations over a period of 15 to 30 years to give a typical average year. The most recent data is Typical Meteorological Year (TMY) defined as TMY 3 for the period 1991-2010, and compares the daily average outdoor temperature with a defined baseline temperature for indoor comfort, in this case 18.3°C (65 F). For example, if the average temperature on a particular day is 26°C (78 F), then that day counts as 13 cooling degree days, as a building's interior would need to be cooled by 7.2°C (13 F) to reach 18.3°C (65 F). This method takes into consideration the wet bulb temperature (humidity) in each country. It has an added advantage in that it differentiates between the "Dry" and "Humid" conditions in countries. However, it looks an integrated cooling load over the year, integrating all conditions for a best design, and would not specifically go into some hottest months per year for an appropriate design.

3. The **"Bin Weather"** Method is based on the refrigeration system operating pressure. EN378-2:2008 (European Standards) and ISO 5149 (based on IEC 60721-2) 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. EN378 specifies design conditions at 32, 38, 43, and 55°C but does not specify what constitutes a high ambient temperature condition. This method is rather complicated and needs specifying a lot of factors (pressure, density…etc.), which necessitates substantial data analysis to derive required final data. It is based on the system pressure values, which can be calculated from actual design temperatures.

4. Using a **data base giving temperature measurements** in many countries in the world, Parties discussed a preliminary proposal at OEWG-37 to define a high ambient temperature criterion that parties could use. For a HAT criterion, it mentions an average of at least two months per year (over 10 consecutive years) of a peak monthly average temperature above 35°C. The Task Force was provided information on this proposal which it reviewed. Countrywide values in the dataset are calculated by taking a spatially weighted average of all weather stations within a country. Countrywide data are extracted from values in a dataset available from the Center of Environmental Data Analysis (CEDA). The "peak monthly average temperature" is calculated by establishing the high temperature for each day in the month and subsequently averaging those daily highs to get average peak temperature values for months (defined as monthly the average daily maximum temperature). Apart from going into the design of equipment, this methodology provides a possible approach for parties to define countries that meet these high ambient temperature conditions criteria.

The Task Force would like to note, that, in this approach under (4), key determining parameters are (1) the source of the data (i.e., weather stations within a country), (2) the choice of peak monthly average temperatures above a value of 35°C, and (3) the 10-consecutive year period having at least two months above the peak monthly average each year. A variation of all the above parameters might result in certain changes, however, the Task Force made no further technical assessment of this proposal (which is still being discussed by parties).

5.2 Results from research projects

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

Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 210/240). The performance of units at different ambient temperatures would then be simulated or extrapolated. The status of the three research projects testing refrigerant alternatives used in specific equipment operating under high ambient temperature conditions were all made public during the period late 2015/early 2016 giving detailed technical results. The three projects are:

- "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).

5.2.1 PRAHA project

"Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries" (PRAHA). PRAHA, which was launched by UNEP/UNIDO in 2013 and completed in 2015, involved custom made prototypes built by manufacturers based in the Gulf Coordination Council countries and tested at an independent lab (PRAHA, 2013). 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. The project tested 14 prototypes using 5 refrigerants and 9 base units running with HCFC-22 or R-410A.

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 5-2 below:

Table 5-2: 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

Table 5-3 shows the result from the testing of the prototypes and their comparison to their respective base units. The table shows the type of equipment tested, the laboratory at which it was tested, the baseline refrigerant against which the porotype is compared, and the constraints and the modifications that were included with the prototype. The table then compares each type of alternative refrigerant to the base unit for COP (efficiency) and capacity at 35°C and a higher ambient temperature which in this case is 50°C.

Table 5-3 PRAHA results for cooling capacity and efficiency as percentage compared to the baseline units

Equipment type	Lab utilized	Baseline refrigerant	Prototype Criterion	Refriger-ant tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 50°C	Capacity % comp to baseline @ 50°C
18,000 Btu/hr. Window Unit	Intertek - USA	HCFC-22 COP = 3.14 at 35°C and 2.26 at 50°C for OEM A COP = 2.76 at 35°C and 2.02 at 50°C for OEM B	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	L-20 (OEM A)	-11%	9%	-10%	7%
				L-20 (OEM B)	-2%	-6%	-5%	-10%
				DR-3 (OEM A)	-9%	2%	-2%	1%
20,000 Btu/hr. split system	Intertek - USA	HCFC-22 COP = 2.75 at 35°C and 1.94 at 50°C for OEM C COP = 2.52 at 35°C for OEM D	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	HC-290 (OEM C)	4%	8%	-2%	5%
				L-20 (OEM D)	-19%	7%	-76%	-78%
				DR-3 (OEM D)	-27%	-33%	-28%	-31%
24,000 Btu/hr. split system	Intertek - USA	R-410A COP = 3.52 at 35°C and 2.30 at 50°C for OEM E COP = 3.08 at 35°C and 2.02 at 50°C for OEM F	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	HFC-32 (OEM E)	-1%	15%	-2%	16%
				HFC-32 (OEM F)	-9%	8%	-22%	-1%
				L-41 (OEM E)	-10%	20%	-7%	22%
36,000 Btu/hr. Ducted Split	Intertek - USA	HCFC-22 COP = 2.83 at 35°C and 1.91 at 50°C for OEM G	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	L-20 (OEM G)	0%	-7%	2%	-5%
				DR-3 (OEM G)	-18%	-25%	-13%	-21%
36,000 Btu/hr. Ducted Split	Intertek - USA	R-410A COP = 2.79 at 35°C and 1.84 at 50°C for OEM G	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	HFC-32 (OEM G)	-1%	-4%	-12%	-18%
90,000 Btu/hr. Rooftop by Intertek	Intertek -USA	HCFC-22 COP = 2.95 at 35°C and 2.07 at 50°C for OEM H	Custom built prototypes to fit in the same box dimension as the base unit. Expansion device and charge amount designed to meet a minimum specified EER	L-20 (OEM H)	1%	6%	-3%	5%
				DR-3 (OEM H)	-3%	-1%	-6%	-4%

Notes on the terms in the table:

1 *Efficiency (COP) is measured in Watts of cooling per Watt of input;*

2 *Under PRAHA, measurements were done at 35, 46 and 50°C ambient temperatures;*

3 *For a full description of refrigerant alternatives and their GWP values, please refer to the relevant chapter on refrigerants in this report;*

4 *Test conditions are as follows: For 35°C ambient, indoor 26.67°C and 50% relative humidity (AHRI –A. For 50°C ambient, indoor 29°C and 50% relative humidity*

5 *Cells shaded grey show results that are not consistent with other results for the same refrigerant and could be the results of optimization or design issues.*

The outcomes of the PRAHA project, other than the testing results, are:

- There is a need to do risk assessment studies at HAT conditions in Parties 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 original equipment manufacturers (OEMs).

For EGYPRA, all prototypes are ready and have been tested at the respective manufacturers. The process of testing the prototypes and base units at the independent lab will start soon and results are expected at the end of the year.

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 Parties. 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).

5.2.2 ORNL Project

"High-Ambient-Temperature Evaluation Program for Low-Global Warming Potential (Low-GWP) Refrigerants" by the Oak Ridge National Laboratory (ORNL). ORNL conducted tests using two "soft-optimized" ductless mini-split air conditioners having a cooling capacity of 5.25 kWh (1.5 TR). One unit which was designed to operate with HCFC-22 refrigerant was used for alternative refrigerants that are equivalent in characteristics to HCFC-22, while the other which was designed to use R-410A refrigerant tested the R-410A alternatives. Eighty-four tests were conducted in total for a total of 10 alternative refrigerants at ambient temperatures varying from 27 to 55°C.

Table 5-4: 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

Table 5-5 shows the results for the ORNL project taken from the various reports available online. ORNL tested two base units and then changed the refrigerant as well as certain components and settings to test the alternative refrigerants.

Table 5-5 ORNL results for capacity and efficiency as percentage compared to the baseline units

Equipment Type	Lab utilized	Baseline Refrigerant	Equipment Criterion	Refriger. Tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 52°C	Capacity % comp to baseline @ 52°C
18,000 Btu/hr. Split unit (Carrier)	ORNL	HCFC-22 COP = 3.07 at 35°C and 1.98 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	N-20B	-13%	-14%	-11%	-15%
				DR-3	-16%	-12%	-14%	-12%
				ARM-20B	-12%	-3%	-11%	-3%
				R-444B (L-20A)	-11%	-9%	-7%	-4%
				HC-290	7%	-8%	7%	-4%
18,000 Btu/hr. split unit (Carrier)	ORNL	R-410A COP = 3.4 at 35°C and 2.07 at 52°C	Same machine to test all refrigerants. Criteria: matching superheat and sub cooling to base unit. Changing expansion devise. Charge level optimized at 35C	HFC-32	4%	5%	5%	11%
				DR-55	3%	-3%	3%	0%
				R-447A (L-41)	-5%	-14%	3%	-6%
				ARM-71a	-1%	-8%	2%	-4%
				HPR-2A	-2%	-9%	5%	-1%

Notes on the terms in the table

1 *Efficiency (COP) is measured in Watts of cooling per Watt of input;*

2 *ORNL did measurements at 27.8, 35, 52 and 55°C ambient temperatures;*

3 *For a full description of refrigerant alternatives and their GWP values, please refer to the relevant chapter on refrigerants in this report;*

4 *Test conditions are as follows: For 35°C ambient, indoor 26.7/19.4°C (AHRI-A). For 52°C ambient, indoor = 29/19°C.*

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.

5.2.3 AREP Project

"Low GWP Alternative Refrigerants Evaluation Program" (AREP) Phase-II. The project was 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 international 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 5-6: 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	R-410A		X			X	X	X
14 SEER 3-ton HP	Carrier	125F	R-410A	X	X		X	X	X	
13 SEER 3-ton HP	Danfoss	115F and 125F	R-410A		X				X*	X**
14 SEER 3-ton split HP	Goodman	115F and 125F	R-410A							X***
5-ton packaged	Lennox	115F	R-410A	X	X	X	X		X	X
4-ton packaged	Trane	125F	R-410A		X	X				X
6-ton packaged	Zamilac	125F	R-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*

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 5-8 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.

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 the test reports of AREP-II that are available publically on-line.

Table 5-7 AREP-II results for capacity and efficiency as percentage compared to the baseline units

Equip-ment Type	Company	Baseline Refrigerant	Prototype Criterion	Refrigerant Tested	COP % comp to baseline @ 35°C	Capacity % comp to baseline @ 35°C	COP % comp to baseline @ 51.6°C	Capacity % comp to baseline @ 51.6°C
36,000 Btu/hr. Split heat pump	Carrier Indiana-polis	R-410A COP = 3.55 at 35°C and 1.87 at 51.6°C	Criteria: Matching superheat and sub cooling to base unit. Charge level determined by criteria and held constant for all temperatures tested	ARM-71A	-1%	-8%	7%	-3%
				R-454A (DR-5A)	-1%	-6%	6%	-1%
				HPR2A	-4%	-11%	3%	-4%
				R-446A (L-41-1)	-2%	-10%	-1%	-3%
				R-447A (L-41-2)	-1%	-7%	-1%	-4%
48,500 Btu/hr. Rooftop	Ingersoll Rand Clarks-ville	R-410A COP = 3.31 at 35°C, 2.00 at 48.9°C and 1.80 at 51.6°C	Adjustable expansion device, Variable Frequency drive matching the capacity with base unit. Varying indoor conditions	DR-55	4%	0%	3%	0%
				HFC-32	6%	1%	NA	NA
				DR-5A	5%	1%	7%	3%
72,000 Btu/hr. Rooftop	Zamil KSA	R-410A COP = 3.57 at 35°C and 2.06 at 51.6°C	Criteria maintained same superheat and sub cooling as base unit by changing expansion devise and adjusting charge. Oil is also different	HFC-32	2%	9%	10%	16%
34,000 Btu/hr. split	Goodman USA	R-410A COP = 3.53 at 35°C and 1.82 at 51.6°C	Tested HFC-32 unit with POE oil and withy prototype oil for the same expansion devise and charge determined by superheat	HFC-32 with prototype oil	3%	7%	13%	14%
60,000 Btu/hr. Rooftop	Lennox USA	R-410A COP = 3.87 at 35°C and 2.07 at 51.6°C	Matching superheat and sub cooling	L-41-2	3%	-7%	10%	-1%
				ARM-71A	3%	-4%	10%	2%
				HPR2A	1%	-5%	8%	1%
				DR-5A	1%	-4%	2%	-3%
				HFC-32	-10%	-4%	-9%	-1%

Notes on terms in the table:

1 *Efficiency (COP) is measured in Watts of cooling per Watt of input*

2 *Under PRAHA, measurements were done at 35, 46 and 50°C ambient temperatures*

3 *For a full description of refrigerant alternatives and their GWP values, please refer to the relevant chapter on refrigerants in this report*

4 *Test conditions are as follows: For 35°C ambient, indoor 26.67°C and 50% relative humidity (AHRI -A). For 50°C ambient, indoor 29°C and 50% relative humidity*

5 *Cells shaded grey show results that are not consistent with other results for the same refrigerant and could be the results of optimization or design issues*

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

5.2.4 General remarks on the three research projects

The March TF XXVII/4 report noted that tests under HAT 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.

In evaluating the three projects, the following conclusions and comments can be drawn from the technical data presented in the capacity and efficiency tables:

- The measured efficiency of the alternative refrigerants is in the vicinity of plus or minus 15% of the base units to which they were compared;
- The R-410A alternatives give results that are close to the performance of R-410A at HAT. However, the performance of R-410A at HAT is lower than HCFC-22 due to the characteristic of the refrigerant;
- The performance of the prototypes can be further improved through optimization of components and design parameters;
- The safety aspect is important for the high ambient temperature countries as the refrigerant charge is higher than for units operating in lower ambient temperatures.
- The efficiency and capacity of the alternative prototypes are two aspects of the comparison. A more complete comparison would also include a cost comparison; however, there is not enough data on cost, neither for some of the alternative refrigerants nor of the components to have a measurable comparison;
- While efficiency is important to meet the regulatory minimum energy performance standards (MEPS), the capacity of air conditioners at HAT conditions is of utmost importance in order to provide the required indoor comfort when these conditions happen.
- As a general rule, the cost of the equipment depends on the characteristics of the refrigerant and the performance of the equipment at high ambient temperatures. For example, if the capacity of the equipment at HAT is 10% lower for the required efficiency, then a larger machine is needed to meet the required load making the equipment more expensive;
- ORNL and PRAHA came to slightly different conclusion about the performance of alternative refrigerants vs. HCFC-22 with PRAHA generally showing better results. This is due to the fact that the PRAHA prototypes were custom built, while ORNL uses the base unit with some optimisation. From this it can be concluded that results can be improved with customisation. The engineering level of the unit is more important than the refrigerant characteristic.

5.3 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 Parties 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 such as 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 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 Parties 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 class A3 or class 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 the 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), such as 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 Parties as the Certification Body (CB) scheme is the actual requirement for import and sales of products. In some Parties, 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 Parties, there is a need for a comprehensive risk assessment for class A3 and A2L refrigerant alternatives at installation, servicing and decommissioning practices at HAT conditions and when field testing the units.

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

This chapter contains the same scenarios as the second version of the TEAP XXVII/4 Task Force Report (June 2016), based on the same existing regulations considered in that report. The chapter also contains the following changes and additions:

- **Additional information on the production of various HFCs important for the R/AC foam blowing, fire protection, MDIs and aerosols sectors (section 6.3).**
- **A comparison of estimated production with the global calculated demand for the R/AC and other sectors (section 6.3);**
- **Related to this chapter, Annex 4 of this report contains updated tables for total, new manufacturing, and servicing demand.**

The chapter is organized as follows:

6.1 Expansion of scenarios
6.2 Method used for calculation
6.3 HFC consumption and production data
6.4 Non-Article 5 scenarios
6.5 Article 5 scenarios
6.6 Demand and climate benefit numbers

6.1 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: The Task Force is aware of various regulations and actions as well as pending regulations applied by Parties. This implies that the F-gas regulation in the European Union (EU) and regulations in the United States (US), making certain HFCs unacceptable for certain sub-sectors by specific dates, have been considered as their impacts are very specific to the R/AC sectors and sub-sectors (see also Annex 3, where specific elements of these regulations are given; the final regulation of Japan has not been incorporated in the BAU scenarios considered in this study). This implies that, in the business-as usual (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. In this report, the impact of a BAU scenario without and with certain national or regional legislations is shown.
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 6.5.3 and 6.5.5 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.

6.2 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 R/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 entire 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 TF report (UNEP, 2015). As in this 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), very low GWP factors have been used. For 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 an averaging exercise, not related to GWP considerations presented in Table 2-6. In Mobile Air Conditioners (MACs), replacement refrigerants are assumed to have negligible GWP.

Table 6-1: Growth rates for high-GWP HFC demands in the various R/AC sub-sectors (manufacturing and total) during the periods 2010-2020, 2020-2030 and 2030-2050

Non-Article 5 Parties				
Sub-sector		**2010-2020**	**2020-2030**	**2030-2050**
Domestic refrigeration	Manufact.	-6.0%	-1.5%	3%
	Total	-6.0%	-1.5%	3%
Commercial refrigeration	Manufact.	-10.5%	0.1%	3%
	Total	-2.0%	-5.5%	2.1%
Industrial refrigeration	Manufact.	-2.1%	-1.8%	3%
	Total	0%	-1.2%	1.8%
Transport refrigeration	Manufact.	-9.5%	-4%	3%
	Total	-1.3%	-0.2%	0.9%
Stationary AC	Manufact.	5.8%	3%	3%
	Total	8.5%	2.8%	2.7%
Mobile AC	Manufact.	-12.5%	3.3%	3%
	Total	-3.6%	-5.5%	1.9%
Article 5 Parties				
Sub-sector		**2010-2020**	**2020-2030**	**2030-2050**
Domestic refrigeration	Manufact.	5.8%	5.8%	4.5%
	Total	4.8%	5.8%	4.5%
Commercial refrigeration	Manufact.	12.9%	8.6%	4.5%
	Total	16.5%	9.6%	5.1%
Industrial refrigeration	Manufact.	8.8%	6.8%	3.7%
	Total	6.1%	6.1%	4.2%
Transport refrigeration	Manufact.	5.8%	4.5%	4.5%
	Total	9.5%	5.7%	4.4%
Stationary AC	Manufact.	15.8%	6.0%	1.5%
	Total	17.7%	8.3%	3.0%
Mobile AC	Manufact.	5.0%	5.0%	5.0%
	Total	6.4%	5.0%	5.0%

Note: this table is different from the one in the March 2016 TF report, since some negative growth in HCFC demand was taken into account in the first 10 (20) years (2010-2030) in Article 5 Parties

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 6-1 above.

A number of considerations substantially complicate the calculations. This includes the preference to apply certain alternatives in specific equipment (and often under certain conditions), combined with the fact that the R/AC banks -the amounts present in the equipment- need recharging (i.e., servicing) over the entire lifetime of the equipment. Details on lifetime and annual leakage are given in (Table 5-2 in) the XXVI/9 report (UNEP, 2015).

The calculation method covers the period from 1990 until 2050, the latter year as requested in Decision XXVII/4. Table 6-1 gives the growth rates assumed for new manufacturing in the various R/AC sub-sectors, as well as for the total demand (manufacturing and servicing). 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 a few percent higher, e.g., varying from 2 up to 5-6%. These percentages can also be derived from the BAU Tables 6-7 and 6-8 and from the more detailed tables as given in Annex 4.

Depending on the application sector, uncertainties are different either because activity data include different uncertainties or because emission factors may vary significantly from one Party 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%.*

The bank of refrigerants is substantially larger (10-20 times) than the annual demand. In fact the bank as calculated determines the amount of emissions, dependent on leakage assumptions during operation. The total demand is the sum of the amount used for new manufacturing and for re-charging to balance the refrigerant lost via all emissions types. Banks of refrigerants could be given for regions and/or for certain Parties as used in the model, but the amounts that would then be presented would not contribute to a better understanding of the demand, which is the essential parameter in this chapter that deals with demand scenarios.

As already mentioned in the Decision XXVI/9 TF September Update Report (UNEP, 2015), estimates should be cross-checked with reported HFC consumption and production data, specified per refrigerant. For the most recent cross-check, information can be found below.

6.3 HFC production and demand (consumption) data

Estimates for global 2012 and 2015 production of the relevant HFC chemicals can be made by combining UNFCCC data, manufacturer's estimates for production capacity as well as global emission data. This was already 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 by developed countries, i.e., the Annex I Parties 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 Article 5 Parties are often made by non-Article 5 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). In 2015, 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 in the period May-July 2016 (Kuijpers, 2016). The HFCs considered above are HFC-32, HFC-125, HFC-134a and HFC-143a, but also HFC-152a, HFC-227ea and HFC-245fa.

This report uses updates for HFC production of the *four* main HFCs (the ones important for R/AC) in Table 6-2 below (the estimated production of HFC-134a in one country has been added that was not included in the XXVI/9 Task Force or the March XXVII/4 Task Force report and this estimate was slightly increased compared to the June XXVII/4 Task Force report). As mentioned, 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 (such as foams, aerosols, MDIs).

The table shows a total HFC production of about 525 ktonnes for these *four* (main) HFCs, which is a forecast for the year 2015 (this can be translated to about 1050 Mt CO_2-eq., if calculated in climate terms). The global production capacity for these four HFCs is estimated at a much higher level, at about 750 ktonnes (Campbell, 2015). It needs to be emphasised that the global HFC production (for these four main HFCs) determined in this way is estimated to have a ±10% uncertainty for the separate HFC chemicals, which implies that the 525 ktonnes value roughly has a 5% uncertainty (500-550 ktonnes).

Table 6-2: 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	176	273
HFC-143a	21	<10	11	17	28
Total		≈ 160	≈ 165	362.5	525

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

Estimated global production quantities for HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc are estimated at around 140 ktonnes, of which HFC-152a production is in the order of 60 ktonnes (Kuijpers, 2016) (the total can be translated into 160-170 Mt CO_2-eq. in climate terms). This estimate is revised from the values given in the June 2016 TF report, particularly where it concerns the Chinese reported HFC-152a production (of which a large part is for feedstock uses). One other HFC is being produced in Article 5 parties, i.e., HFC-236fa; it is estimated to be at a level of about 300-400 tonnes (Kuijpers, 2016). The quantities in the sub-sectors where HFC-236fa is being applied are difficult to identify, they are only in non-Article 5 parties. It is considered a minor issue in the total.

The total HFC production for the year 2015 is estimated at about 1220 Mt CO_2-eq.

While the production data for the four main HFCs are reasonably reliable global estimates, they have been used to check (and calibrate) the R/AC demand data determined via the bottom-up method used; details are given in the section below.

For the R/AC sector as a whole, the total bottom-up demand that has been calculated for the year 2015 for non-Article 5 Parties (200.5 ktonnes) and Article 5 Parties (272.9 ktonnes) equals 473.4 ktonnes. This relates to the four main HFCs given in Table 6-2.

By calculating back from the amounts given in Table 6-2, it would imply that about 50-55 ktonnes of the four main HFCs (mainly HFC-134a) are used in sectors other than R/AC, globally; these other sectors would mainly be foams, medical and technical aerosols. Further data related to HFC-134a and other HFCs can be found in the September 2016 Ex.III/1 TEAP working group report (Ex.III/1, 2016).

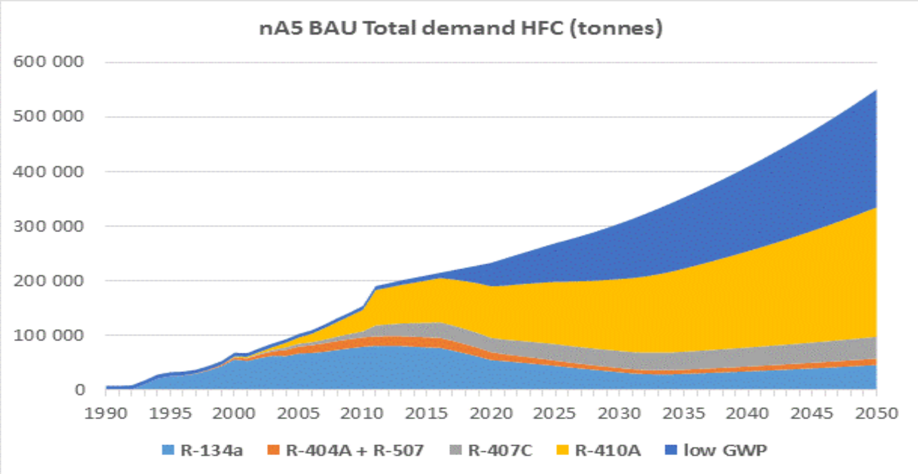
In all of the above, one needs to take into account that both the production estimates and the bottom up calculated R/AC demand have >10% uncertainties for the separate chemicals and (sub) sectors.

6.4 Non-Article 5 scenarios up to 2050

6.4.1 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.



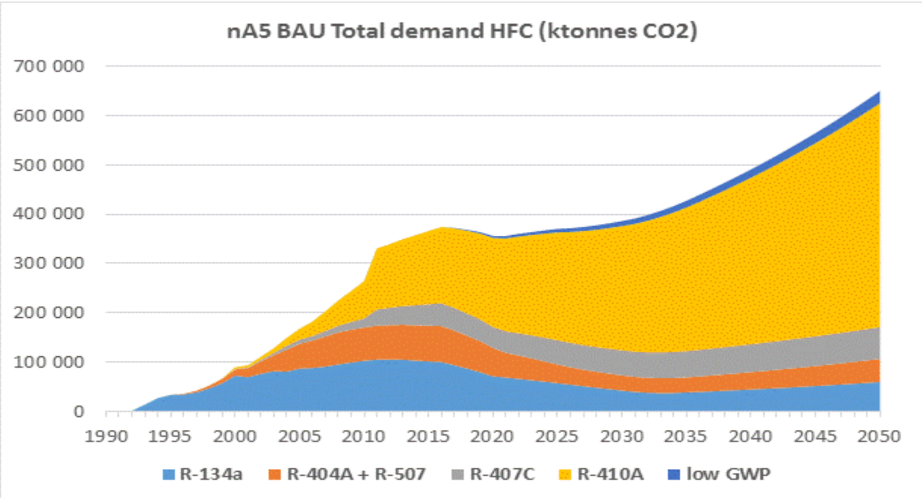
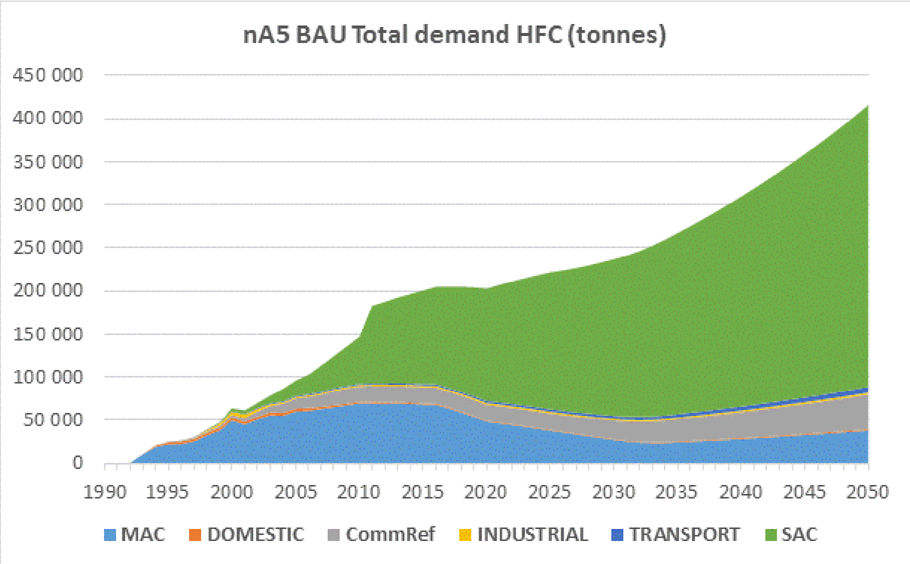


Figure 6-1: Non-Article 5 BAU scenario with subdivision for the various refrigerants or refrigerant blends in tonnes and ktonnes CO_2-eq.

Figure 6-1 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 6-2 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 6-1). This is due to the fact that only a small amount of regulatory restrictions have been built in.



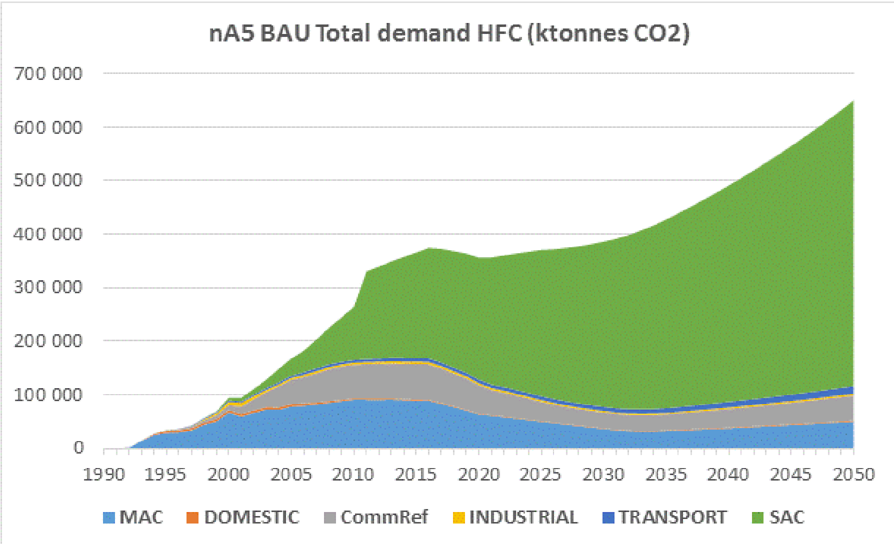


Figure 6-2: Non-Article 5 BAU scenario; subdivision for the various R/AC sub-sectors

It is interesting to compare the Non-Article 5 BAU scenario without and with certain regulations; it then shows the impact of these regulations over the time period considered (in fact the values for these two types of BAU scenarios can be found in the Annexes of the XXVI/9 Task Force and this XXVII/4 Task Force report. Annex 3 gives the summary table with the regulations for the EU, USA and Japan. In the BAU scenario in this report the EU and US regulations, making certain HFCs unacceptable for certain sub-sectors by specific dates, have been applied as their impacts are very specific related to the R/AC sectors and sub-sectors. The EU regulation that mandates a reduction to 29% of total HFC consumption in climate terms in 2030 could not be considered in the total, since R/AC is only part of this.

Figure 6-3 shows the impact of regulations on the BAU demand. The demand is expected to be lower as of 2015 when certain regulations enter into force, the difference will increase after 2019-2020 when more regulations are assumed to be in place and the impact of the servicing demand becomes more visible. The difference between both types of BAU demand is in the order of 140 Mt CO_2-eq. in the year 2030. The demand with regulations does not increase much between the years 2015 and 2030, after which the growth in certain commercial refrigeration subsector and particularly in the stationary AC subsector are determining.

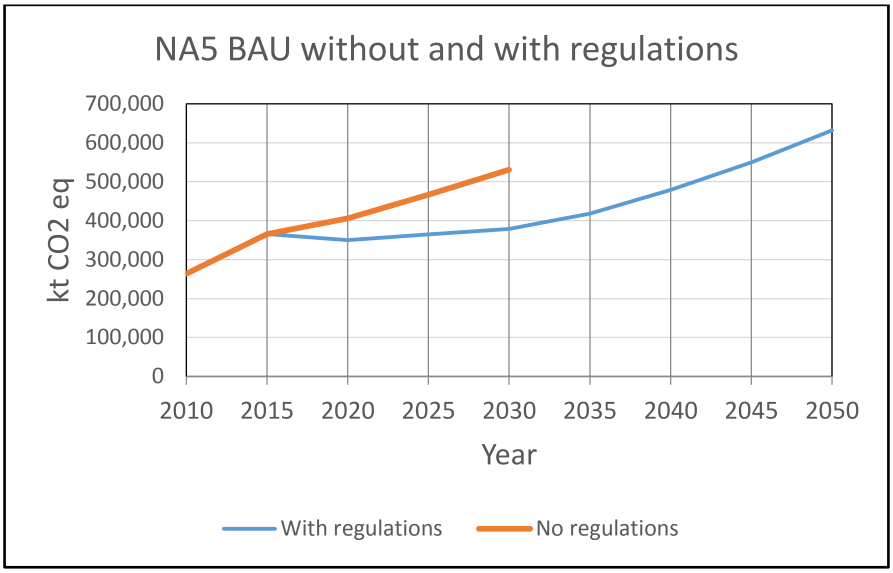
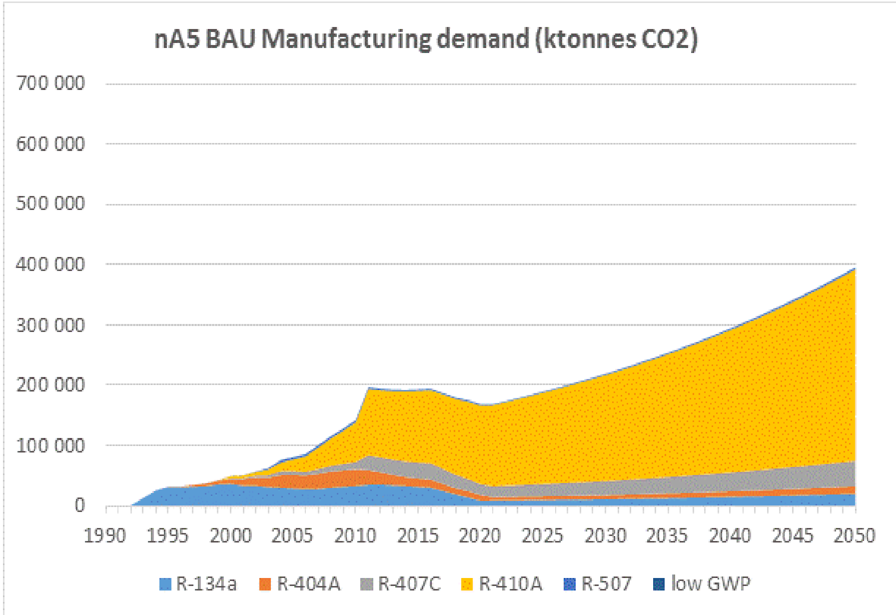


Figure 6-3: Non-Article 5 BAU scenario without and with consideration of national and reginal regulations (without regulations until 2030; with regulations until 2050)

Figure 6-4 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.



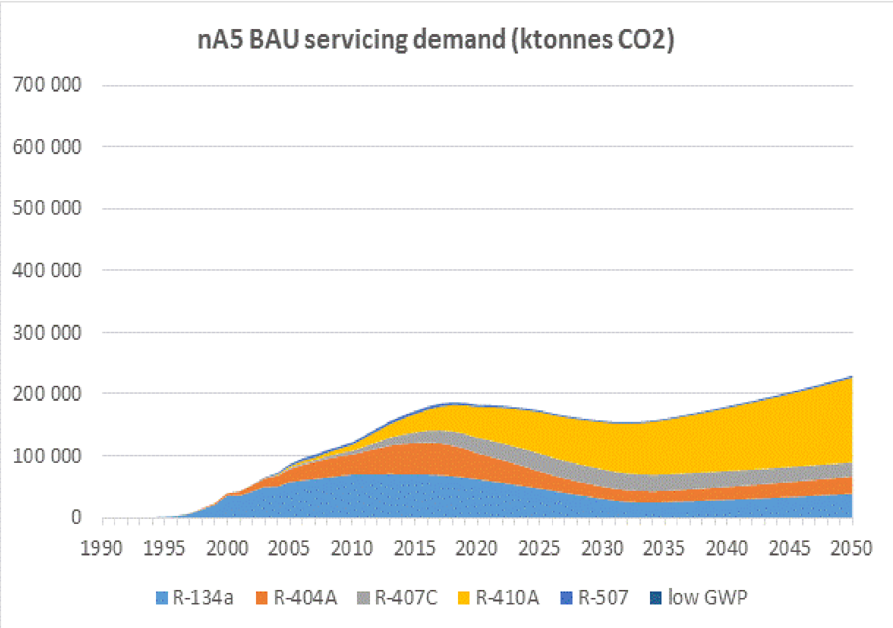


Figure 6-4: New manufacturing and servicing parts of the non-Article 5 BAU scenario with a subdivision for the various R/AC sub-sectors

6.4.2 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 6-5, 6-6, and 6-7.

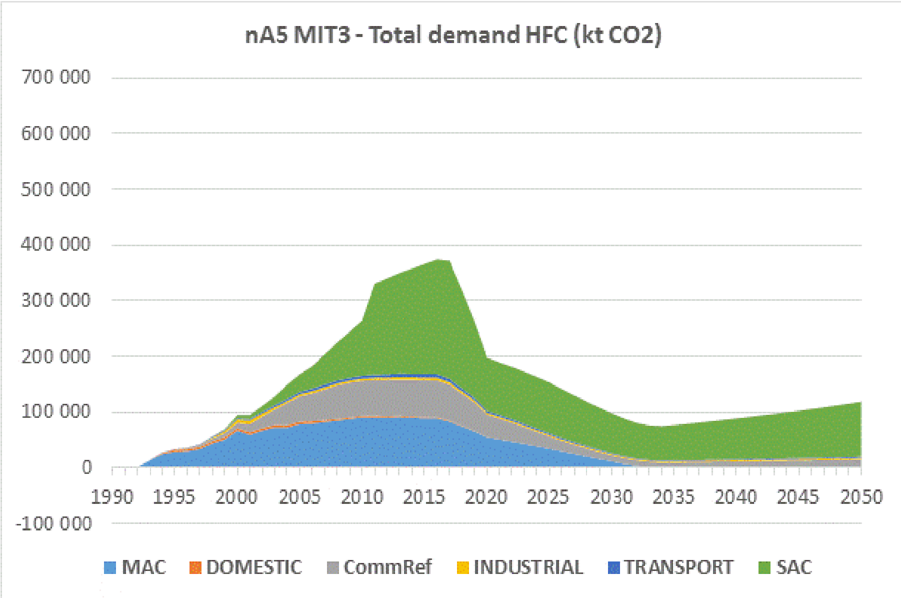


Figure 6-5: Total demand for the Non-Article 5 MIT-3 scenario with a subdivision for the various R/AC sub-sectors

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 6-5 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 6-6, 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.

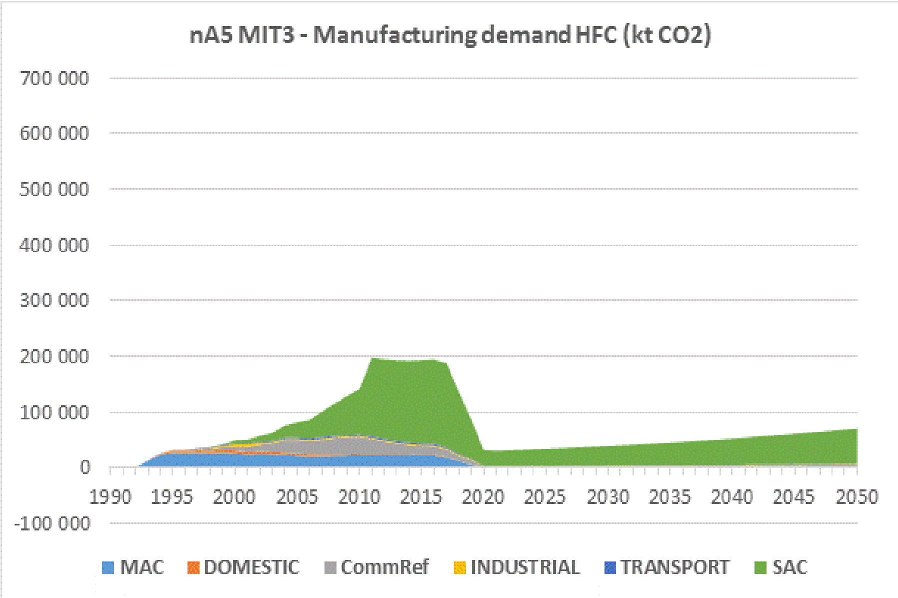


Figure 6-6: Non-Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors in ktonnes CO_2-eq. (assuming manufacturing conversion over a period of 3 years, 2017-2020).

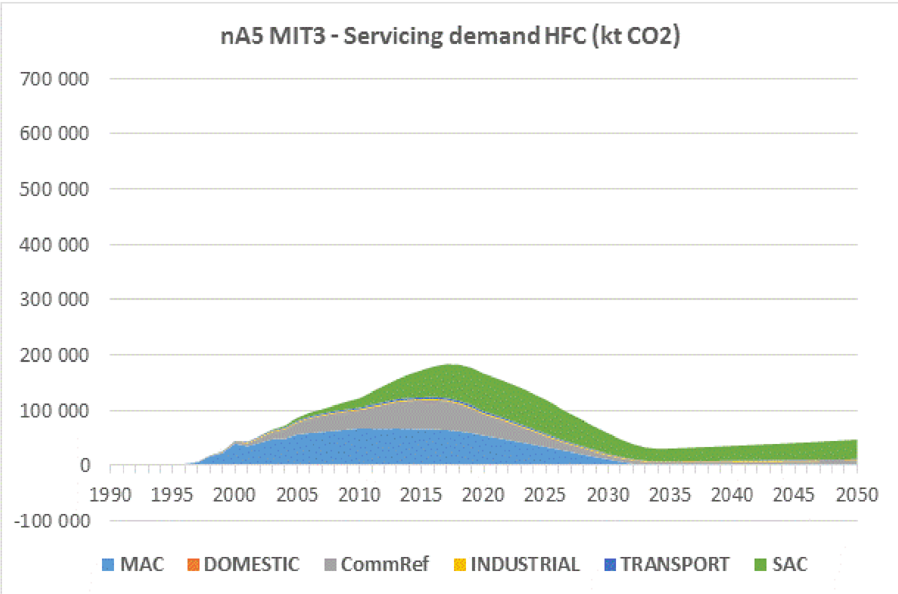


Figure 6-7: Non-Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (assuming manufacturing conversion over the period 2017-2020)

Figure 6-7 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.

6.4.3 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 6-8, 6-9 and 6-10.

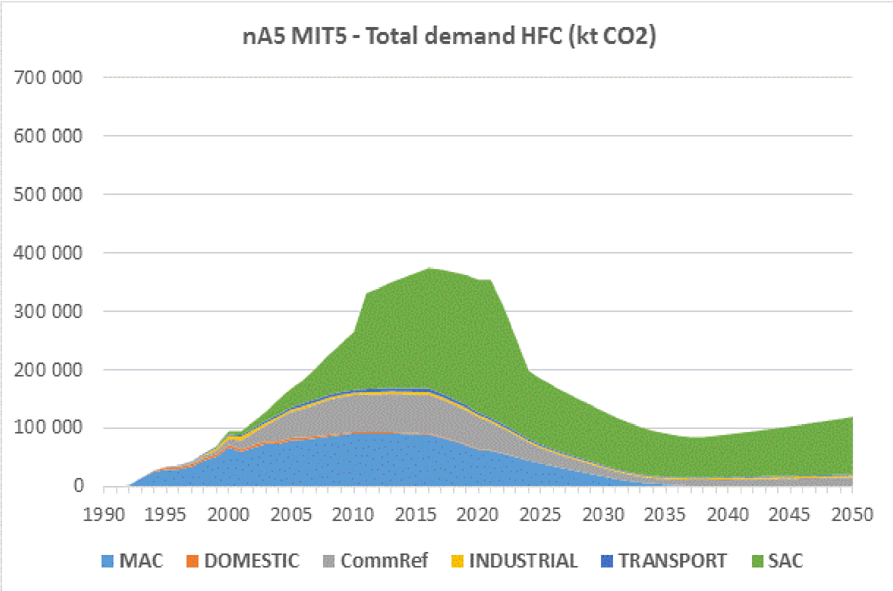


Figure 6-8: Non-Article 5 MIT-5 scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 4-4 for MIT-3)

Figure 6-8 includes both manufacturing and servicing, and is similar to Fig 6-6 for MIT-3. Figure 6-9 shows the same data for HFCs used in new manufacturing only.

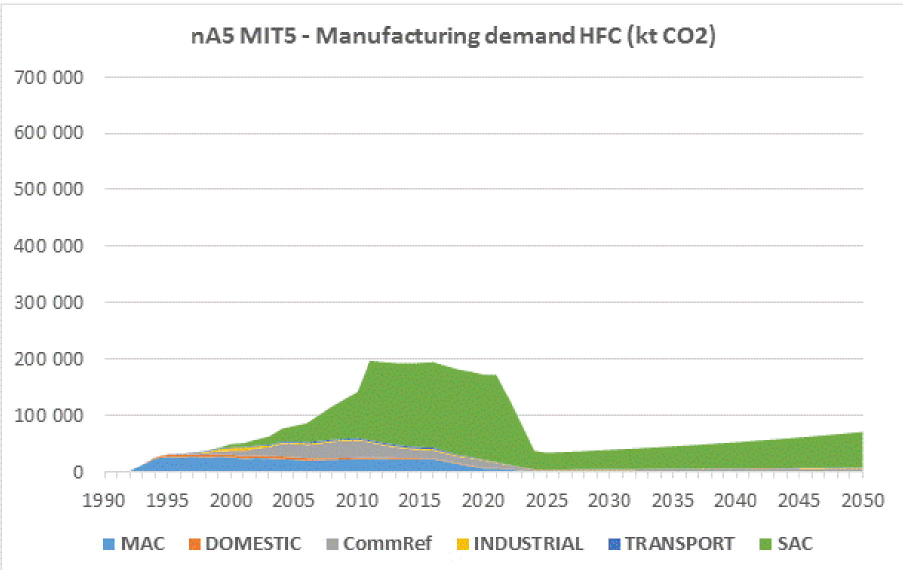


Figure 6-9: Non-Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in GWP weighted terms (compare Fig. 6-6 for MIT-3)

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.

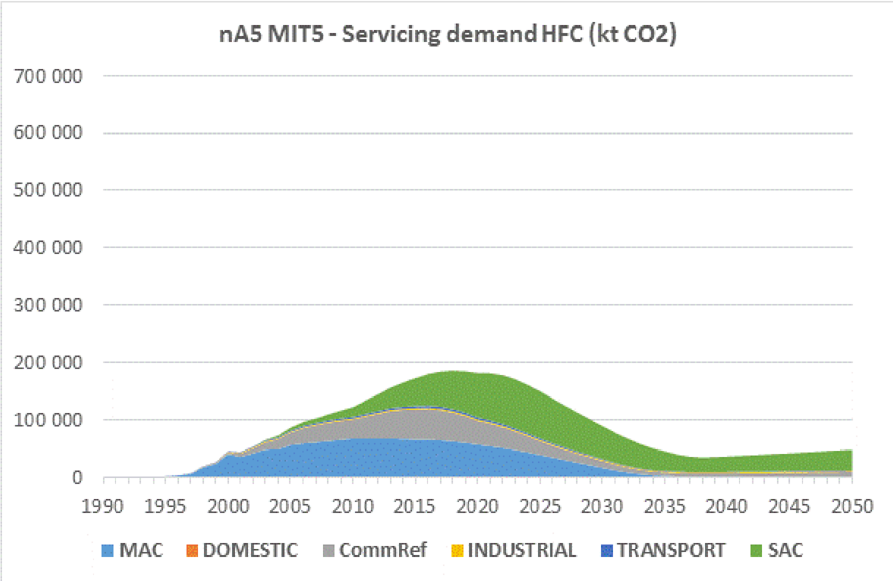


Figure 6-10: Non-Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors in GWP weighted terms (compare Fig. 6-7 for MIT-3)

6.5 Article 5 scenarios up to 2050

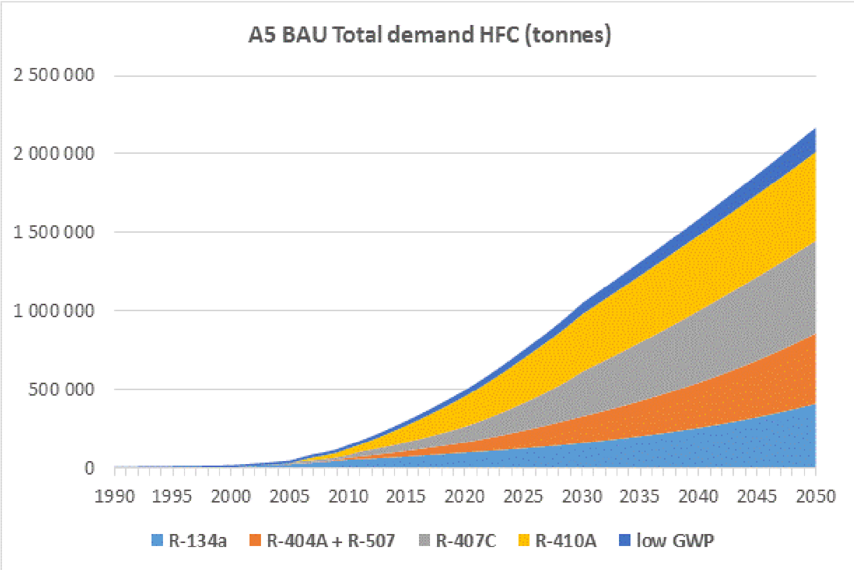
6.5.1 BAU scenario

Figure 6-11 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).

Figure 6-12 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.



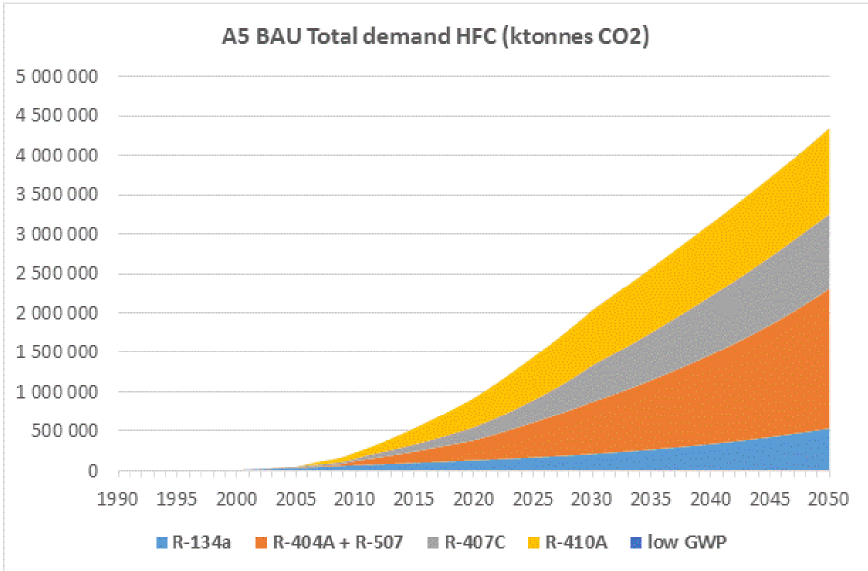
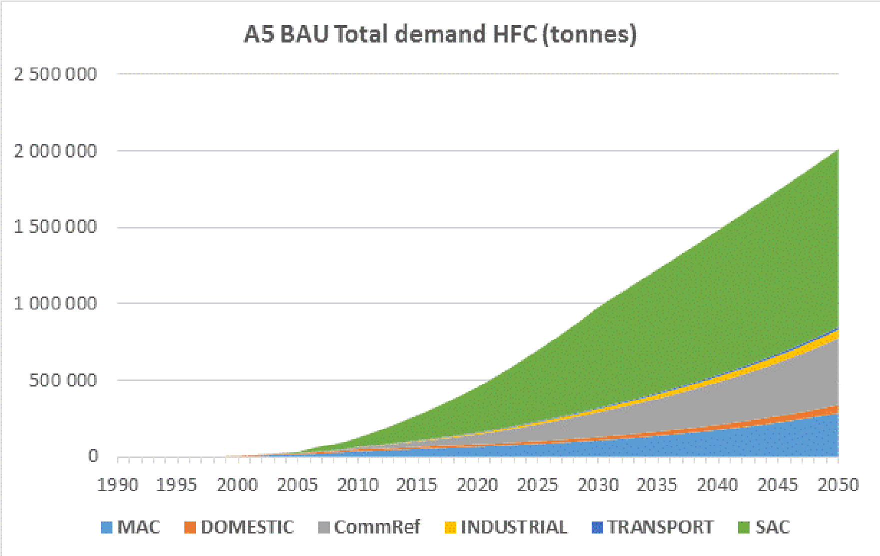


Figure 6-11: Article 5 BAU scenario with a subdivision for the various refrigerants and refrigerant blends in tonnes and ktonnes CO_2-eq.



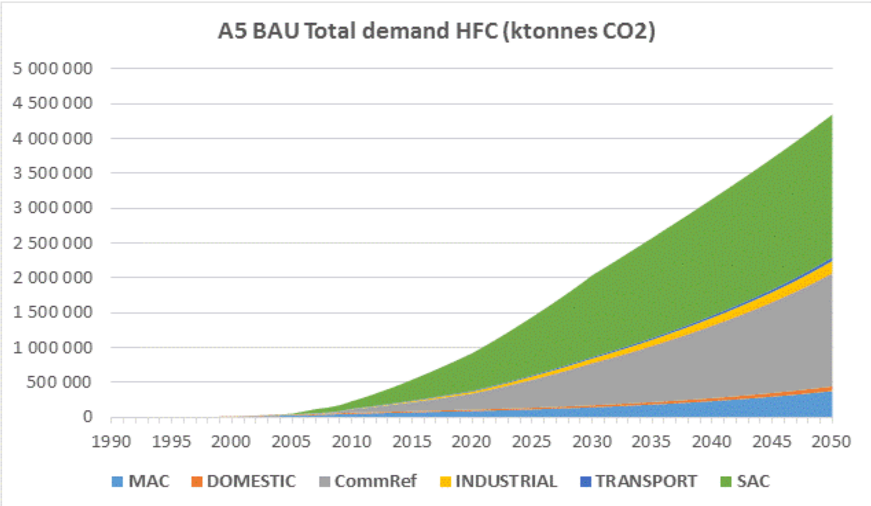


Figure 6-12: Article 5 BAU scenario with a subdivision for the various sub-sectors in tonnes and ktonnes CO_2-eq.

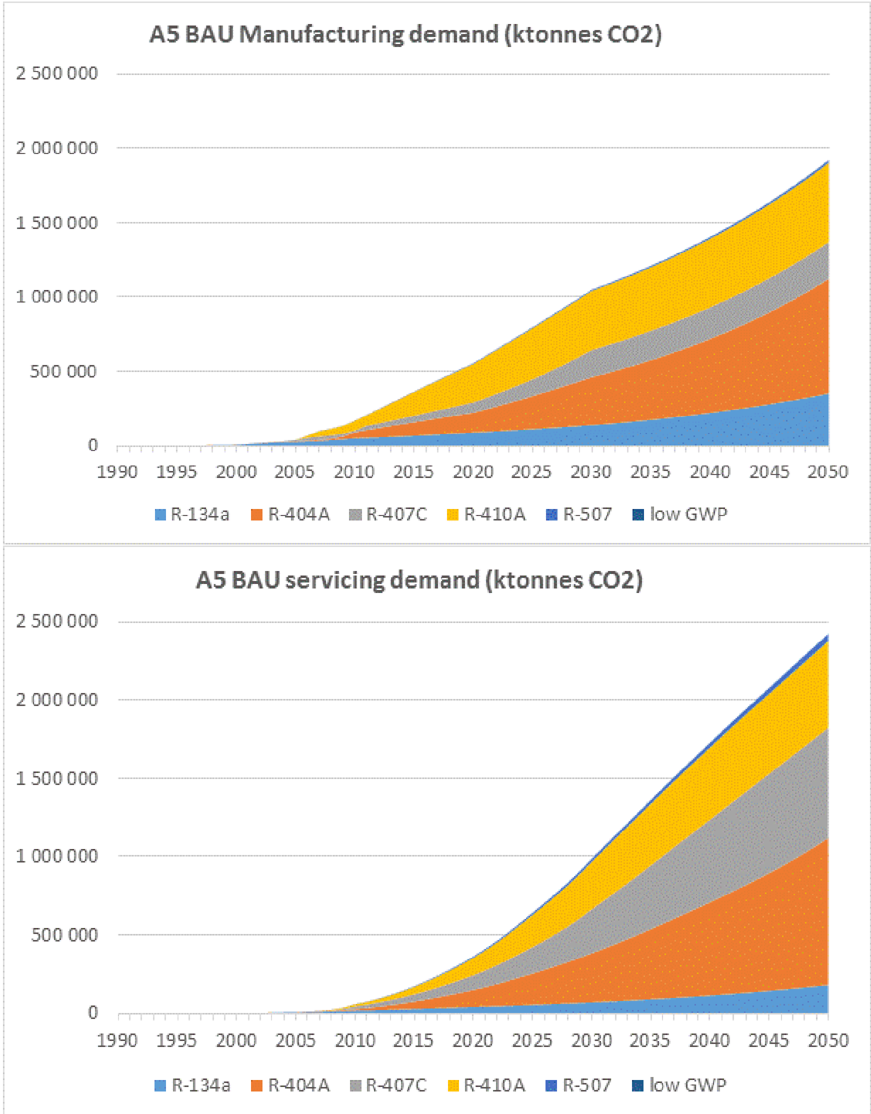


Figure 6-13: Article 5 BAU scenario with new manufacturing and servicing demand for the various refrigerants (both in ktonnes CO_2-eq.) (note the scale difference with Figs. 6-11 and 6-12)

Figure 6-13 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

6.5.2 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.

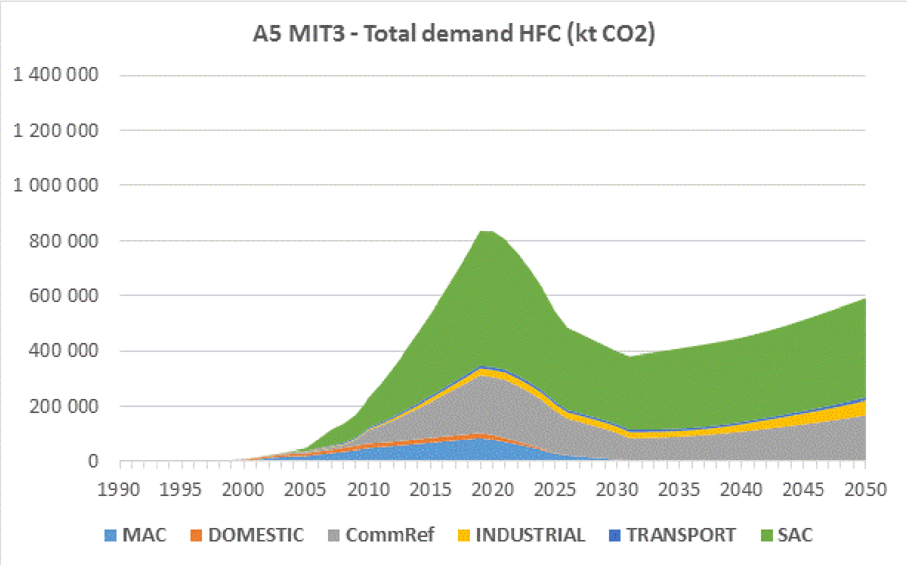


Figure 6-14: Article 5 MIT-3 scenario with the demand for the R/AC sub-sectors, including both new manufacturing and servicing

Figure 6-14 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 6-15, 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.

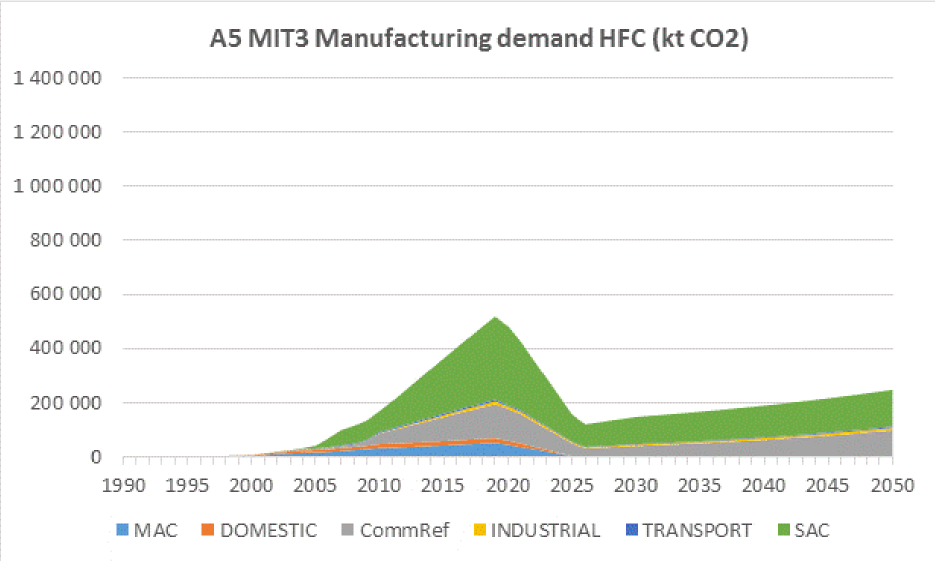


Figure 6-15: Article 5 MIT-3 scenario for new manufacturing demand for high-GWP refrigerants in the various R/AC sub-sectors in ktonnes CO_2-eq. (compare Fig. 6-6 for non-Article 5 manufacturing demand)

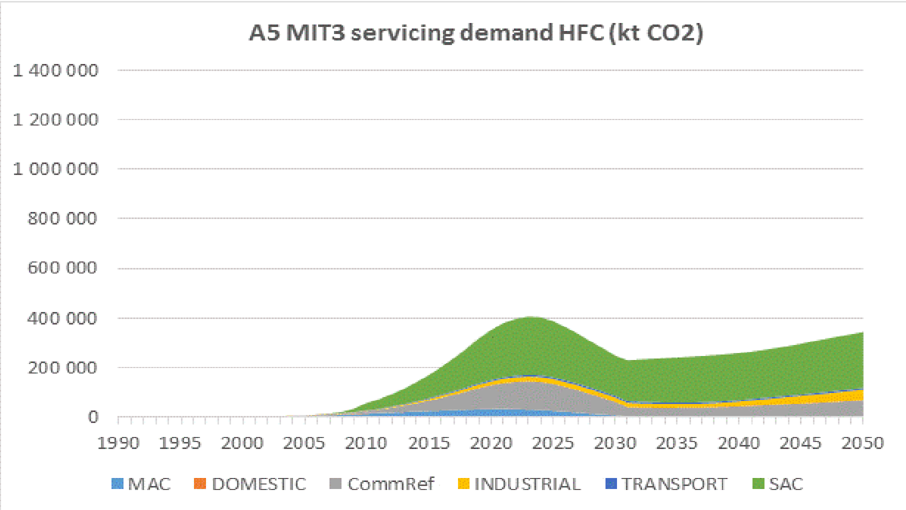


Figure 6-16: Article 5 MIT-3 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (compare Fig. 6-7 for non-Article 5 servicing demand)

Figure 6-16 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.

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

Figure 6-17 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.

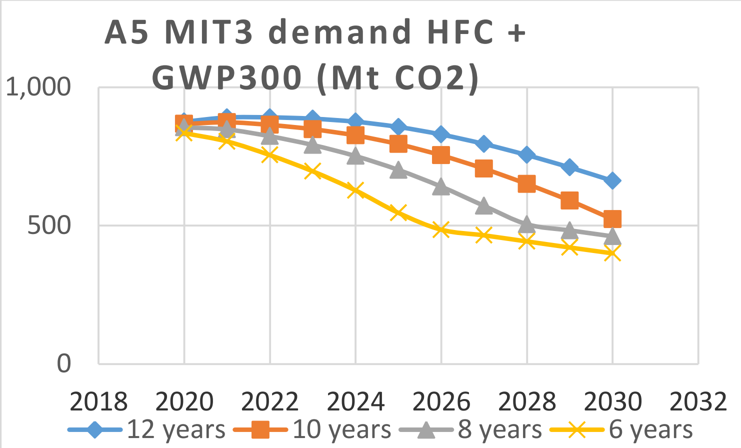


Figure 6-17: Article 5 MIT-3 demand scenario for all R/AC sectors for new manufacturing conversion periods of 6-8-10-12 years in Mt CO_2-eq. (UNEP, 2015)

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 chapter 6 in the XXVI/9 Task Force report).

A longer period than 12 years, i.e., 18 years has been considered where it concerns the total demand compared to the 6 and 12 years conversion period. The various demands are given in Figure 6-18 (with also BAU demand as developing 2020-2024). The demand for a 18 years conversion period first increases (servicing build-up) then decreases after 2028-2030.

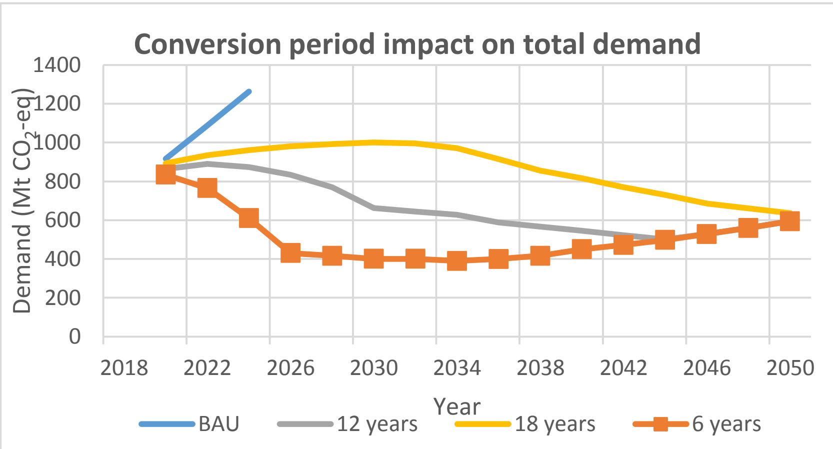


Figure 6-18: Article 5 MIT-3 total demand scenarios for 6, 12 and 18 years manufacturing conversion periods (compare also Figure 6-14 and 6-17 for MIT-3, 6 years and 6-8-10-12 years conversion periods)

Whereas the 6 and 12 years conversion periods result in a demand decrease after 2020, the 18 years conversion period yields an almost 10% increase in demand first, until the year 2030, then starts to decrease and reaches the 2020 demand level again in the year 2037.

This is due to the build-up of servicing demand from HFC products still being manufactured, while there is economic growth for the various R/AC sub-sectors. The 6 years conversion has no high GWP servicing demand after 2032-2034, the 12 years conversion has high GWP HFC servicing demand until 2042-2044, for the 18 years conversion period there is still some high GWP servicing demand until around 2050.

The demand for the period 2020-2050 for a 6 years conversion period is about 15,800 Mt CO_2-eq., increases to 20,500 Mt CO_2-eq. for a 12 years, and to 27,000 Mt CO_2-eq. for a 18 years conversion period, a 70% increase compared to the 6 years conversion period.

6.5.4 MIT-4 scenario

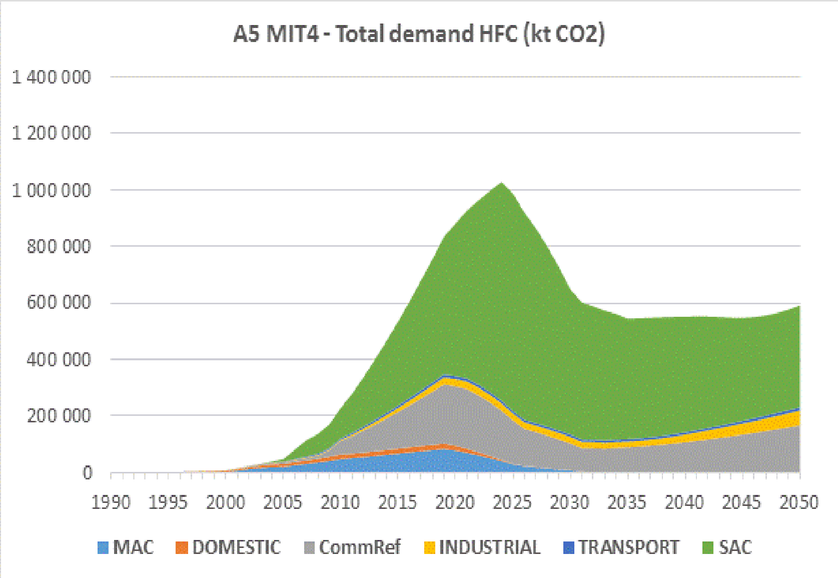


Figure 6-19: Article 5 MIT-4 total demand scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 6-14 for MIT-3)

Figure 6-19 includes both manufacturing and servicing, and is the same as Fig 6-14 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 6-20 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.

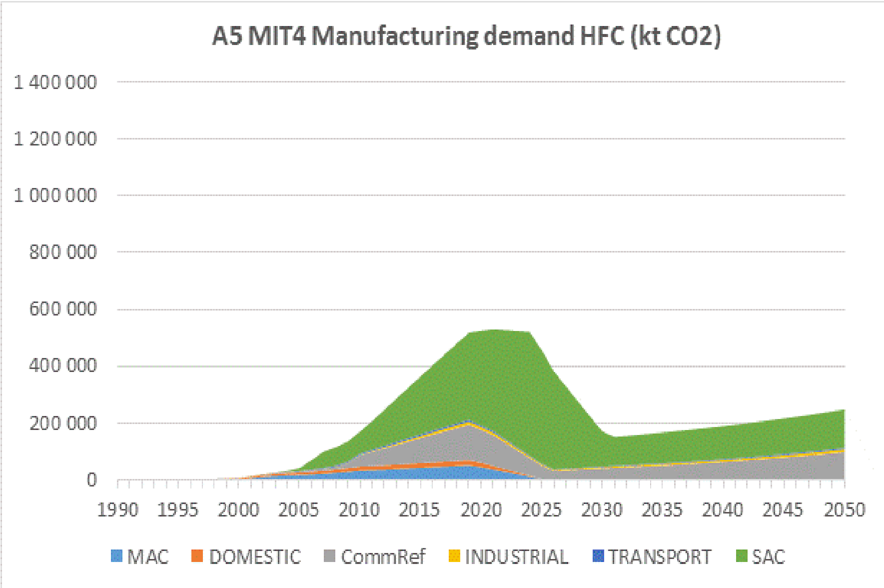


Figure 6-20: Article 5 MIT-4 scenario for new manufacturing demand for the various R/AC sub-sectors in ktonnes CO_2-eq. (compare Fig. 6-15 for MIT-3)

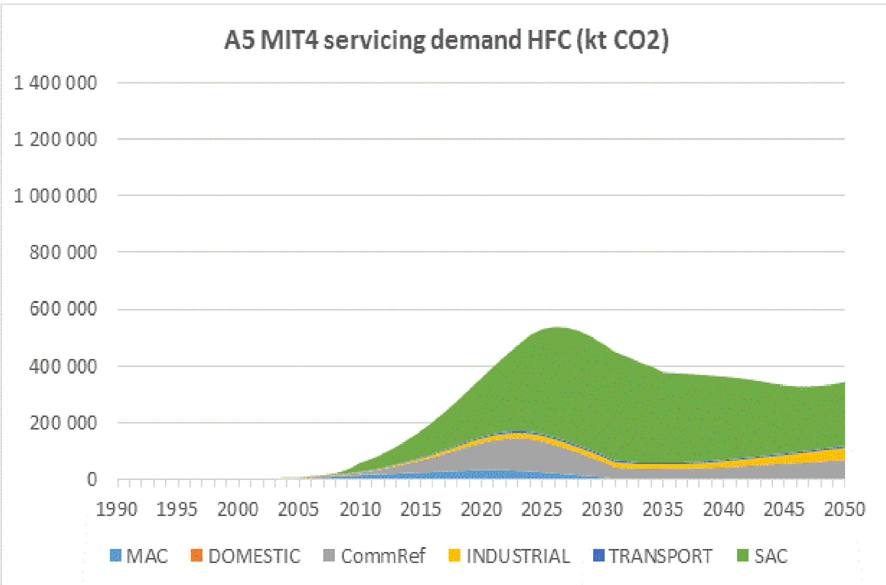


Figure 6-21: Article 5 MIT-4 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (stationary AC starting in 2025, and assuming a conversion of manufacturing over a period of six years) (compare Fig. 6-16 for MIT-3)

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.

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

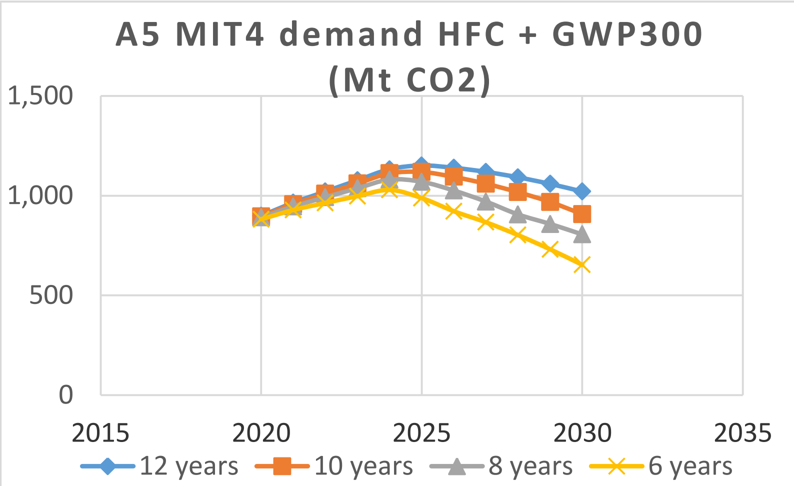


Figure 6-22: Article 5 MIT-4 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years in Mt CO_2-eq. (compare Figure 6-17 for the MIT-3 scenario) (UNEP, 2015)

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. 6-22 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. 6-17 and 6-22):

- 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)).

6.5.6 *MIT-5 scenario*

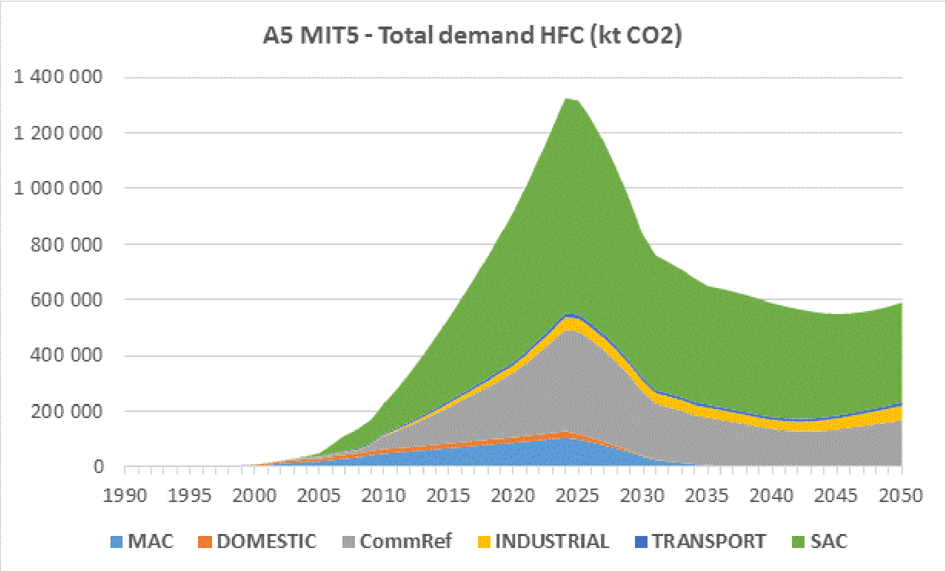


Figure 6-23: Article 5 MIT-5 scenario by R/AC sub-sectors in ktonnes CO_2-eq. (compare Figure 6-14 and 6-19 for MIT-3 and MIT-4)

Figure 6-23 includes both manufacturing and servicing, and is similar to Figs 6-14 and 6-19 for MIT-3 and MIT-4 (replacement refrigerant blends at a GWP of 300; six year manufacturing conversion).

Figure 6-24 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).

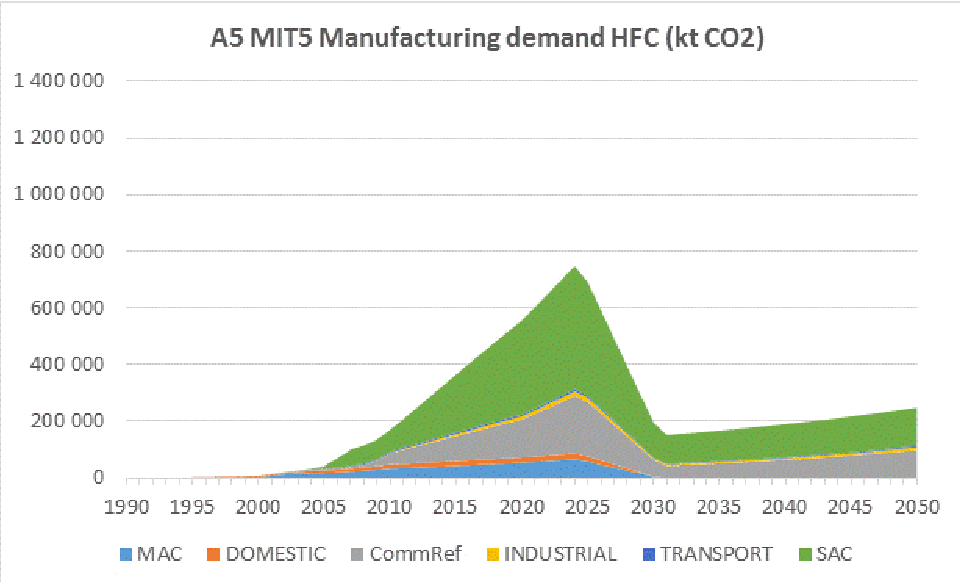


Figure 6-24: Article 5 MIT-5 scenario for new manufacturing demand for the various R/AC sub-sectors in ktonnes CO_2-eq. (manufacturing conversion over a period of six years) (compare Figure 6-15 and 6-21 for MIT-3 and MIT-4)

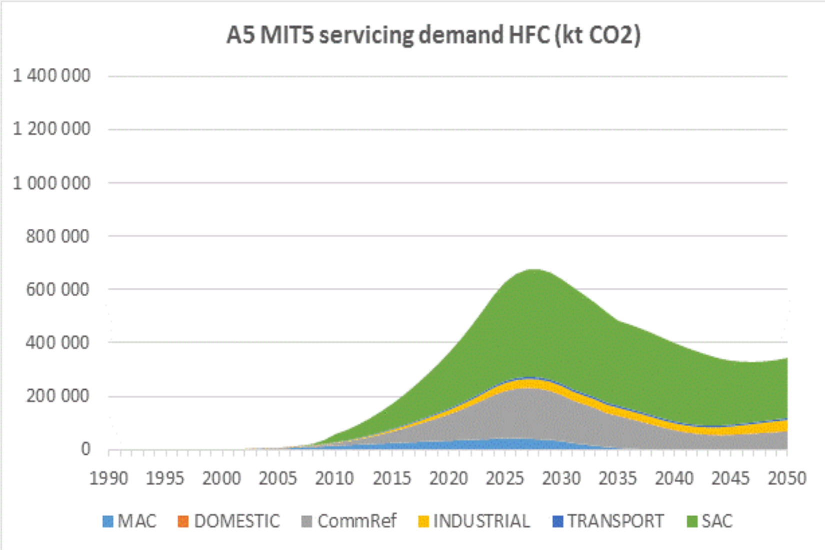


Figure 6-25: Article 5 MIT-5 scenario with the servicing demand for the various sub-sectors in ktonnes CO_2-eq. (assuming a conversion of manufacturing over a period of six years) (compare Figure 6-16 and 6-21 for MIT-3 and MIT-4)

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).

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

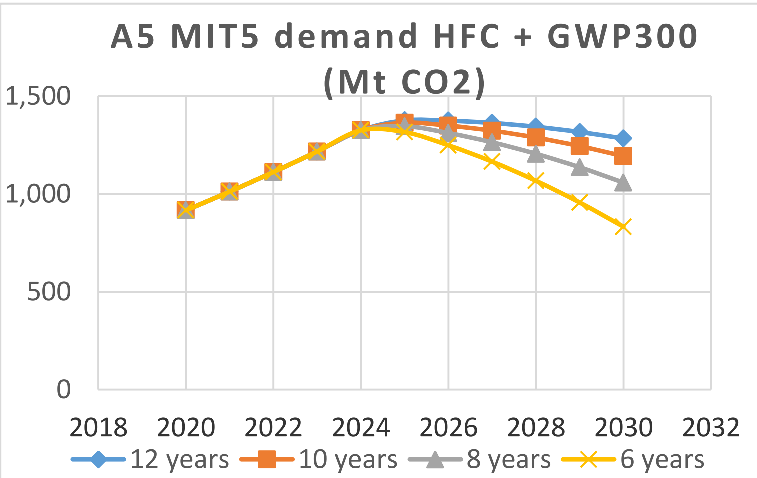


Figure 6-26: Article 5 MIT-5 demand scenario for all R/AC sectors combined for new manufacturing conversion periods of 6-8-10-12 years (compare Figures 6-17 and 6-23 for the MIT-3 and MIT-4 scenarios) (UNEP, 2015)

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. 6-26 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).

6.6 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 6-3: 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 6-4: 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 6-5: 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 6-6: 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 6-7: 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 6-8: 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 6-9: 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 6-10: 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 6-11: 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 6-12: 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 6-11 and 6-12 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 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 6-13: 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 6-14: 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 6-13 (and 6-14) show 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 savings 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.

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7 Foam blowing agents

This is a new chapter in this final update version of the Task Force report. It presents new information on alternative blowing agents compared to the XXV/5 report in 2014 for the various types of foam, specified for the various application sectors. It also gives detailed information on the consumption of blowing agents in BAU and mitigation scenarios for both non-Article 5 and Article 5 parties in this sector.

7.1 Blowing agent overview

The foams sector continues to make significant strides in addressing the phase out of ozone depleting materials, while the industry as a whole continues to grow at a rate of approximately 3 % per year in Article 5 and 1.5% per year in non-Article 5 regions. Hydrocarbons have been a major part of Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) reduction for large parts of the foam sectors, however national and regional regulations regarding ODP and GWP, codes and standards related to thermal performance and energy consumption, fire safety, and volatile organic compound (VOC) emissions are currently driving the choice of blowing agents used by foam manufacturers.

HCFC-141b and -142b are still dominant blowing agents for rigid foams in major ASEAN and African countries along with other co-blowing agents. Transition to next generation hydrocarbon or HFC blowing agents is occurring however it may be appropriate for some manufacturers to transition directly to HFO/HCFOs. HFO and HCFOs have been judged good technical options for HCFC replacement but these are more expensive than HCFCs and HFCs. Not all HFOs are non-flammable. 1234ze shows some flammability at elevated temperatures, which will have to be taken into consideration by potential users.

High GWP HFCs (e.g. HFC 134a) are still widely used in non-Article 5 countries mainly for the production of extruded polystyrene foams (XPS) and specific PU products such as PU spray foam. New regulations however will lead to a phase down of these materials and phase out in many non-A5 countries by 2022. Here again the emergence of HFO/HCFOs represents a significant opportunity although costs remains a key issue, and blends with hydrocarbons or oxygenated hydrocarbons (e.g. dimethyl ether) may be required to deliver commercially viable alternative technology.

Hydrocarbons (HCs) remain a popular alternative to HCFCs for large and medium sized polyurethane foam producers who have installed safety equipment, and have procedures and operating discipline to safely handle these flammable materials in countries worldwide. In some countries, regulations around flammability and use of VOCs may limit their use. Similarly, transitioning small and medium enterprises (SMEs) to HCs is problematic because of capital costs, safe handling and training concerns.

Other blowing agents also represent potential replacements for HCFCs and HFCs. These include a group of oxygenated hydrocarbons (HCOs) which include methyl formate and methylal. The use of these low GWP blowing agents has been slowly growing and are generally seen as less flammable than hydrocarbons themselves, although their use can be dependent on local codes and the regulatory framework governing foam manufacture.

CO_2(water) blown foam is used to make rigid spray polyurethane foams for a number of applications including pipe and water heater insulation and more recently in some construction application in North America and Europe where insulation per thickness unit are less critical.

Similarly, predominantly CO_2 blown in blends with co-blowing agents used in the Extruded Polystyrene sector represent a cost effective low-GWP alternative, however these foams have poorer thermal efficiency than HCFC or HFC alternatives. Additionally, processing difficulties and conversions costs mean that considerable portions of the XPS industry have remained using HCFCs and HFCs. Typical co-blowing agents used with CO_2 are hydrocarbons, oxygenated hydrocarbons and ethanol.

The following table summarizes blowing agent classes which have either previously offered, or are currently offering, alternatives to ozone depleting substances in the sectors being specifically considered in this chapter.

Table 7-1 Summary of alternative foam blowing agents to ODS, by application

Sector	CFCs	HCFCs	HFCs	HCs	HCOs	HCFO/HFOs	CO_2-based
	ODS being replaced						
PU Appliances	CFC-11	HCFC-141b HCFC-22	HFC-245fa HFC-365mfc/227ea	cyclo-pentane cyclo/iso-pentane	Methyl[Δ] Formate	HFO-1233zd(E) HFO-1336mzzm(Z)	CO_2 (water)*[Δ]
PU Board	CFC-11	HCFC-141b	HFC-365mfc/227ea	n-pentane cyclo/iso pentane		HFO-1233zd(E) HFO-1336mzzm(Z)	
PU Panel	CFC-11	HCFC-141b	HFC-245fa HFC-365mfc/227ea	n-pentane cyclo/iso pentane		HFO-1233zd(E) HFO-1336mzzm(Z)	CO_2 (water)*
PU Spray	CFC-11	HCFC-141b	HFC-245fa HFC-365mfc/227ea			HFO-1233zd(E) HFO-1336mzzm(Z)	CO_2 (water)* Super-critical CO_2
PU In-situ/Block	CFC-11	HCFC-141b	HFC-245fa HFC-365mfc/227ea	n-pentane cyclo/iso pentane		HFO-1233zd(E) HFO-1336mzzm(Z)	CO_2 (water)*
PU Integral Skin	CFC-11	HCFC-141b HCFC-22	HFC-245fa HFC-134a		Methyl Formate Methylal		CO_2 (water)*
XPS Board	CFC-12	HCFC-142b HCFC-22	HFC-134a HFC-152a		DME	HFO-1234ze(E)	CO_2 CO_2/ethanol
Phenolic	CFC-11	HCFC-141b	HFC-245fa HFC-365mfc/227ea	n-pentane cyclo/iso pentane		HFO-1233zd(E) HFO-1336mzzm(Z)	

*CO_2(water) blown foams rely on the generation of CO_2 from reaction of isocyanate with water in the PU system itself
[Δ] Primarily in the commercial refrigeration sector (e.g. vending machines)

7.2 Regulations and codes (extract from the TEAP June 2016 progress report)

The development and implementation of national and regional regulations relating to the energy efficiency of appliances and buildings continues to drive the global demand for high performance insulation materials, typically polymeric foams.

In the **United States (US)**, the Significant New Alternatives Policy (SNAP) program implemented by the Environmental Protection Agency (EPA) has changed the landscape for foam blowing agents. The SNAP program lists alternatives to ozone-depleting substances (ODS) as acceptable or unacceptable, depending on the overall health and environmental impacts of available substitutes.
In Rule 20 in July 2015, the SNAP program communicated a change of status to unacceptable for the blowing agents HFC-134a, HFC-245fa and HFC-365mfc and other higher GWP HFCs for use in polyurethane, phenolic, and polystyrene foams between 2017 and 2021. The SNAP program excluded changes to HFC blowing agents used in spray foams and one component foams in Rule 20; however, they were included in proposed Rule 21 (published April 2016) with transition dates all prior to January 1, 2021. The proposed Rule 21 also includes a change of status to unacceptable for methylene chloride for use in flexible foams, integral skins, and polyolefins as well. There are extended timelines in both rules for military, space and aeronautics related applications. A final Rule 21 is currently under review and anticipated to be finalized in the coming weeks.

Table 7.2 Final Rule – Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Program

Foams***	
Rigid Polyurethane and Polyisocyanurate Laminated Boardstock	January 2017
Flexible Polyurethane	January 2017
Integral Skin Polyurethane	January 2017
Polystyrene Extruded Sheet	January 2017
Phenolic Insulation Board and Bunstock	January 2017
Rigid Polyurethane Slabstock and Other	January 2019
Rigid Polyurethane Appliance Foam	January 2020
Rigid Polyurethane Commercial Refrigeration and Sandwich Panels	January 2020
Polyolefin	January 2020
Polyurethane Marine Flotation Foam	January 2020
Polystyrene Extruded Boardstock and Billet (XPS)	January 2021
Rigid Polyurethane Spray Foam	No status change finalized
Closed Cell Foams	Applicability to imports not finalized

***SNAP Fact Sheet July 20, 2015 Final Rule – Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Program

In the **European Union (EU),** high GWP fluorinated gases are being phased down, according to the F-gas regulation (EU regulation 517/2014). In 2015, all HFCs with GWP greater than 150 were banned for foam use in domestic appliances. Labelling is obligatory on foams and polyol-blends, and the presence of HFC has to be mentioned in the technical documentation and marketing brochures for spray polyurethane foams (SPF) used in building insulation, refrigerated containers and trucks. By 1/1/2023 all HFCs with GWP greater than 150 will be banned from all foam manufacturing. (See Fig 7-1)

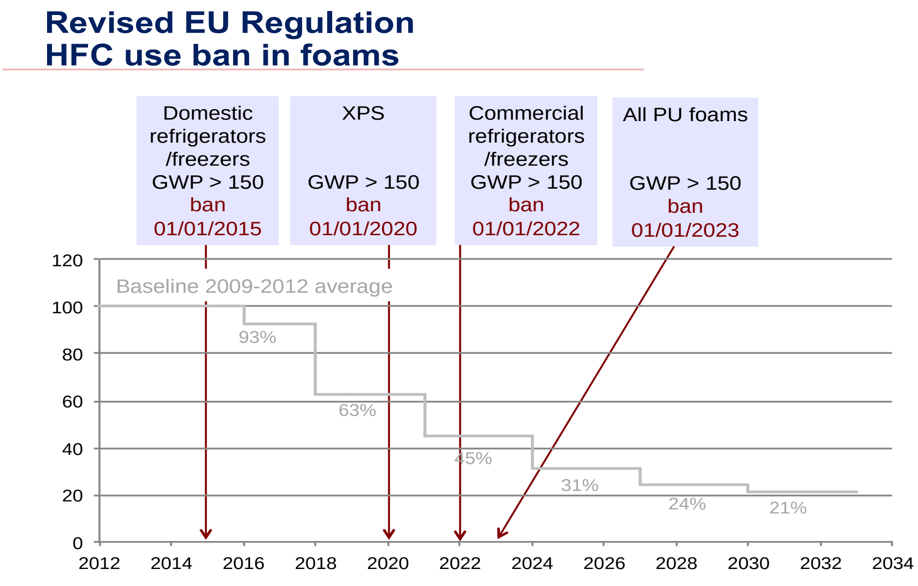

Fig 7-1 HFC phase down according to the F-Gas Regulation in the EEA

The F-Gas regulation operates on the supply side through a quota system, which will likely mean that supply of blowing agents to the foam sector could become restricted well before the phase-out dates noted above. This is especially likely because the bulk of the demand is in the refrigeration and air conditioning (RAC) sector. A recent EPEE Study (presented at a side event at MOP-27) indicated that the RAC sector will have difficulty in meeting its phase-down targets, leading to an inevitable increase in price. Shortages of supply of HFC-365mfc/227ea mixtures for foam blowing are already being observed.

In other non-Article 5 parties, there have been substantive new national and regional regulatory requirements for foam blowing agents with respect to their GWP. Regulations have been enacted or proposed that will require the elimination of the use of high GWP blowing agents in Canada, Japan; and Australia has proposed a GWP phase down.

Manufacturers of HFO and HCFO chemicals are planning to increase manufacturing capacity to meet the expected need for low GWP blowing agents. Capital costs for a new plant are in the region of $100-200 million and can take 18 months to several years to construct and achieve full production. Optimized foam formulations using HFO and HCFO chemicals or blends of HFO and HCFO chemicals with other blowing agents (such as HC and methyl formate) will require product approval and qualification/certification testing, not only for the blowing agent itself, but also for the foam products where the blowing agent is used. This foam formulation development, qualification and gaining of foam approvals can take also from 18 months to several years, but is often done in parallel with the construction of the HFO/HCFO manufacturing facility using product from existing facilities.

Article 5 parties have an interest in transitioning to low GWP solutions directly from HCFCs. However, there is concern about the safe handling of flammable alternatives, price, and adequacy of supply of suitable alternatives such as HFO and HCFO chemicals for SMEs in these parties, as they make decisions about transitions. Foam manufacturers and blowing agent producers need re-assurance that market shift will be driven through regulatory changes in A5 Parties, in order to make the necessary and timely investment.

New regulations affecting the use of blowing agents in extruded polystyrene (XPS) have been introduced that will drive the point of sale replacement of HFC-134a foams by low GWP alternatives in the EU (Jan 1 2020) and the US (January 1 2021). Manufacturing conversion will have to be completed in early 2019 to remove higher GWP HFCs from the supply chain in Europe. HFO-1234ze(E) is only available from a single supplier, and has significantly higher cost when used as a direct replacement for HFC-134a. Blends are also being tested by some companies, as a lower cost option.

Some Article 5 XPS producers have already converted to zero ODP alternatives. Other A5 XPS producers continue testing zero ODP alternatives and/or low GWP alternatives to prepare for transition away from HCFCs. In China, HCFC-142b/22 blends are used with HCFC-22 predominating because of its price and availability. These could transition directly to low GWP alternatives, including HFC-152a, CO_2, HCs, dimethyl ether (DME), alcohols etc. However, building codes for fire protection will limit HCs as an alternative. HFC-134a has low solubility in foam systems and lower thermal conductivity than the low GWP alternatives, and is used in blends with the aforementioned alternatives to better balance XPS foam performance. HFO/HCFO technology is also being evaluated either neat or blended with one or more of the aforementioned blowing agents

7.3 Trends in blowing agent choice by sector

The next section of this chapter briefly summarises trends in blowing agent choice by specific sector. These are summaries and updates of materials presented in the Decision XXV/5 Task Force report.

7.3.1 Polyurethane Appliance

Non-Article 5 parties	***Article 5 parties***
In EU and Japan cyclo-pentane, iso pentane hydrocarbon blends are dominant for domestic appliance, while in North America partly due to design, safety and insurance concerns, 245fa is primarily used but also HFC-134a and more recently HFC-365mfc/227ea. Although North America remains largely dependent on high-GWP HFCs for domestic refrigeration, conversion to HFOs and hydrocarbons has started. For commercial appliances, solutions are more complex with greater reliance on lower flammability options such as high GWP HFCs. The emergence of HFOs, and HCFOs has generated interest in all regions, offering good thermal insulating properties with low-GWP.	Similar trends exist in highly populated Article 5 parties where multi-national companies are able to adopt global technology strategies. There has been significant transition to pentanes for larger producers. However, in some cases the transition from HCFCs to alternatives has not yet occurred and there are opportunities to avoid-high GWP HFCs by using HFOs, and HCFOs which is expected to mirror decisions made in non-article 5 regions. For transitions covered under the Multilateral Fund, virtually all HCFC phase out has been directed to low-GWP alternatives including hydrocarbon conversion, methyl formate and methyal.

7.3.2 Polyurethane Boardstock

Non-Article 5 parties	***Article 5 parties***
In virtually all non-Article 5 regions hydrocarbons (typically n-pentane or mixture of cyclo-pentane and iso pentane) have been the dominant choice of blowing agent to replace ozone depleting substances. HFOs, and HCFOs may be of interest in the future only if they are necessary to meet energy efficiency standards as their cost is likely to be otherwise prohibitive in this application.	There is no significant manufacture in Article 5 regions with the exception of China, however it is likely that hydrocarbons will be the blowing agent of choice for any new capacity.

7.3.3 Polyurethane Panels

Non-Article 5 parties	***Article 5 parties***
For the continuous panel sector hydrocarbons predominate, with only limited instances of high-GWP HFCs being adopted where fire performance requirements have dictated otherwise, however their use continues to decline. For discontinuous panels there is a greater reliance on high-GWP blowing agents to overcome flammability concerns, however this is expected to decline as manufacturers become more proficient in handling hydrocarbons.	There is a higher preponderance of discontinuous production in Article 5 regions, and continued use of HCFCs in many small manufacturers. Oxygenated hydrocarbons as methyl formate and methyal are also considered but their uptake is low.

7.3.4 Polyurethane Spray

Non-Article 5 parties	*Article 5 parties*
Polyurethane spray represents one of the more challenging areas from a technical viewpoint, because of processing risks with using hydrocarbons in field applications. HCFCs were replaced “en masse” with high-GWP blowing agents such as HFC 245fa (particularly in NA) and HFC-365mfc/227ea (in Europe). HFOs and HCFOs are seen as a future possibility but cost and shelf life stability of these formulations in low-pressure pre-blends have significantly slowed adoption of this technology.	PU spray foams are highly reliant on HCFCs in Article 5 regions and if solutions to HCFCs/HFCs are not found in a timely manner to phase out 141b, then high-GWP options may be considered.

7.3.5 Polyurethane In-situ/Block

Non-Article 5 parties	*Article 5 parties*
For a variety of processes including continuous, semi continuous and discontinuous processes hydrocarbons predominate although HFCs may exist where process flammability is an issue. There is a possibility that methyl formate and/or methyal might replace saturated HFCs in some discontinuous processes where thermal performance is less demanding.	Discontinuous production prevails and HCFCs remain the blowing agent of choice although uptake of methyl formate or methylal is predicted within a number of HPMPs, while the remainder will likely go to high -GWP HFCs

7.3.6 Polyurethane Integral Skin

Non-Article 5 parties	*Article 5 parties*
CO_2(water) technologies play a significant role, however hydrocarbons are increasingly accepted as a reliable replacement for HCFCs, while HFCs (typically 134a and 245fa) are used in some small specialist applications. Conversion is required in the US in 2017, and it is anticipated that there may be conversion to HFOs, HCFOs and CO_2 (water)	Technology not so prevalent except where multinational clients (e.g. automotive sector) have been involved. Tendency to remain with HCFCs and transition to high-GWP HFCs represents the easiest technical solutions. Where hydrocarbons are considered methyl formate and methyal are also options which might mitigate flammability risks.

7.3.7 Extruded Polystyrene (XPS)

Non-Article 5 parties	*Article 5 parties*
Extruded polystyrene represents a technology challenging sector. CO_2 technology has been successfully adopted by some multinational producers, however it is not very versatile even when modified with Alcohols such as Ethanol or HCOs such as di-methyl ether. Hydrocarbons have proved acceptable in Japan. A broad sector in other countries uses HFCs such as 134a, 152a or blends thereof. It is possible that low GWP solutions could be a blend of lower GWP alternatives like HFC-152a, HFOs, HCFOs, CO_2, butane, or DME.	Extruded polystyrene manufacture has grown substantially in Article 5 regions with much of the manufacture being based on HCFCs. In China particularly there are a large number of small plants and while there is some hope that low-GWP technologies can achieve widespread conversion. the outcome of an important pilot study is awaited.

7.3.8 Phenolic Foam

Non-Article 5 parties	***Article 5 parties***
Technologies are universally based on hydrocarbon or 2-chloropropane blowing agents as phenolic foams have intrinsic fire properties. One potential change may be if improved thermal properties might be obtained with HFOs and HCFOs.	Very little production exists in Article 5 regions with the exception of China which already uses hydrocarbon technologies.

7.4 BAU – Foams

This report updates the information in Decision XXV/5 task force report to update the BAU scenario for non-A5 parties to reflect changes in legislation and extend the outlook to 2050. As indicated in the regulations and codes section it is now assumed that the US EPA Rule 21 and the modified Canadian regulation are implemented as proposed Assumptions also include the EU F-gas phase down impacts from 2020, impacts to foam from the Australian phase down 2023, and that Japan has significant conversion by 2020. Beyond the previous estimates in Decision XXV/5 which went out to 2030, it is assumed a 1.5% growth rate beyond 2030 in non-A5 countries. The overall outcome is shown in Tables 7-4 and 7-5.

Table 7-4 Current and future demand by blowing agent for ODS and their alternatives (BAU scenario) for the period 2010- 2050 in Non-Article 5 parties

	Non-A5 : BAU - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	0	0	0	0	0	0	0	0	0
HCFC-142b	16,665	0	0	0	0	0	0	0	0
HCFC-22	4,334	0	0	0	0	0	0	0	0
HFC-245fa	28,063	32,000	5,000	0	0	0	0	0	0
HFC-365mfc/HFC-227ea	9,609	9,042	4,850	0	0	0	0	0	0
HFC-134a/HFC-152a	24,230	26,000	14,000	13,000	14,000	15,082	16,248	17,503	18,856
HFO/HCFO	0	4,000	42,000	53,000	65,000	70,023	75,435	81,265	87,546
Hydrocarbon	121,999	140,000	150,000	170,000	180,000	193,911	208,897	225,042	242,434
Other	0	0	0	0	0	0	0	0	0
Totals	***204,900***	***211,042***	***215,850***	***236,000***	***259,000***	***279,017***	***300,580***	***323,810***	***348,835***
% Growth		3.00%	2.28%	9.34%	9.75%	7.73%	7.73%	7.73%	7.73%
	Non-A5 : BAU - Year in ktCO2-eq								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	0	0	0	0	0	0	0	0	0
HCFC-142b	12,082	0	0	0	0	0	0	0	0
HCFC-22	7,844	0	0	0	0	0	0	0	0
HFC-245fa	28,905	32,960	5,150	0	0	0	0	0	0
HFC-365mfc/HFC-227ea	9,840	9,259	4,966	0	0	0	0	0	0
HFC-134a/HFC-152a	18,899	20,280	1,960	1,820	1,960	2,111	2,275	2,450	2,640
HFO/HCFO	0	28	294	371	455	490	528	569	613
Hydrocarbon	1,220	1,400	1,500	1,700	1,800	1,939	2,089	2,250	2,424
Other	0	0	0	0	0	0	0	0	0
Totals	***78,790***	***63,927***	***13,870***	***3,891***	***4,215***	***4,541***	***4,892***	***5,270***	***5,677***
Average GWPs	385	303	64	16	16	16	16	16	16

Table 7-5 Current and future demand by application for ODS and their alternatives (BAU scenario) for the period 2010- 2050 in Non-Article 5 parties

	Non-A5 : BAU - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
PU Dom Appliance	31,253	34,251	35,500	40,000	42,000	45,246	48,743	52,510	56,568
PU Other Appliance	7,272	8,471	9,382	10,682	11,794	12,705	13,687	14,745	15,884
PU Reefers	2,521	3,500	3,086	3,407	3,761	4,052	4,365	4,703	5,066
PU Boardstock	69,227	77,814	79,000	85,000	93,000	100,187	107,930	116,272	125,258
PU Cont. Panel	21,128	21,000	21,379	23,000	25,500	27,471	29,594	31,881	34,345
PU Disc. Panel	13,788	13,691	14,400	15,768	17,409	18,755	20,204	21,765	23,448
PU Spray	10,463	12,000	12,000	13,000	15,000	16,159	17,408	18,753	20,203
PU Pipe-in-Pipe	2,718	3,000	3,000	3,069	3,389	3,651	3,933	4,237	4,564
PU Block	4,904	5,500	5,389	6,256	6,907	7,441	8,016	8,635	9,302
PF Block	939	1,000	996	1,130	1,248	1,345	1,448	1,560	1,681
Extruded Polystyrene	40,685	31,000	30,902	35,520	39,217	42,248	45,513	49,031	52,820
Totals	***204,900***	***211,227***	***215,034***	***236,832***	***259,225***	***279,259***	***300,841***	***324,092***	***349,139***
	Non-A5 : BAU - Year in ktCO2-eq								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
PU Dom Appliance	12,175	10,275	46	52	55	59	63	68	74
PU Other Appliance	5,045	5,870	12	14	15	17	18	19	21
PU Reefers	1,698	2,356	25	27	30	32	35	38	41
PU Boardstock	2,459	9,727	632	680	744	801	863	930	1,002
PU Cont. Panel	7,386	7,875	107	115	128	137	148	159	172
PU Disc. Panel	12,481	5,134	72	79	87	94	101	109	117
PU Spray	10,726	11,400	9,600	17	20	21	23	24	26
PU Pipe-in-Pipe	1,179	1,299	4	4	4	5	5	6	6
PU Block	1,919	2,151	27	31	35	37	40	43	47
PF Block	362	713	5	6	6	7	7	8	8
Extruded Polystyrene	23,190	6,200	3,100	2,936	3,019	3,333	3,591	3,869	4,168
Totals	***78,620***	***63,000***	***13,630***	***3,960***	***4,142***	***4,544***	***4,895***	***5,273***	***5,680***

Figure 7-2 provides a graphical assessment of the output from these assumptions for the period to 2050.

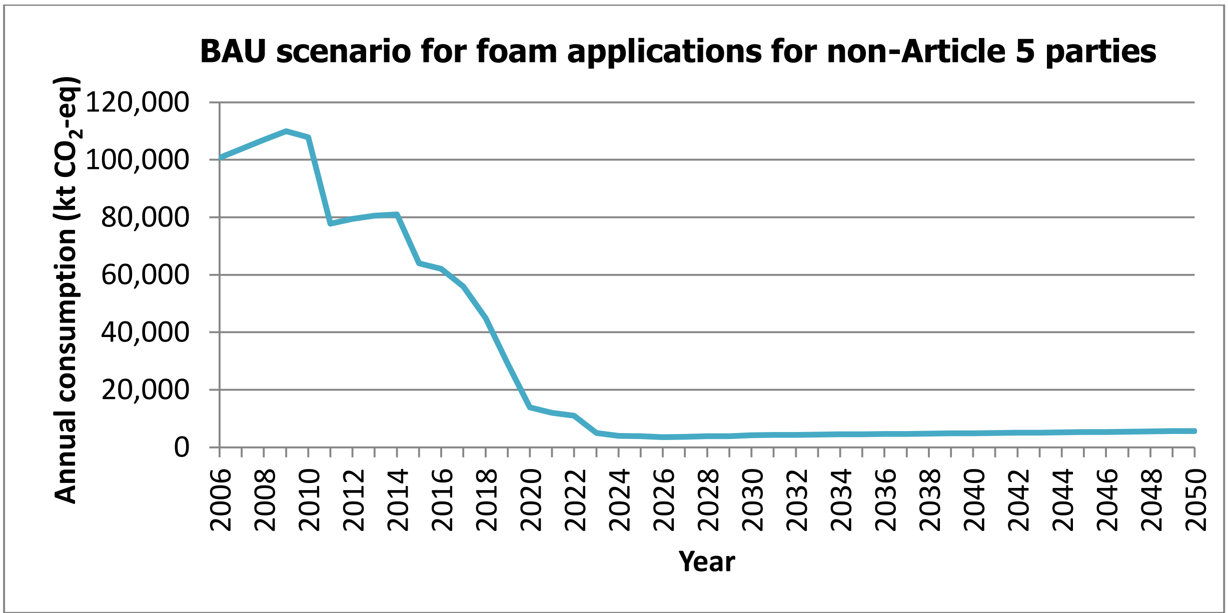

Fig. 7-2 BAU scenario for foam applications for non-Article 5 parties

For the Business as Usual case for Article 5 parties the most significant regulatory framework from a foams perspective is Decision XIX/6 under the Montreal Protocol. The phase-down schedule under Decision XIX/6 is shown below:

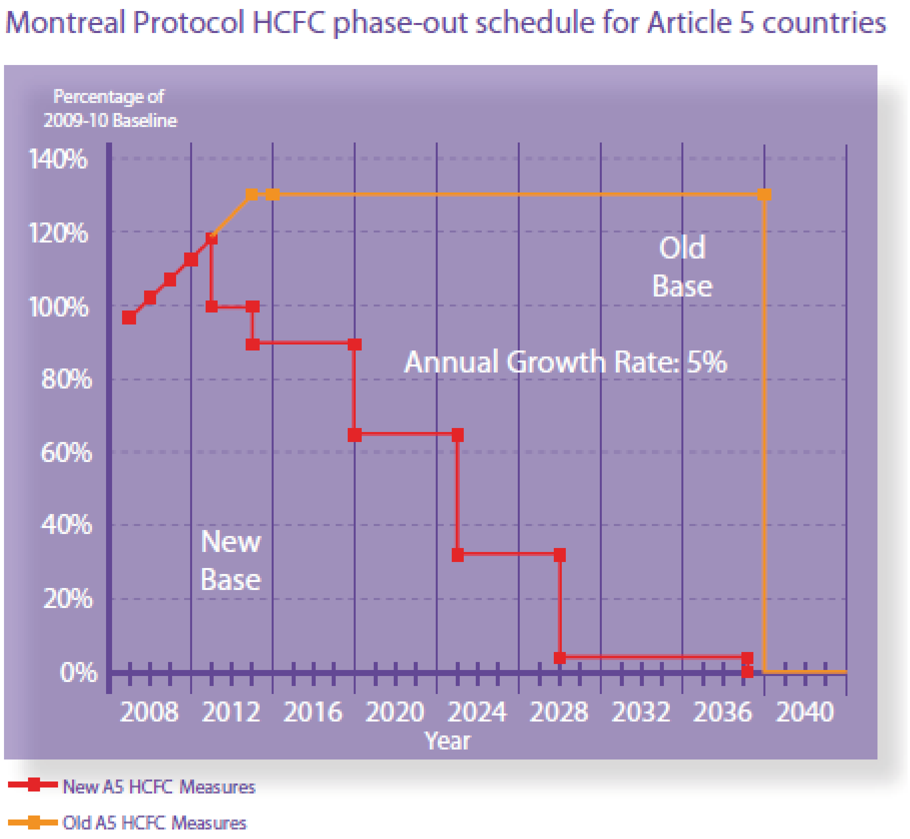

Figure 7-3 Schematic of the Article 5 phase-down steps following Decision XIX/6

As indicated in Decision XXV/5 "A major challenge created by the terms of Decision XIX/6 is that the freeze in 2013 is based on the average of the 2009 and 2010 consumption. This means that growth in the period from 2010 to 2012 needs to be offset in 2013. Figure 7-3 shows how the BAU would look for an annual growth rate of 5% during that period. This remains a challenge for both the RAC and foam sectors".

The assumptions therefore for Article 5 parties remain as in Decision XXV/5 and are set out in the Table 7-6. A growth rate of 3% is used for the foams sector beyond 2030.

Table 7-6 Assumptions used for Business-as-Usual foam assessment in Article 5 parties

A5	
PU Appliance	**All countries**
ODS transitions complete by 2022*	Yes
% high GWP options by weight	10%
PU Boardstock	**All countries**
ODS transitions complete by 2022	Yes
% high GWP options by weight	20%
PU Panel	**All countries**
ODS transitions complete by 2022	Yes
% high GWP options by weight	20%

PU Spray	All countries
ODS transitions complete by 2022	Yes
% high GWP options by weight	100%/50%**
PU Insitu/Block	**All countries**
ODS transitions complete by 2022	Yes
% high GWP options by weight	20%
XPS Board	**All countries**
ODS transitions complete by 2028^	Yes
% high GWP options by weight	100%/50%**
Phenolic	**All countries**
ODS transitions complete by 2022	Yes
% high GWP options by weight	20%

* Assumes a 10 year linear phase down from peak in 2012
^ Assumes a 10 year linear phase down from peak in 2018
** Assumes 100% high GWP prior to 2017 and 50% high GWP from 2017 onwards

The following two tables give further data on the BAU tonnage projections have been expanded to show data out to 2050 and assumes an annual growth rate of 3% beyond 2030:

Table 7-7 Current and future demand by blowing agent for ODS and their alternatives (BAU scenario) for the period 2010-2050 in Article 5 parties

	A5 : BAU - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	39,895	29,032	8,295	0	0	0	0	0	0
HCFC-142b	16,508	22,562	17,895	6,678	0	0	0	0	0
HCFC-22	17,436	23,345	18,118	6,678	0	0	0	0	0
HFC-245fa	354	2,171	3,841	4,986	5,504	6,381	7,398	8,576	9,942
HFC-365mfc/HFC-227ea	0	1,758	3,428	4,547	5,020	5,820	6,747	7,822	9,067
HFC-134a/HFC-152a	955	6,729	11,338	22,560	30,450	35,300	40,923	47,441	54,997
HFO/HCFO	0	0	10,996	23,296	31,081	36,031	41,770	48,423	56,135
Hydrocarbon	31,665	43,764	54,459	63,939	71,189	82,528	95,672	110,911	128,576
Other	0	0	0	0	0	0	0	0	0
Totals	***106,814***	***129,360***	***128,370***	***132,684***	***143,245***	***166,061***	***192,510***	***223,171***	***258,717***
% Growth		21.11%	-0.77%	3.36%	7.96%	15.93%	15.93%	15.93%	15.93%
	A5 : BAU - Year in ktCO2-eq								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	28,445	20,700	5,914	0	0	0	0	0	0
HCFC-142b	37,473	51,216	40,621	15,160	0	0	0	0	0
HCFC-22	31,036	41,555	32,251	11,887	0	0	0	0	0
HFC-245fa	361	2,214	3,918	5,085	5,615	6,509	7,545	8,747	10,141
HFC-365mfc/HFC-227ea	0	1,789	3,489	4,628	5,110	5,924	6,867	7,961	9,229
HFC-134a/HFC-152a	1,347	9,463	13,628	23,695	30,908	35,831	41,538	48,154	55,824
HFO/HCFO	0	0	77	163	218	252	292	339	393
Hydrocarbon	348	481	599	703	783	908	1,052	1,220	1,414
Other	0	0	0	0	0	0	0	0	0
Totals	***99,011***	***127,418***	***100,497***	***61,322***	***42,633***	***49,423***	***57,295***	***66,421***	***77,000***
Average GWPs	927	985	783	462	298	298	298	298	298

Table 7-8 Current and future demand by application for ODS and their alternatives (BAU scenario) for the period 2010-2050 in Article 5 parties

	A5 : BAU - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
PU Dom Appliance	42,004	46,192	45,202	47,548	52,497	60,859	70,552	81,789	94,816
PU Other Appliance	2,757	3,055	3,055	3,242	3,579	4,150	4,811	5,577	6,465
PU Reefers	3,100	3,294	3,294	3,496	3,860	4,475	5,187	6,014	6,971
PU Boardstock	175	192	192	203	225	260	302	350	406
PU Cont. Panel	2,689	2,788	2,788	2,959	3,267	3,787	4,391	5,090	5,901
PU Disc. Panel	7,908	7,583	7,583	8,047	8,885	10,300	11,940	13,842	16,047
PU Spray	7,653	7,306	7,306	7,753	8,560	9,923	11,504	13,336	15,460
PU Pipe-in-Pipe	4,764	5,039	5,039	5,347	5,904	6,844	7,935	9,198	10,663
PU Block	2,591	2,777	2,777	2,946	3,253	3,771	4,372	5,068	5,875
PF Block	101	117	117	124	137	159	184	214	248
Extruded Polystyrene	33,071	51,017	51,017	51,017	53,078	61,532	71,333	82,694	95,865
Totals	***106,814***	***129,360***	***128,370***	***132,684***	***143,245***	***166,061***	***192,510***	***223,171***	***258,717***
	A5 : BAU - Year in ktCO2-eq								
	2,010	2,015	2,020	2,025	2,030	2,035	2,040	2,045	2,050
PU Dom Appliance	12,135	10,304	4,522	2,346	2,590	18,258	21,166	24,537	28,445
PU Other Appliance	1,966	1,720	954	687	759	2,876	3,334	3,865	4,480
PU Reefers	2,309	1,993	1,226	975	1,077	3,011	3,491	4,047	4,692
PU Boardstock	2	2	2	2	2	33	38	44	51
PU Cont. Panel	1,254	1,013	567	413	456	1,420	1,646	1,909	2,213
PU Disc. Panel	4,797	3,559	1,980	1,431	1,580	3,862	4,478	5,191	6,017
PU Spray	4,794	5,079	3,494	3,440	3,798	9,427	10,929	12,669	14,687
PU Pipe-in-Pipe	3,378	2,820	1,564	1,127	1,244	2,964	3,436	3,983	4,617
PU Block	1,847	1,563	867	624	689	1,475	1,709	1,982	2,297
PF Block	72	66	37	26	29	113	131	152	177
Extruded Polystyrene	66,458	99,300	85,286	50,249	30,408	14,152	16,406	19,020	22,049
Totals	***143245***	***99011.3***	***127418***	***100497***	***61321.6***	***42633.1***	***57591***	***66763.8***	***77397.5***

Figure 7-4 provides a graphical assessment of the output from these assumptions for the period to 2050.

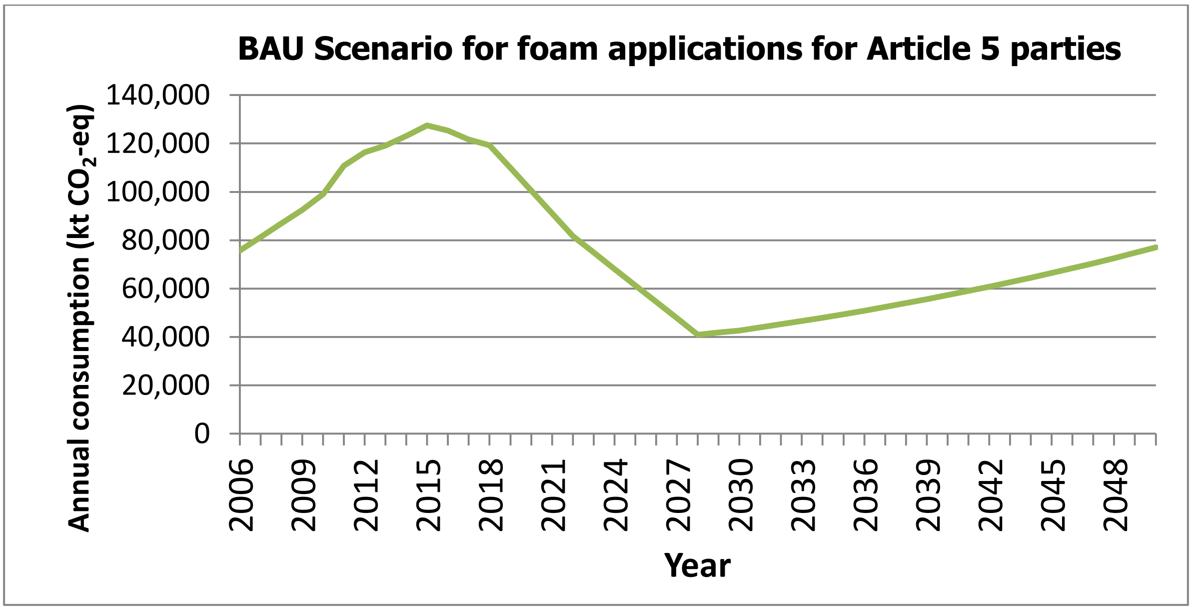

Fig. 7-4 BAU Scenario for foam applications for Article 5 parties

7.5 Article 5 foams mitigation scenarios

As in Decision XXV/5 two mitigation scenarios have been selected based on a potential acceleration of the achievable HCFC phase-out date and a reduction in high GWP uptake cited in the BAU scenario (Table 7-6). The following two tables provide the assumptions in full.

Table 7-9 Assumptions adopted for Mitigation Scenario 1 in the Article 5 foams sector

MIT 1 scenario	
A5	
PU Appliance	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	5%
PU Boardstock	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	10%
PU Panel	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	10%
PU Spray	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	25%
PU Insitu/Block	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	10%
XPS Board	**All countries**
ODS transitions complete by 2026	Yes
% high GWP options by weight	25%
Phenolic	**All countries**
ODS transitions complete by 2020	Yes
% high GWP options by weight	10%

It can be seen that Mitigation Scenario 1 foresees an accelerated phase-out of HCFCs in the polyurethane foam sector by 2020 and in the XPS sector by 2026.

Table 7-10 Assumptions adopted for Mitigation Scenario 2 for foams in Article 5 parties

MIT 2 scenario	
A5	
PU Appliance	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%
PU Boardstock	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%
PU Panel	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%
PU Spray	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%
PU Insitu/Block	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%
XPS Board	**All countries**
ODS transitions complete by 2024	Yes
% high GWP options by weight	0%
Phenolic	**All countries**
ODS transitions complete by 2018	Yes
% high GWP options by weight	0%

Mitigation Scenario 2 is viewed as having an aggressive substitution deadline for all polyurethane foams of 2018 with the additional challenge of ensuring that all alternatives are low-GWP. For extruded polystyrene the target date for HCFC phase-out is 2024 – four years ahead of the BAU scenario and only four years later than the requirements of the revised F-Gas regulation in Europe.

Accordingly, Mitigation Scenario 2 is viewed as amongst the most progressive options available to the foam sector.

7.5.1 *Impact Assessment of Mitigation Scenarios*

Tables 7-11 and 7-12 show the Mitigation Scenarios in terms of blowing agent:

Table 7-11 Current and future demand by blowing agent for ODS and their alternatives (MIT-1 scenario) for the period 2010-2050 in Article 5 parties

	A5 : MIT-1 - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	39,895	25,921	0	0	0	0	0	0	0
HCFC-142b	16,508	22,530	13,356	2,226	0	0	0	0	0
HCFC-22	17,436	23,229	13,356	2,226	0	0	0	0	0
HFC-245fa	354	2,102	2,556	2,822	3,115	3,611	4,187	4,854	5,627
HFC-365mfc/HFC-227ea	0	1,689	2,142	2,365	2,612	3,028	3,510	4,069	4,717
HFC-134a/HFC-152a	955	6,693	10,798	15,839	18,236	21,141	24,508	28,412	32,937
HFO/HCFO	0	0	31,825	47,973	55,439	64,269	74,505	86,372	100,129
Hydrocarbon	31,665	47,047	62,510	70,538	78,175	90,627	105,061	121,795	141,193
Other	0	0	0	0	0	0	0	0	0
Totals	***106,814***	***129,211***	***136,544***	***143,989***	***157,577***	***182,675***	***211,771***	***245,500***	***284,602***
	A5 : MIT-1 - Year in ktCO2-eq								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	28,445	0	0	0	0	0	0	0	0
HCFC-142b	37,473	51,143	30,319	5,053	0	0	0	0	0
HCFC-22	31,036	41,348	23,774	3,962	0	0	0	0	0
HFC-245fa	361	2,144	2,607	2,878	3,178	3,684	4,270	4,951	5,739
HFC-365mfc/HFC-227ea	0	1,719	2,181	2,408	2,658	3,081	3,572	4,141	4,801
HFC-134a/HFC-152a	1,347	9,422	13,465	18,418	21,008	24,355	28,234	32,731	37,944
HFO/HCFO	0	0	223	336	388	450	522	605	701
Hydrocarbon	348	518	688	776	860	997	1,156	1,340	1,553
Other	0	0	0	0	0	0	0	0	0
Totals	***99,011***	***106,293***	***73,256***	***33,830***	***28,092***	***32,567***	***37,754***	***43,767***	***50,738***

Table 7-12 Current and future demand by blowing agent for ODS and their alternatives (MIT-2 scenario) for the period 2010-2050 in Article 5 parties

	A5 : MIT-2 - Year in tonnes								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	39,895	21,130	0	0	0	0	0	0	0
HCFC-142b	16,508	18,920	8,313	0	0	0	0	0	0
HCFC-22	17,436	19,480	8,313	0	0	0	0	0	0
HFC-245fa	354	1,987	430	475	524	608	704	816	947
HFC-365mfc/HFC-227ea	0	1,574	0	0	0	0	0	0	0
HFC-134a/HFC-152a	955	7,630	6,383	6,524	7,203	8,350	9,680	11,221	13,009
HFO/HCFO	0	0	35,537	52,612	58,088	67,340	78,066	90,499	104,914
Hydrocarbon	31,665	52,334	68,464	77,067	85,089	98,641	114,352	132,565	153,679
Other	0	0	0	0	0	0	0	0	0
Totals	***106,814***	***123,056***	***127,442***	***136,678***	***150,903***	***174,938***	***202,801***	***235,102***	***272,548***
	A5 : MIT-2 - Year in ktCO2-eq								
	2010	*2015*	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
HCFC-141b	28,445	0	0	0	0	0	0	0	0
HCFC-142b	37,473	42,949	18,871	0	0	0	0	0	0
HCFC-22	31,036	34,674	14,798	0	0	0	0	0	0
HFC-245fa	361	2,027	439	484	535	620	718	833	965
HFC-365mfc/HFC-227ea	0	1,602	0	0	0	0	0	0	0
HFC-134a/HFC-152a	1,347	10,759	9,001	9,198	10,156	11,773	13,648	15,822	18,342
HFO/HCFO	0	13	249	368	407	471	546	633	734
Hydrocarbon	348	576	753	848	936	1,085	1,258	1,458	1,690
Other	0	0	0	0	0	0	0	0	0
Totals	***99,011***	***92,600***	***44,110***	***10,899***	***12,033***	***13,949***	***16,171***	***18,747***	***21,733***

Figure 7-5 shows the incremental climate savings achieved for Mitigation Scenarios 1 and 2 against the BAU baseline.

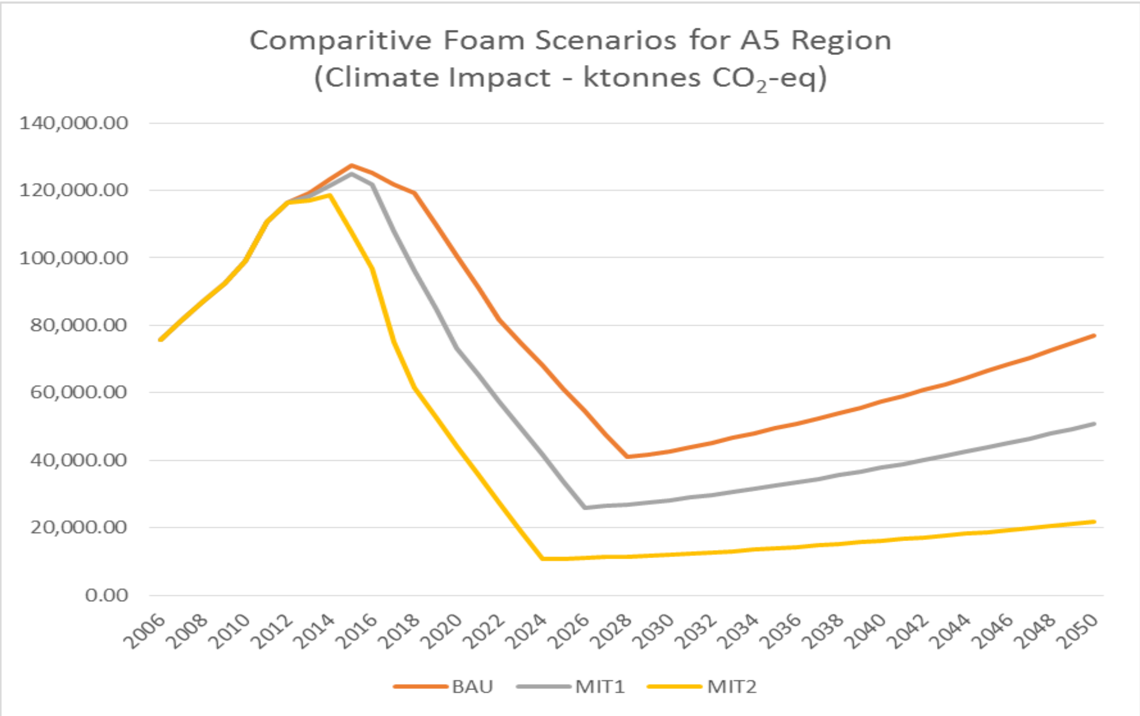

Figure 7-5 Impact of mitigation scenarios compared to BAU for foams in Article 5 parties

7.5.1 Economic factors

The acceleration of phase out dates is likely to increase the cost of transitions, since it makes it less likely that costs can be allocated against other drivers such as equipment renewal. In the case of foams, the range of processes involved and the variation in size of the manufacturing facilities makes it very difficult to quantify transitional costs in absolute terms.

8 Update on alternatives and BAU scenarios for 2015-2050: MDIs and Aerosols

This is a new chapter in this final (update) version of this Task Force report (update of the chapter in the XXVI/9 TF report, September 2015). It presents some brief background on all aerosols technologies, an update of information on alternatives, and BAU scenarios for the HFC demand for 2015-2050 in metered dose inhalers (MDIs). It also deals with aerosols, including non-MDI medical, consumer and technical aerosols.

8.1 Introduction

With the Decision XXVII/4 Task Force and previous Task Force reports in response to decisions XXVI/9 and XXV/5, this chapter presents adequate background on the aerosol technologies as well as an update of all available information on alternatives. It also gives BAU scenarios for the HFC demand for 2015-2050 in metered dose inhalers (MDIs); and aerosols, including non-MDI medical, consumer and technical aerosols. Rather than annual demand, it focuses on the integrated demand for the period 2015-2050. This chapter will not provide an update on sterilants as there is no new information since the previous XXVI/9 TF report.

8.2 Metered Dose Inhalers

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

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

- HFC MDIs: the CFC propellant in MDIs has been gradually replaced with HFCs (HFC-134a and to a lesser extent HFC-227ea), and there are now HFC MDI alternatives available to cover all key classes of drugs used in the treatment of asthma and COPD. Approximately 790 million HFC MDIs (with an average 13g HFC/MDI) are estimated to have been manufactured worldwide in 2015, using about 10,300 tonnes of HFCs and accounting for a relatively small proportion of global HFC usage.
- Dry Powder Inhalers (DPIs): do not require a propellant, are a “not-in-kind” (NIK) alternative to MDIs. DPIs fall into two categories: single-dose DPIs, which have been in use for more than 60 years, and multi-dose DPIs, which have been in use for more than 20 years. There are two main types of multi-dose DPI, reservoir and multi-unit dose devices. New drugs continue to be developed in the DPI format, sometimes exclusively. Approximately 300 million DPIs are estimated to have been manufactured worldwide in 2015.
- Nebulisers: are used to inhale aqueous formulations of drug and account for about 10 per cent or less of the market on a dose basis.
- Propellant-free aqueous mist inhalers have been recently launched by one company.
- Emerging alternatives are in the earlier stages of development, commercialization or marketing, such as iso-butane propelled MDIs. These include applications for systemic delivery of drugs by the inhaled route for the treatment of non-respiratory illnesses.

8.2.1 Availability and market penetration of alternatives

Assessments have been presented of the technical and economic feasibility, and the potential limitations, of the two main alternatives to CFC-propelled MDIs, HFC MDIs and DPIs, in the TEAP XXV/5 Task Force Report October 2014 and the TEAP Update XXV/5 Task Force Report September

2015. Published information on the range of alternatives is also available elsewhere[3]. Decision XXVII/4 requests TEAP, *inter alia*, to highlight any new information on the availability and market penetration of alternatives in different regions. A summary of relevant information follows.

IMS Health data supplied by IPAC[4] shows a continued increase in the availability to patients of alternatives to CFC MDIs globally. In 2014, CFC MDIs accounted for about 13 per cent of all inhaled medication globally, HFC MDIs for about 46 per cent, DPIs about 32 per cent, and nebulised solutions about 8 per cent, based on dose equivalence, with considerable regional variation. The total global use of MDIs has remained constant at about 60 per cent versus DPIs at 32 per cent. This overall ratio is not expected to change greatly in the next decade due to the relatively low cost of salbutamol MDIs compared to multi-dose DPIs.

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

Proprietary non-MDI devices in development and on the market have continued to diversify and multiply, and companies are investing in their own unique delivery technologies. DPIs are technically and economically feasible alternatives that could minimise the use of HFC MDIs. New drugs are often being developed as DPIs. Nebulisers and emerging technologies may also be technically feasible alternatives for avoiding the use of some HFC MDIs. The general exception is for salbutamol; currently salbutamol HFC MDIs account for the large majority of HFC use in inhalers, and are significantly less expensive per dose than multi-dose DPIs, making them an essential and affordable therapy. At present, it is not yet technically or economically feasible to avoid HFC MDIs completely because there are economic impediments in switching from HFC MDIs to multi-dose DPIs for salbutamol (see Section 8.2.3 for more information), and because a minority of patients (10-20 per cent or less), notably the very young and very old, cannot use available alternatives to HFC MDIs optimally[5]. As noted below, there are also regional variations in the availability and usage patterns of MDIs, DPIs, and other treatments, and variations depending on the setting. For example, in China, a recent study shows the significance of nebulisers in large hospital settings.

The availability of affordable alternatives to salbutamol HFC MDIs varies from country to country. In Article 5 Parties, single-dose DPIs are relatively affordable and available for the short-acting bronchodilator salbutamol, as well as other inhaled therapies such as beclomethasone. In India and Bangladesh, doctors prefer single-dose DPIs for the majority of their economically challenged patients. In India, for example, single-dose DPIs account for more than 50 per cent of inhaled therapy, and DPIs generally for about half of the market value [6]. While affordable based on the monetary outlay needed to acquire a limited number of doses (whereas MDIs often contain a month’s supply of medicine), the use of single-dose DPIs for daily use medications may not be as cost effective over time in comparison to MDIs or multi-dose DPIs when considered as cost-per-dose.

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[3] *TEAP Progress Report June 2016*, pp.46-48, and *2014 Assessment Report of the UNEP Medical Technical Options Committee*, *2014, pp.7-38.*

[4] IMS Health is a company that gathers and analyses pharmaceutical market data. IPAC is the International Pharmaceutical Aerosol Consortium, a group of companies that manufacture medicines for the treatment of respiratory illnesses, such as asthma and COPD. IMS Health; IMS MIDAS granted IPAC permission to submit this data to MCTOC/TEAP.

[5] That is, patients with low inspiratory flow and for acute attacks, for which, currently, MDIs with a spacer and nebulisers may be the only suitable devices. See also *TEAP Update XXV/5 Task Force Report September 2015, pg. 95.*

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

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

Healthcare professionals continue to consider that a range of therapeutic options is important. Any consideration of policy measures to control HFCs should carefully assess patient health implications with the goals of ensuring patient health and maintaining a range of therapeutic options. Each country has its own unique and complex makeup in terms of availability of medicines, overarching health care systems, and patient preferences. Nevertheless, DPIs may play an increasing role over the next decade.

8.2.2 BAU scenario for HFC demand in MDIs, 2015-2050

The current and future demand for alternatives to CFC MDIs has been presented in previous reports, including the September 2015 TEAP Update XXV/5 Task Force Report[7], the TEAP XXV/5 Task Force Report October 2014, and the 2014 Assessment Report of the Medical Technical Options Committee[8]. Despite *significant* reservations about the accuracy of predicting future HFC demand in MDI manufacture beyond 2030, this report presents *one* possible business as usual scenario for 2015-2050. A summary of conclusions follows.

Based on HFC manufacturing industry estimates[9], approximately 790 million HFC based MDIs (with an average 13g/MDI)[10] were manufactured worldwide in 2015, using an estimated 10,300 tonnes of HFCs. HFC-134a made up the major proportion of MDI manufacture (~9,500 tonnes), with HFC-227ea accounting for about 7 per cent (~760 tonnes). This corresponds to direct emissions with a climate impact of approximately 15,000 ktCO_2-eq., which is about 3 per cent of global GWP-weighted emissions of HFCs used as ODS replacements in 2014[11]. HFC emissions from MDIs are estimated as about 0.03 per cent of annual global greenhouse gas emissions[12].

Under a business as usual model, global HFC demand in MDI manufacture (HFCs -134a and -227ea) has been estimated by industry for the period from 2015 to 2050 (see Figure 8-1). It is worthwhile noting that accuracy is likely to decline beyond about 2020. This modelling does not allow for any other regulatory impact, other than in the flattening of demand for HFC-227ea due to the European Union's (EU) F-gas regulations[13]. Neither does it account for the on-going trend towards smaller

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[7] *TEAP Update XXV/5 Task Force Report September 2015, pp. 92-94.*

[8] *2014 Assessment Report of the UNEP Medical Technical Options Committee, 2014, pp.21-24, 36-38.*

[9] T.J. Noakes, Mexichem Fluor, United Kingdom, personal communications, 2016. HFC consumption data derived from this source differs from that derived from IMS Health market data. For the purposes of this report, the HFC industry data has been used to derive HFC demand.

[10] This compares with industry data indicating sales of 750 million cans in 2015, which might imply that MDI charge size is closer to between 13-14 grams.

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

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

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

metering chambers[14], which may have a net effect of a 25-30 per cent reduction in future HFC demand. Nevertheless, based on these predictions, global HFC demand for MDI manufacture is estimated to increase by a compound average growth rate of 2 per cent over the period 2015-2050. It is worth noting a recent short term surge in developing country market growth that may result in an over-estimation of consumption when extrapolated over the longer term.

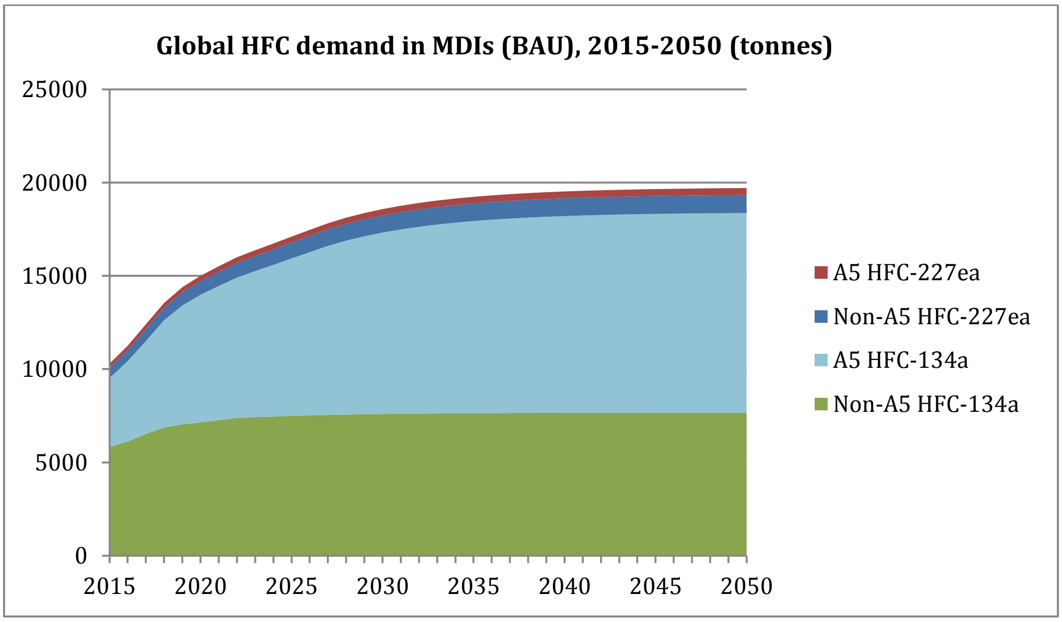

Figure 8-1: Global HFC demand (-134a and -227ea) in MDIs (BAU), 2015-2050 (tonnes)

HFC-134a accounts for about 93 per cent of global HFC demand for MDI manufacture over the entire period. HFC-227ea accounts for about 7 per cent of global HFC demand for MDI manufacture over the entire period, with compound annual growth of 2 per cent. However, HFC-227ea MDIs are unlikely to expand significantly due to expected increasing HFC-227ea prices and uncertainty as a result of HFC regulations.

Under a business as usual scenario, for the period 2015 to 2050, the total cumulative HFC demand in MDI manufacture is estimated as 638,000 tonnes (594,500 tonnes HFC-134a; 43,500 tonnes HFC-227ea). This corresponds to direct HFC emissions with a warming impact of approximately 990,000 ktonnes CO_2-eq., which would be significantly less than the direct emissions warming impact of CFC MDIs had they not been replaced[15].

Figures 8-2 and 8-3 present the estimated warming impact of direct emissions from HFC demand in MDI manufacture (HFCs -134a and -227ea) for Article 5 and non-Article 5 Parties from 2015 to 2050. Direct emissions from MDIs manufactured in Article 5 Parties are estimated to contribute a warming impact of 506,000 ktonnes CO_2-eq., and non-Article 5 Parties 483,000 ktonnes CO_2-eq., over the period.[16]

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exempted from on-going HFC reductions.

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

[15] Assuming that all HFCs consumed in MDIs (HFC demand) are emitted over time.

[16] Due to the aggregated source data, estimations for contributions from Article 5 Parties for MDIs include a non-Article 5 Party (Japan). This is not likely to be a large discrepancy and could not easily be removed from the aggregated data without further analysis, which was not feasible in the available time.

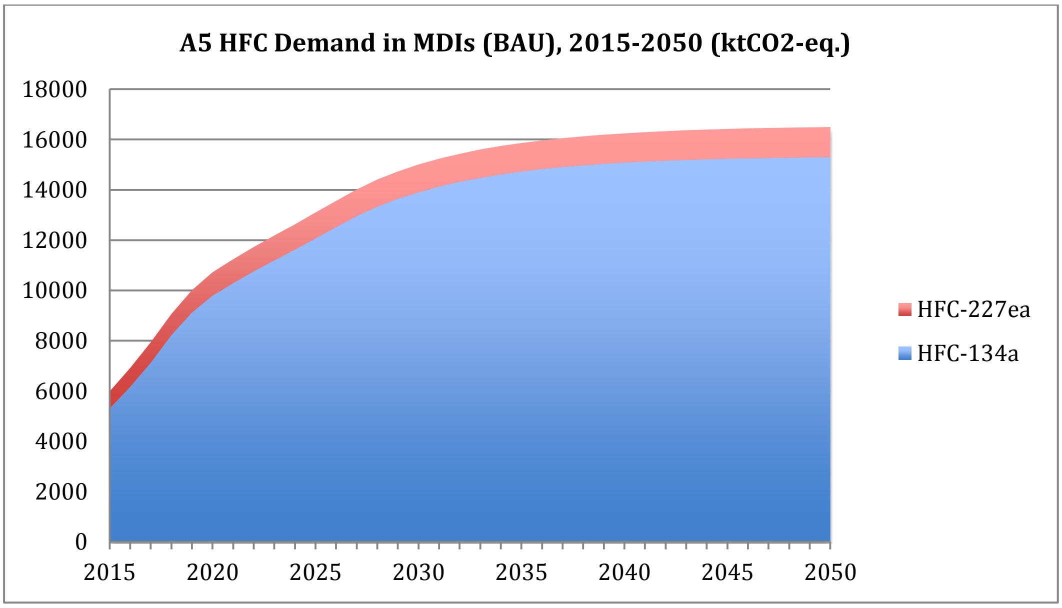

Figure 8-2: Warming impact from Article 5 HFC demand (-134a and -227ea) in MDIs (BAU), 2015-2050 (ktonnes CO_2-eq.)

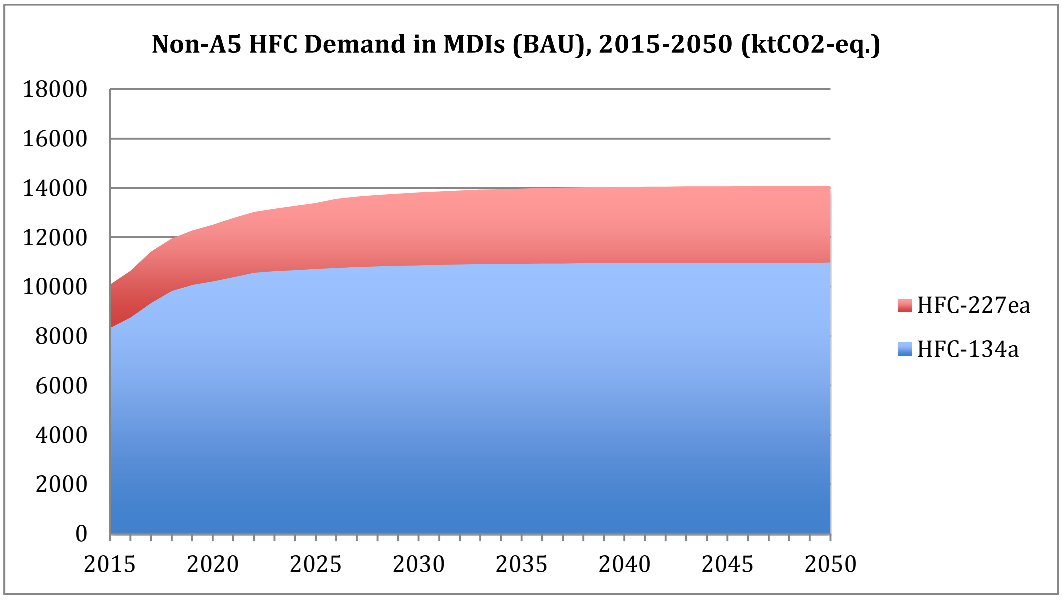

Figure 8-3: Warming impact from non-Article 5 HFC demand (-134a and -227ea) in MDIs (BAU), 2015-2050 (ktonnes CO_2-eq.)

8.2.3 Qualitative costs associated with avoiding high-GWP alternatives

The hypothetical cost of switching MDIs to DPIs has been estimated previously. Multi-dose salbutamol DPIs are generally more expensive than salbutamol HFC MDIs, in part because many of these MDIs are off patent. MDIs containing salbutamol constitute about 50 per cent of all MDIs. Switching these to an equivalent salbutamol DPI would incur significant costs to health care systems. In 2000, the cost effectiveness of a gradual switch from MDIs to DPIs in the European Union was estimated at the time to cost more than €500/tonne of CO_2 equivalent saved, greater than a range of low cost opportunities to reduce greenhouse gas emissions in other sectors, such as energy efficiency measures [17]. An accelerated transition[18] was estimated to be even less cost effective at more than €710/tonne of CO_2 equivalent saved.

In 2005, the hypothetical cost of a complete shift from HFC MDIs to multi-dose DPIs was estimated at US$ 150-300 per tonne of CO_2-equivalent, assuming a minimal twofold increase in price, with an estimated emission reduction of about 10,000 ktonnes CO_2-equivalent per year by 2015[19]. Currently, a salbutamol DPI, where commercially available, is roughly estimated as 2 times the cost of a salbutamol MDI on a per dose basis. By about 2025, when patents expire, or even despite patent protection, there is likely to be more competition and more widespread DPI manufacture, such as in Article 5 Parties, and more affordable DPIs. These factors are likely to improve the cost effectiveness of DPIs compared with HFC MDIs.

Further information about costs associated with alternatives are included in the TEAP Update XXV/5 Task Force Report September 2015[20].

8.3 Aerosols

Aerosols are used in a wide range of different applications. The term aerosol product describes a product *pressurized* with a propellant that expels its contents from a canister through a nozzle. Aerosols incorporate propellants and solvents with the appropriate technical properties and characteristics in formulations designed to deliver a product for its intended purpose.

Propellants include compressed gases (nitrogen, nitrous oxide, carbon dioxide), or liquefied gases, which are a liquid inside the pressurized container; these liquefied gas propellants include chlorofluorocarbons (CFCs) (no longer used), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) (-134a, -152a), hydrofluoroolefins (e.g. HFO-1234ze(E)), hydrocarbons, and dimethyl ether (DME). Some aerosol products also contain solvents, including CFCs, HCFCs, HFCs, hydrofluoroethers, aliphatic and aromatic solvents, chlorinated solvents, esters, ethers, alcohols, ketones, and low-GWP fluorinated chemicals, e.g. hydrofluoroolefins.

Aerosols can be divided into categories:

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

This aerosols section addresses, specifically, consumer, technical and non-MDI medical aerosols, referring to them generically as aerosols. MDIs are described earlier in this chapter, and are treated separately for the analysis of aerosols that follows (unless otherwise specified).[21]

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

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

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

[20] *TEAP Update XXV/5 Task Force Report, September 2015, pp.94-97.*

[21] The captions embedded within figures in this section refer to "non-MDI Aerosols", which also refers specifically to consumer, technical and non-MDI medical aerosols.

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

A smaller proportion of aerosols migrated to HFC propellants where:

- Emissions of VOCs, such as hydrocarbons and DME, are controlled;
- A non-flammable propellant is needed; and/or
- A propellant is necessary that is safe to inhale, such as HFC-134a[22].

HFC-134a is used more commonly as a propellant in technical and non-MDI medical aerosols where its non-flammable and inhalation safety properties have advantages. Extensive respiratory toxicological studies were conducted that proved its safety as a propellant in respiratory use (e.g. MDIs).

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

CFC and HCFC solvents (CFC-113, methyl chloroform, HCFC-141b) used in aerosols have migrated to hydrofluorocarbons (HFC -43-10mee, -365mfc, -245fa), hydrofluoroethers (HFEs), aliphatic and aromatic solvents, chlorinated solvents, oxygenated organic chemicals, and low-GWP chemicals, such as hydrofluoroolefins and hydrochlorofluoroolefins, including HCFO-1233zd(E) and methoxytridecafluoroheptene (MPHE).

There are also NIK technologies that compete with aerosol products to perform the same or similar functions, including trigger sprays, finger pumps, squeeze bottles, roll-on liquid products (e.g., for deodorants), and non-sprayed products (e.g., for polishes and lubricating oils). NIK alternatives are sometimes not as easy to use or achieve lower performance for some applications.

Some alternative propellants and solvents are suitable for certain product types depending on the properties of the alternatives and/or the intended product purpose. Some alternatives will not be technically suitable for some formulations. Like CFCs before them, non-flammable and non-toxic HFCs are often used in aerosols when flammability or toxicity is a consideration. HFCs are also used where emissions of VOC are controlled. However, HFCs are more expensive than hydrocarbons and are therefore mostly used when their properties are necessary for the aerosol product and the advantages outweigh the costs.

8.3.1 Availability and market penetration of alternatives

Assessments have been presented of the technical and economic feasibility of the alternatives to ODS-containing aerosols in the TEAP Update XXV/5 Task Force Report September 2015[23]. Decision XXVII/4 requests TEAP, *inter alia,* to highlight any new information on the availability and market penetration of alternatives in different regions. A summary of new and relevant information follows.

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[22] In China, HCFC-22 is also used for some non-MDI medical aerosols.

[23] *TEAP Update XXV/5 Task Force Report, September 2015, pp.106-111.*

Aerosol market profile— Global aerosol demand is currently estimated at about 15 billion units (cans) per year. Recent market analysis[24] indicates that global demand is likely to exceed 18 billion units by 2020, reaching USD70 billion. Personal care aerosol products accounted for the largest application, with over 40 per cent of global market demand in 2013. Household aerosols were the second largest application, with growing demand for products such as stain removers, water repellents for furnishings, and pre-wash sprays. Growth in personal care and household aerosol products is expected to drive the overall growth in the global market.

Europe is the largest regional aerosol producer and market, with estimated production of over 6 billion units, accounting for about 40 per cent of global production. North America is the second largest regional market, accounting for about 30 per cent, and China for about 18 per cent. Based on an earlier analysis[25], while the European Union's aerosol market is the largest overall, its HFC consumption for aerosols is much smaller than in the United States, reflecting market variations in aerosol propellant and solvent choices based on the different industry and regulatory environments for HFCs and VOCs. For example, the European Aerosol Federation (FEA) has agreed to a voluntary industry production and import ban of HFC-152a, facilitated by the absence of HFC-152a production plants in Europe.[26] The market share of Asia Pacific and Latin America is expected to increase by 2020 (as a proportion of global output volume), owing to regulations controlling VOCs, CFCs, HCFCs and HFCs in the European Union and the United States. Asia Pacific is expected to be the fastest growing regional market owing to its economic development, a growing demand for personal care and household products, and a less stringent regulatory environment.[27]

An analysis by ICF for US EPA[26] is characterising global and regional market consumption of aerosols containing HFCs. Preliminary results indicate HFC consumption (HFCs -134a and -152a, as production plus imports minus exports) in aerosols was dominated by North America, with about 85 per cent of the global total consumed to supply this regional market in 2015. The next most significant regional consumer of HFCs in aerosols was the Asia and Asia-Pacific region at about 10 per cent. These estimated consumption trends take into account import and export flows. Assumptions about

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[24] *Aerosol Market Analysis by Application (Personal Care, Household, Paint, Medical) and Segment Forecasts to 2020*, Grand View Research, December 2014, ISBN 978-1-68038-288-4, http://www.grandviewresearch.com/industry-analysis/aerosol-market, accessed May 2015. *Aerosol Market To Be Worth $70.15 Billion, Growing At CAGR Of 3.1% From 2014 To 2020: New Report By Grand View Research, Inc.*, GlobeNewswire, http://globenewswire.com/news-release/2014/12/09/689728/10111568/en/Aerosol-Market-To-Be-Worth-70-15-Billion-Growing-At-CAGR-Of-3-1-From-2014-To-2020-New-Report-By-Grand-View-Research-Inc.html, accessed May 2015. *Global Aerosol Cans Market - By Products, Regions and Vendors - Market Trends and Forecasts (2015 - 2020)*, http://www.researchandmarkets.com/publication/m2qk76n/3804344, accessed August 2016.

[25] *TEAP Update XXVI/9 Task Force Report*, September 2015, pp.111-112.

[26] *Preliminary Assessment of Global HFC Consumption in Aerosols*, ICF International, August 2016, advance copy draft report prepared for US EPA, through personal communications. Subsequent to the analysis undertaken for this report, and close to publication, new updated data was provided from the EPA/ICF study, indicating estimated global HFC demand for aerosols as 46,700 tonnes for 2015, with 13,700 tonnes of HFC-134a and 33,000 tonnes HFC-152a, with a warming impact of 23,700 ktonnes CO_2-eq. Consumer aerosols were the largest category (36,300 tonnes, 78 per cent), with technical aerosols (9,400 tonnes, 20 per cent) and non-MDI medical aerosols (1,000 tonnes, 2 per cent) making up the remainder. Final data from the study will be used in any future BAU analyses by TEAP.

[27] *Research Report on Global and China Aerosol Industry, 2013-2017*, Research and Markets, 2013, http://www.researchandmarkets.com/reports/2546162/research_report_on_global_and_china_aerosol, accessed August 2016. British Aerosol Manufacturer's Association, http://www.bama.co.uk/history, accessed August 2016. *Aerosol Products Industry Steadfast, Survey Reveals North American Production Reaches All-Time High*, Consumer Specialty Products Association's (CSPA), 2015, http://www.cspa.org/aerosol-pressurized-products-survey-2014-release/, accessed August 2016, European Aerosol Federation (FEA), http://www.aerosol.org/about-aerosols/history-of-aerosols, accessed August 2016.

the regional distribution of HFC non-MDI aerosol production, for the purposes of developing a business as usual scenario of HFC demand, are outlined below. Production is expected to expand in Article 5 Parties.

Based on preliminary data from the ICF analysis, global HFC demand for aerosols is estimated as 44,000 tonnes for 2015, with 15,000 tonnes HFC-134a and 29,000 tonnes HFC-152a. This corresponds to a warming impact from direct emissions of 25,500 ktonnes CO_2-eq[28]. Consumer aerosols were the largest category (37,000 tonnes, 84 per cent), with technical aerosols (6,100 tonnes, 14 per cent) and non-MDI medical aerosols (1,000 tonnes, 2 per cent) making up the remainder. The majority of consumer aerosols used HFC-152a propellant (74 per cent) and the remainder HFC-134a. For technical aerosols the majority used HFC-134a propellant (80 per cent) and the remainder HFC-152a. The majority of non-MDI medical aerosols used HFC-134a propellant (90 per cent). Figure 8-4 presents a comparison of the relative HFC demand of each aerosol category, including MDIs, by total weight, and Figure 8-5 by warming impact of direct HFC emissions.

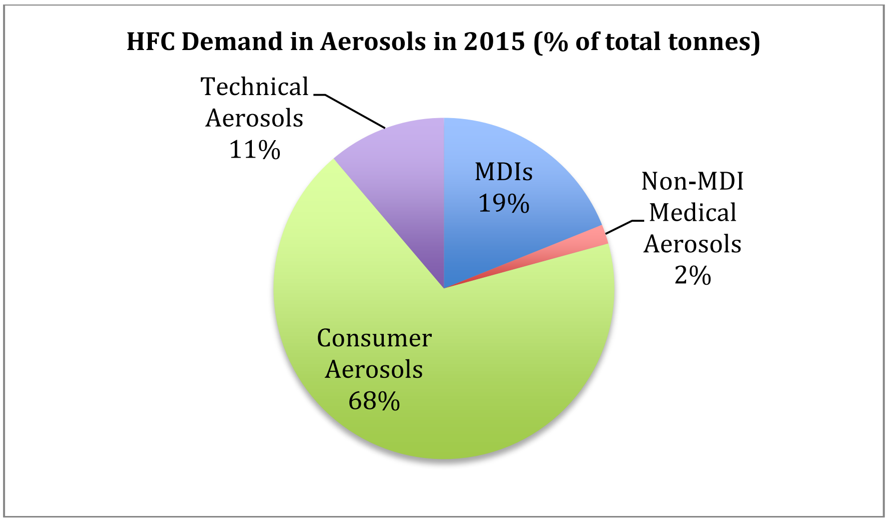


Figure 8-4: Relative HFC demand in aerosols by category and weight, 2015

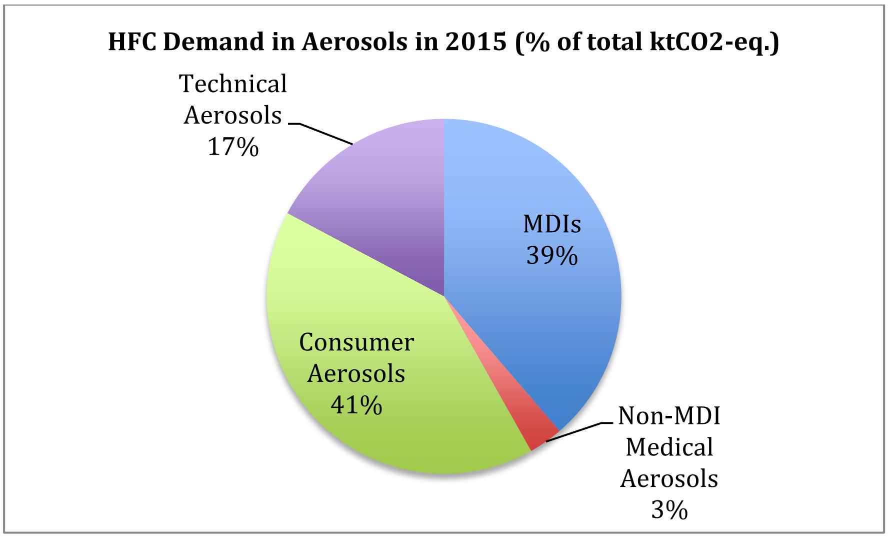


Figure 8-5: Relative warming impact from HFC demand in aerosols by category and GWP-weighted, 2015

[28] Assuming that all HFCs consumed in aerosols (HFC demand) are emitted over time.

Market developments— HFOs are becoming increasingly available as low-GWP alternatives for aerosol applications that would otherwise use HFCs. HFO-1234ze(E) is commercially available in the United States for technical and some consumer aerosol applications. One propellant supplier in France is advocating a mixture of 90 per cent HFO-1234ze(E) and 10 per cent HFC-134a for use as propellant in aerosols, such as dusters and tyre sealant/re-inflators, as a less flammable blend than pure HFO-1234ze(E). Duster products that were previously manufactured in the United States with HFC-134a propellant are now being manufactured with HFO-1234ze(E). Solstice™ 1233zd(E) and MPHE isomers can be used as solvents for technical aerosols.[26]

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

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

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

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

US EPA has promulgated a final rule[29] to prohibit certain high-GWP HFC alternatives that were previously listed as acceptable under its Significant New Alternatives Policy (SNAP) Program, based on information that suitable alternatives are now available. The final rule for aerosol propellants establishes that, from specified dates in 2016 onwards:

- HFC-125 is an unacceptable alternative;
- HFC-134a is acceptable only in specific technical and medical aerosols (e.g. MDIs), and is effectively prohibited in consumer aerosols;
- HFC-227ea is acceptable only in MDIs.
- The rule applies to imported products as well as to manufacture of products in the United States.

8.3.2 BAU scenario for HFC demand in aerosols, 2015-2050

The current demand for alternatives to ODS-containing aerosols is described in this and previous reports, including the September 2015 TEAP Update XXV/5 Task Force Report[30], the TEAP XXV/5 Task Force Report October 2014, and the 2014 Assessment Report of the Medical Technical Options Committee[31]. Based on preliminary data from the analysis by ICF for US EPA[26] and taking into account other publicly available information, this report presents *one* possible business as usual

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

[30] *TEAP Update XXV/5 Task Force Report September 2015, pp. 111-113.*

[31] *2014 Assessment Report of the UNEP Medical Technical Options Committee, 2014, pp.21-24, 36-38.*

scenario for HFC demand in aerosols, for the period from 2015 to 2050. The assumptions made in designing the business as usual scenario are outlined below.

1. Annual growth rate for global HFC demand in aerosols is estimated as 2 per cent. This is close to, but less than, global aerosol market forecasts of 3 per cent annual growth[32]. A lower growth rate for HFC aerosols might better reflect expected flattened growth due to the different industry, market and regulatory environment for HFC aerosols.
2. The estimated regional distributions of HFC aerosol production in Article and non-Article 5 Parties is based on global aerosol market trends outlined earlier. The BAU distribution assumes 30 and 70 per cent production in Article 5 and non-Article 5 Parties respectively starting in 2015, changing linearly to 50 and 50 per cent in 2050, to account for expected market loss in North America and Europe, and gain in Asia-Pacific and Latin America.
3. Both annual growth and regional distribution were applied consistently across HFC types.
4. The BAU scenario approximates the introduction of SNAP rules by removing HFC-134a consumption for consumer aerosols intended for the North American market in 2017[33] (as an approximation of SNAP requirements relating to US prohibitions commencing 20th July 2016), and converting in a 1:1 weight ratio from HFC-134a to HFC-152a only, as a possible worst case scenario. In reality, it is more likely that many HFC-134a consumer aerosols manufactured in the United States might be reformulated with other possible alternatives, including low GWP HFCs such as HFO-1234ze(E). The scenario retains all non-MDI medical aerosols (even though some are no longer allowed), and all technical (even though only those with flammability concerns are allowed) intended for the North American market, as a conservative estimate, and in the absence of better information and methodologies. The step change to remove HFC-134a was applied across all regions proportionally, according to the regional distribution profile, noting that the SNAP rule also applies in the United States to imported products.
5. EU F-gas requirements prohibit the use of HFCs with GWPs above 150 for the market entry of new aerosols for one component foams from 2008 onwards, novelty aerosols and signal horns from 2009 onwards, technical aerosols except for national standards from 2018 onwards. EU industry has already been moving away from HFCs voluntarily since 2002. F-gas requirements allow the continued production of HFC aerosols for export. In the absence of better information and estimation methodologies, the BAU scenario assumes no specific additional change as a result of EU F-gas to HFC volumes (starting in 2015, and assuming major step change has already taken place), with current (relatively small) volumes extrapolated at 2 per cent annual growth as a possible worse case.

Under a business as usual scenario, global HFC demand in aerosols (HFCs -134a and -152a) has been estimated for the period 2015 to 2050 (see Figure 8-6). The total cumulative HFC demand in aerosols is estimated as 2,300,000 tonnes (350,000 tonnes HFC-134a; 1,950,000 tonnes HFC-152a). This corresponds to direct emissions with a warming impact of approximately 742,000 ktonnes CO_2-eq (see Figure 8-7).

[32] *Global Aerosol Cans Market - By Products, Regions and Vendors - Market Trends and Forecasts (2015 - 2020),* http://www.researchandmarkets.com/publication/m2qk76n/3804344, accessed August 2016.

[33] As extrapolated from preliminary ICF consumption data, *Preliminary Assessment of Global HFC Consumption in Aerosols*, ICF International, August 2016, advance copy draft report prepared for US EPA, through personal communications.

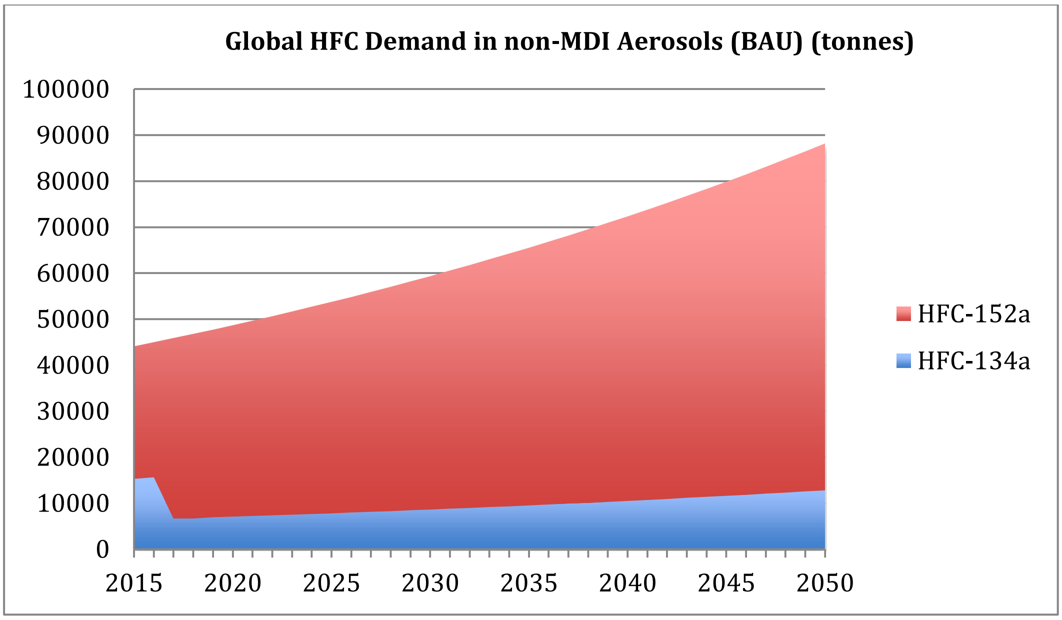


Figure 8-6: Global HFC demand (-134a and -152a) in Aerosols (BAU), 2015-2050 (tonnes)

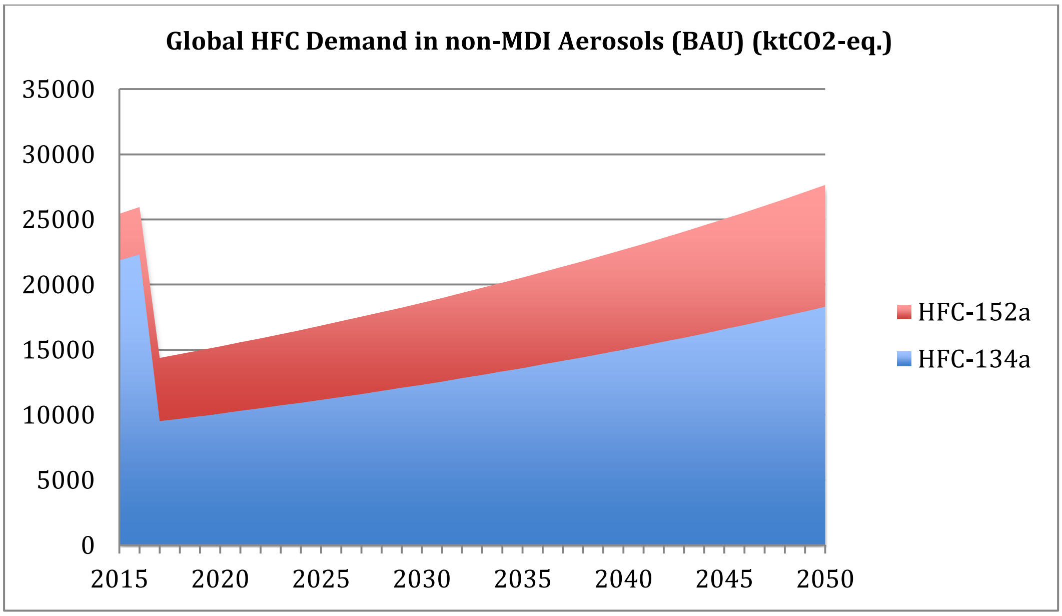


Figure 8-7: Warming impact from global HFC demand (-134a and -152a) in Aerosols (BAU), 2015-2050 (ktonnes CO_2-eq.)

Figures 8-8 and 8-9 present the estimated warming impact of direct emissions associated with HFC demand in aerosols manufacture (HFCs -134a and -152a) for Article 5 and non-Article 5 Parties from 2015 to 2050. Direct emissions from MDIs manufactured in Article 5 Parties are estimated to contribute a warming impact of 303,000 ktonnes CO_2-eq., and non-Article 5 Parties 439,000 ktonnes CO_2-eq., over the period.

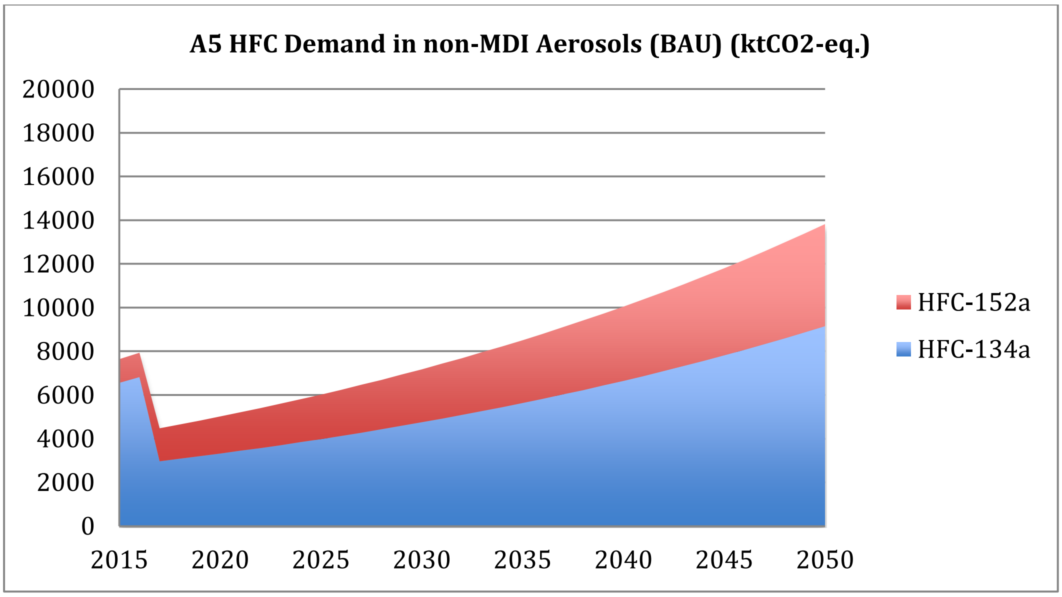


Figure 8-8: Warming impact from Article 5 HFC demand (-134a and -152a) in Aerosols (BAU), 2015-2050 (ktonnes CO_2-eq.)

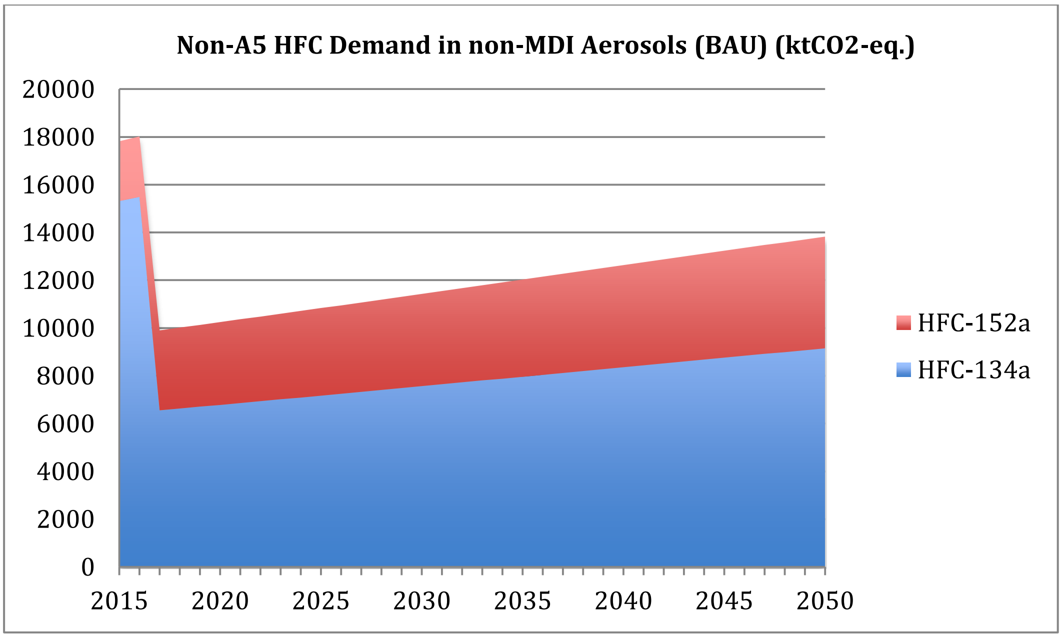


Figure 8-9: Warming impact from non-Article 5 HFC demand (-134a and -152a) in Aerosols (BAU), 2015-2050 (ktonnes CO_2-eq.)

Figure 8-10 presents the cumulative warming impact of direct emissions associated with HFC demand in MDIs and aerosols for Article 5 and non-Article 5 Parties from 2015 to 2050. The GWP weightings associated with MDIs (HFC-134a and -227ea) and other aerosols (HFC-134a and -152a) result in relatively higher cumulative warming impacts for MDIs compared with other aerosols integrated over the period, despite the relatively smaller estimated cumulative HFC emissions for MDIs (nearly one quarter of the amount) compared with other aerosols.

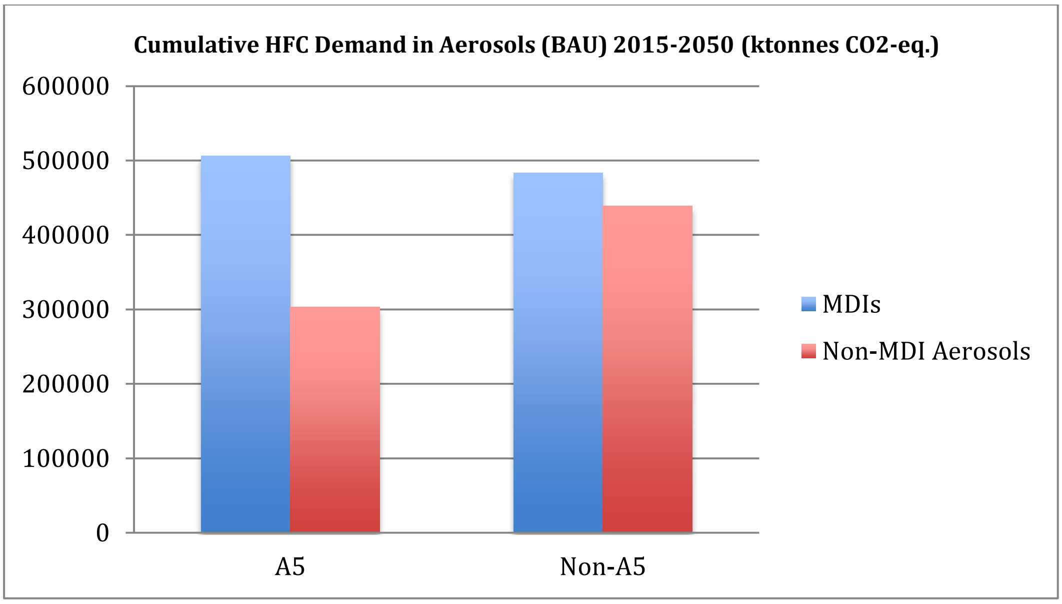


Figure 8-10: Cumulative warming impact from HFC demand in MDIs and other Aerosols for Article 5 and non-Article 5 Parties (BAU), 2015-2050 (ktonnes CO_2-eq.).

8.3.3 Qualitative costs and benefits associated with avoiding high-GWP alternatives

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

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

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

9 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 - Discussion on the TEAP Decision XXVII/4 Task Force Report at OEWG-38

The text below is a copy of the relevant paragraphs in the OEWG-38 meeting report that address work on the XXVII/4 update report.

Responding to questions on the testing programmes for alternatives in high ambient temperatures, Mr. Peixoto explained that it was difficult to compare the results from the different programmes because the tests had been conducted on different types of equipment under different conditions using different testing protocols; no standard protocol had yet been developed. In general, the alternatives had been compared against either HCFC-22 or R-410A because those two substances were in widespread use but possessed different characteristics. He added, however, that it was hoped that in the near future testing would be developed that would permit broader comparisons to be drawn. He said that more information on the timeframes of the testing programmes would be included in the next report of the task force.

Responding to a question on the future commercial availability of new refrigerants, he said that it depended on several factors. While the task force could monitor the current situation in the market, it was impossible to foresee future developments.

Responding to questions on the cost of alternatives for use on fishing vessels, Mr. Peixoto and Mr. Fabio Polonara, co-chair of the Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee, explained that the different pressures and toxicities of alternative refrigerants such as carbon dioxide and ammonia required investment in new or modified equipment. In addition, while the cost of the refrigerants themselves was low, other factors, such as the need for additional safety measures, system adjustments to ensure optimum efficiency, and training of technicians unfamiliar with the substances, had all contributed to the task force's decision to rate the operational cost as "medium" rather than "low". Given the pace of development, however, he expected that such costs would change in the future, and the task force would continue to monitor the situation.

Thanking another representative who had indicated the intention to provide updated information on the retrofitting of refrigeration systems on fishing vessels, Mr. Peixoto said that the task force's next report would contain relevant updated information, as well as further information on short-term retrofitting options.

Responding to a question on the safety of ammonia in refrigeration systems, he said that options for minimizing refrigerant charge were currently being explored, and that new systems should be able to use much lower charges than older ones.

In response to data provided by one representative suggesting that total global HFC production capacity and consumption were both higher than the figures included in the report of the task force, Mr. Kuijpers recalled that the report included figures on the use of HFCs only in the refrigeration and air-conditioning sector, not on HFC use in other sectors. In addition, while non-Article 5 parties reported data on HFCs under the United Nations Framework Convention on Climate Change, Article 5 parties had no such obligation, and it was difficult to be precise about production and consumption data for those countries. The task force would welcome any further information that Parties could provide and would aim to improve the data included in its next report.

In response to a request for the report to include figures for emissions of HFCs as a proportion of total greenhouse gas emissions, Mr. Kuijpers pointed out that the task force report contained data on consumption, not on emissions, which depended on a wide range of factors. The task force would consider what additional clarifying information it could provide in its next report.

Responding to a request for information on the price of alternatives, and a specific question on the cost of using carbon dioxide in supermarkets, he said that it was impossible to provide accurate information because prices varied too much with the use of the substances and the situation was evolving very rapidly. The task force, furthermore, considered patents to be important but could not go into information on the expiry dates for the various intellectual property rights applicable to the alternatives, since that concerned new chemicals and the specific application patents for them. He also explained that in calculating the global warming potential of blends of HFCs, an average figure for the blends had been used, independent of the components of these blends. He confirmed that some of those components had high global warming potentials.

In response to a question on the reasons behind the projected growth in HFC consumption in the task force's mitigation scenarios, he said that it was mainly due to the projections for economic growth included in the model that had been used by the task force. He expressed agreement with one representative's request to consider the impact of all sectors in the scenarios in future iterations, and he said that the task force would review whether it would be possible to include in the scenarios for non-Article 5 parties the impact of the phasedown of HFC consumption that would follow the implementation of the EU's F-Gas regulation.

In response to another question, he said that the energy efficiency of the alternatives had not been taken into account in the scenarios because it was not related to the scenarios that only considered demand and related amounts of refrigerant. Energy efficiency was very much dependent on the type of equipment in use, ambient temperature and several other factors. While it was impossible to derive a single figure for the energy efficiency of a given substance, the task force would aim to provide more background information in its next report.

He agreed with one representative's observation that the consumption of HFCs in the servicing sector – the only use of such substances in most Article 5 parties – would become more important in the future, as it was projected to account for the majority of HFC use by 2030. Further investigation of ways to consider sub-scenarios for those future servicing needs would be considered by the task force.

One representative queried the conclusions of the report regarding progress with the revision of safety standards, which he suggested were too optimistic, as well as the report's conclusion that district cooling systems could only be installed in new building developments but not retrofitted. Mr. Kuijpers said that the task force would look again at both issues and would attempt to further assess the safety issues raised by different alternatives.

One representative suggested that it would be helpful if the Panel could develop its mitigation scenarios further to reflect the proposals for the phasedown schedules for the consumption and production of HFCs set out in the proposals to amend the Montreal Protocol in respect of HFCs, which she said would enable the parties to appreciate the climate benefits of the proposals and their potential cost to the Multilateral Fund. She said that her delegation intended to submit a conference room paper on the subject.

Annex 2 - Background information about refrigeration in the fishing industry

A2.1 The fishing industry

The total number of fishing vessels in the world in 2010 is estimated at about 4.36 million, which is similar to previous estimates. Of these, 3.23 million vessels (74%) are considered to operate in marine waters, with the remaining 1.13 million vessels operating in inland waters. Overall, Asia and the Pacific have the largest fleet, comprising 3.18 million vessels and accounting for 73% of the world total, followed by Africa (11%), Latin America and the Caribbean (8%), North America (3%), Europe (3%) and rest of world (2%). Globally, 60% of all fishing vessels were engine-powered in 2010, but although 69% of vessels operating in marine waters were motorised, the figure was only 36% for inland waters. For the fleet operating in marine waters, there were also large variations among regions, with non-motorised vessels accounting for less than 7% of the total in Europe and the Near East, but up to 61% in Africa (UN, 2010).

As shown in Figure A2-1, almost 80% of the motorised fishing vessels in the world are less than 12m in overall length (LOA). Such vessels dominate in all regions, but markedly so in Africa, the Near East, and Latin America and the Caribbean. About 2% of all motorised fishing vessels correspond to industrialised fishing vessels of 24 m and larger (with a gross tonnage (GT) of roughly more than 100 GT or 100 Gross Register Tonnage (GRT)) and that fraction was larger in the Pacific and Oceania region, Europe, and North America.

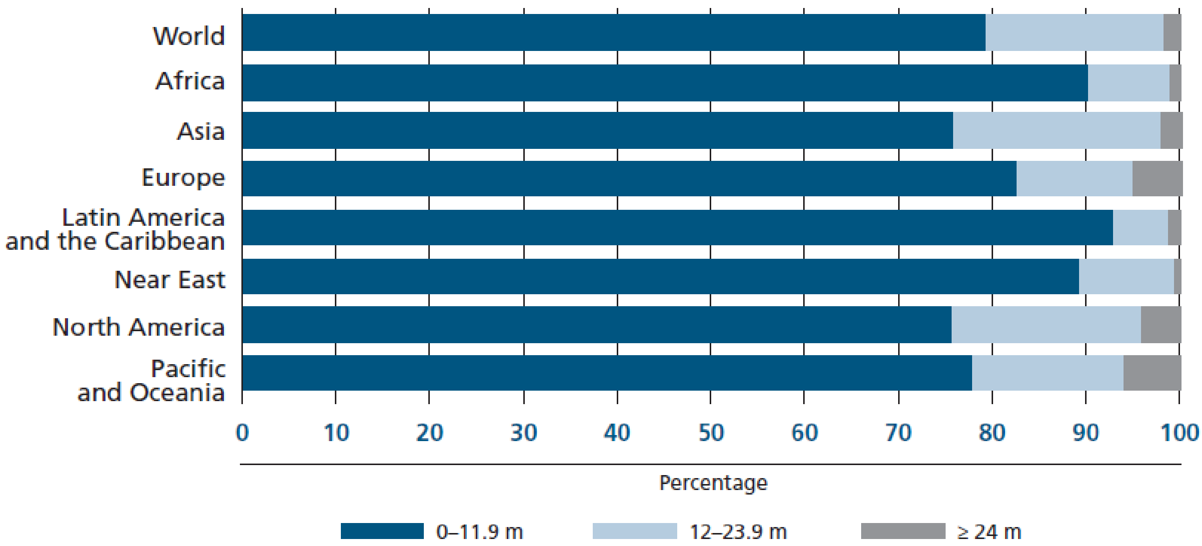


Figure A2-1 Ship Length (FAO, 2014)

A2.1.1 Pacific fishing vessels

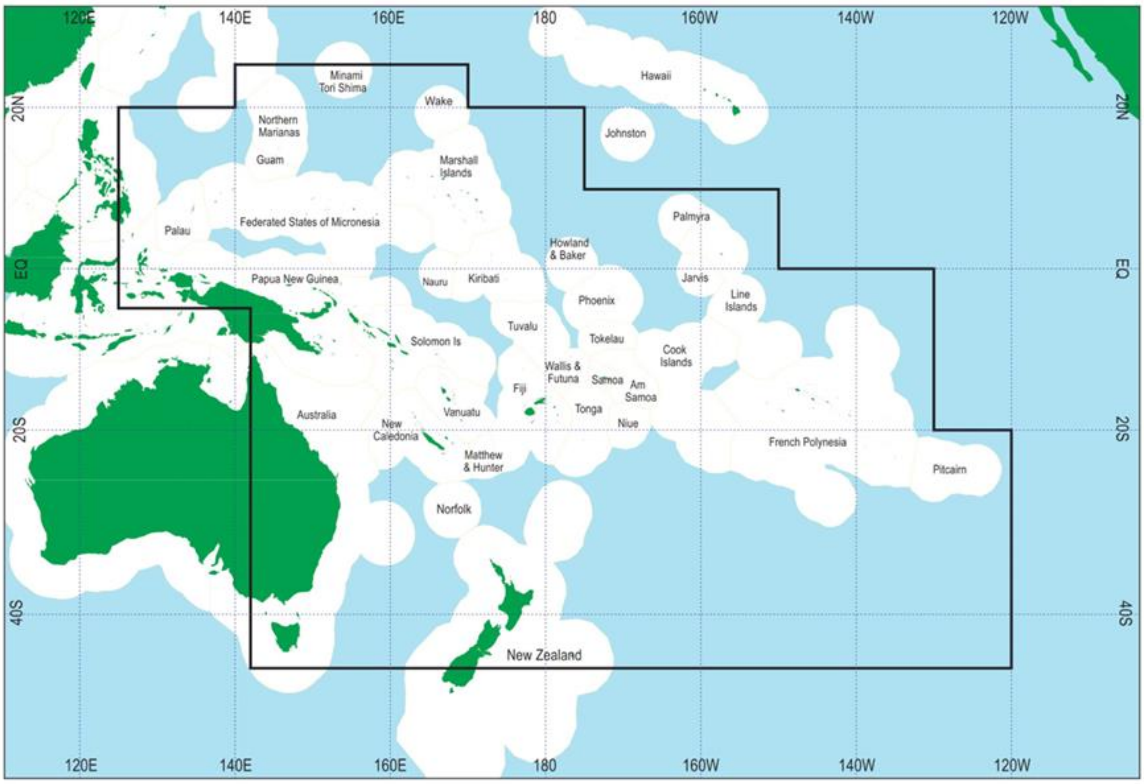
The area described as the Pacific Islands is shown in the Figure A2-2 below.

Marine Fisheries is the single largest industry and source of income for many Pacific Island Countries (PICs) (Awira, 2014). Economic benefit derived from this sector is sourced through a direct involvement of PICs in fishing, fish processing and through the licensing arrangement between PICs and foreign fishing nations. Many different nations operate fishing vessels in the PIC region and refrigeration is essential in all stages of the fisheries industry: from catching to processing to the consumer. Although PICs are complying with their obligations under the Montreal Protocol on the phasing out of HCFCs, this sector is still an elusive area.

The demand and market supply routes of refrigerants and refrigerant servicing in the marine fishing sector is not known for PICs and perhaps for other regions.

The management of Ozone Depleting Substances (ODS) in the fishing sector has to be intimately aligned with the complex nature and magnitude of this industry including that of clarifying the responsibility of flag states and vessels owners in the context of sustainable development. As of June 2014 the number of vessels registered under the Pacific Islands Forum Fisheries Agency (FFA), Good Standing Register stands at a total of 1,332 vessels (FFA database 2014) including bunkers, fish carriers, long liners, mother ships, pole and liners and purse seiners. Out of this total, the vessels with cold storage capabilities that have a direct link to the consumption of refrigerants with ozone depleting properties are long liners, purse seiners, fish carriers and pole and line fishing vessels.

One may ask why there are so many vessels operating in the region vying for the same four species of tuna? The answer is that the tuna fishery in the waters of the FFA member countries is the largest in the world and there is a need to generate and maximise economic benefit from fishery resources for PICs, as for some this is the only resource they have. Ten years ago, income from fisheries access was around US$ 40 million but now PICs are getting somewhere around US$ 250 million in fishing revenue and other direct benefits. This shows an increase of over 500% which can be attributed to the management measures put into place by FFA and the Tuna Commission as well as the introduction of the Parties of the Nauru Agreement vessel day scheme in 2007. In 2013 the total catch of tuna resources from the Western and Central Pacific - Commission Area (WCP-CA) was 2.61 million tonnes and this is valued at US$ 6.3 billion. Catch taken from waters of the FFA member countries is 1.56 million tonnes or 60% of the WCP-CA total and this is valued at US$ 3.4 billion.



Source: SPC; the dark lines represent the SPC statistical area.

Figure A2-2 Map showing Pacific Islands region (Gillet, 2011)

With more than 1,000 vessels roaming the Pacific Ocean from various nationalities fishing for tuna, there is an urgent need to have mechanisms to monitor and control the consumption of all refrigerants used on fishing vessels to ensure that PICs meet their obligations under the Montreal Protocol and the International Maritime Organization's (IMO) agreement on the prevention of air pollution from ships which is covered under MARPOL 73/78 Annex VI. FFA Members do not have this capacity, nor do they have the financial, human or institutional resources. Monitoring, reporting and enhanced enforcement of refrigerant supplies to fishing vessels is also recommended. Often the fishing vessels enter and received supplies at designated fish depots. The level and adequacy of customs controls at these ports need to be studied.

Effective enforcement of supplies to vessels can also support control requirements on illegal, unreported and unregulated (IUU) fishing. Previously published IUU loss estimates for the Western and Central Pacific region are somewhere in the region of US$ 750 million to US$ 1.5 billion a year. Where IUU involves vessels not already licensed in the fishery, it can be assumed that for IUU there will also be a high demand for refrigerants and that they may be traded illegally to meet the demand of illegal fishers. This also extends the subject of application of for example Decision XIX/12: Preventing illegal trade in ozone-depleting substances.

The distribution of ship types is shown in Figure A2-3.

Main fishing methods are Purse Seine and Long Line. Out of 1270 ships, 77% were flagged with flagged outside the area and only 23% were FFA flagged (Awira, 2015)

The biggest part of the Pacific Purse Seine, Bigeye Tuna are caught around the equator +/-10° degrees (see Figure A2-4). This means that a significant distance has to be travelled and that the fish have to be kept refrigerated or alive until landing to avoid spoilage (Honolulu, 2015).

A variety of methods are used for freezing tuna including air blast cooling or immersion in brine. Plate freezers are not generally used for larger fish due to the difficulty of getting them to fit between the plates.

One of the requirements for freezing the fish is related to parasite kill in the fish. According to European Union regulations, freezing fish at -20°C for 24 hours kills parasites. The U.S. Food and Drug Administration (FDA) recommends freezing at -35°C for 15 hours, or at -20°C for 7 days.

Figure A23-3 Ship types in Pacific Islands Countries (Awira, 2015)

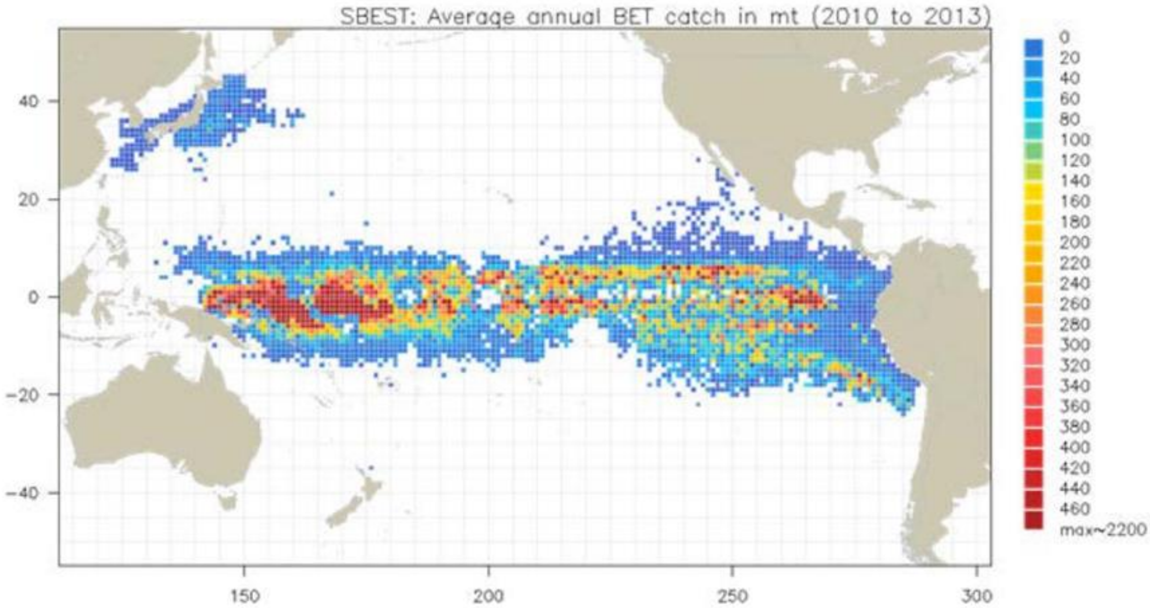


Figure A2-4 Distribution of tuna catch

Not all fish is for export and much is used in the local economy. Industrial-scale shrimp fisheries, for instance, only occur in Papua New Guinea.

Costal fishing is very important for the local economy and nutrition, but in the global market it is only a small part of the total production. In any case these smaller boats usually use ice whereas the larger ships have mechanically refrigerated holds.

Coastal fishing in the region can be placed mostly into the following categories:

- *Small-scale commercial fishing,* (also referred to as "artisanal") which can be further broadly sub-divided into those supplying domestic markets, and those producing export commodities.
- *Subsistence fisheries,* which support rural economies and are extremely important to the region's nutrition and food security (Gillet, 2011)

The cold chain is not a concept implemented globally. The food spoilage in this part of the world is relatively high, in part due to the high ambient temperatures. There are numerous other techniques for storing non canned fish such as smoking, drying, brining and dry salting which do not involve refrigeration.

A2.1.2 The EU fishery fleet

Considering that more than 70% of fishing fleet operating in the Pacific Islands is flagged outside the area (Awira, 2015), a look to the situation of other fleets is worthwhile. As an example of how the fishing fleets of non-Article 5 Parties are organised, the European Union (EU) fishery fleet situation is described here.

The EU fleet is very diverse, with the vast majority of boats being no more than 12 metres long, with a small number of vessels exceeding 40 metres in length.

Reducing fleet capacity is an essential tool for achieving a sustainable exploitation of fisheries resources. That is why the EU's fishing fleet capacity has declined steadily since the early 1990s, in terms of both tonnage (an indicator of fish-holding capacity) and engine power (an indicator of the power available for fishing gear). The size of the EU-28 fishing fleet has dropped to about 86'500 vessels in 2013 compared to 104'000 vessels for the EU-15 in 1995, although it increased by 7.2 % between 2012 and 2013, following Croatia's EU accession. The EU's fishing fleet in 2013 had a combined capacity of 1.7 million gross tonnes and a total engine power of 6.6 million kW.

Almost one fifth (18.3%) of the EU-28's fishing fleet is registered in Greece. Generally however, these Greek vessels are small, with an average size of 4.9 gross tonnes (much less than the EU-28 average of 19.2 gross tonnes) and an average engine power of 28.9 kilowatts in 2013 (compared with an EU-28 average of 76.0 kW). In terms of capacity, Spain, France, Italy and the United Kingdom had the largest fishing fleets, accounting for 54.2 % of gross tonnage and 55.8 % of engine power in 2013 (EUROSTAT, 2014).

A2.2 Refrigeration within the fishing industry

A2.2.1 Refrigeration on board

In order to avoid spoilage and increase shelf-life, fish must be kept refrigerated as soon as they are caught.

If the fish are caught for local use, ice is the best suited refrigeration medium, as it can be used without any machinery on board ships and provides cold storage. Ice is very well suited for fish, as i) it provides the quick cooling after harvesting, needed for good quality, ii) its temperature is just right for short term conservation, and iii) though melt water can affect the quality of other goods, it does not alter the quality of fish, which are protected by skin and scales.

If not consumed fresh, fish is processed for conservation. This yields the different products that can be found on markets: canned, frozen, freeze dried or cured. Industrial processing of fish can be done on board factory ships or in land based plants. In all cases the process is similar to other kinds of food processing, with just some peculiarities which will be pointed out later on (de Larminat, 2015).

Table A2-1 summarizes the type of conservation method for the fish depending on the type of catch and on the type of vessel used for the catch.

Table A2-1 Type of fish conservation used depending on the catch (de Larminat, 2015)

Catches	Conservation method
local	ice
mid-distance	brine freezing/RSW
long-distance	deep freezing

The smallest ships have no refrigeration at all aboard. When a little larger, they load up flake ice every morning from the harbour. The catch is then iced as it comes on-board and held cold with the ice. Larger ships have Refrigerated Sea Water (RSW) tanks and produce ice on-board. Only the largest vessels have complete factory installations with blast freezers, plate freezers, RSW tanks and ice-machines.

In recent decades, major innovations in refrigeration, ice-making, packaging and transportation to ensure product integrity have also allowed an expansion of fish distributed in fresh, chilled and frozen forms. Developing countries have experienced a growth in the share of fish production utilised as frozen products (24% of fish for human consumption in 2012, up from 20% in 2002 and 13% in 1992).

However, many countries, especially those with less-developed economies, still lack adequate infrastructure and services including hygienic landing centres, electricity, potable water, roads, ice, ice plants, cold rooms and refrigerated transport. These factors, associated with tropical temperatures, result in high post-harvest losses and quality deterioration, with subsequent risks for consumers' health. In addition, fish marketing is also more difficult owing to often limited and congested market infrastructure and facilities. Due to these deficiencies, together with well-established consumer habits, fish in developing countries is commercialised mainly live or fresh soon after landing or harvesting, or it is processed using traditional preservation methods, e.g. salting, drying and smoking. These methods remain prevalent in many countries, in particular in Africa and Asia, which show higher proportions of cured fish compared with other continents (FAO, 2014).

A2.2.2 Ice plants and Refrigerated Sea Water (RSW)

The ice plant is a complete installation for the production and storage of ice, including the icemaker itself together with the associated refrigeration machinery, harvesting and storage equipment, and infrastructure.

Other than by description of the ice produced, there is no simple way to classify the different types of ice makers; hence we have block, slice, plate, tube, slush ice and so on.

Typically, ice plants are vapour compression refrigerating plants able to produce up to 10 tons per hour with evaporating temperatures ranging from -10°C to -30°C.

Ice can also be produced from sea water: when seawater is frozen slowly, freshwater ice crystals are initially frozen out of the mixture. The whole solution will not be frozen until the temperature has reached -22°C, the eutectic point (the eutectic point is a physical constant for a mixture of given substances). At higher freezing rates, the ice crystals will be salt-contaminated from the very beginning but this salt will eventually migrate to the outer surface and separate during storage. As the crystals are made mainly of fresh water, the residual liquid will contain an ever increasing concentration of salt as the temperature is reduced. The special structure of seawater ice gives it different properties from freshwater ice. Seawater ice is rather soft and flexible and, at normal subcooled ice temperatures of -5 to -10°C, it will not keep the form of flakes; in fact, at -5°C, seawater ice will look rather wet. For this reason, seawater ice is usually produced at lower temperatures than freshwater ice, and often this adjustment has to be made to the ice maker. Otherwise the plant required is basically the same.

A number of ice plants are suitable for operation at sea with little modification to their design and they may use either fresh or seawater supplies. Many vessels which process their catch at sea have ice makers installed for cooling the fish during processing. Since they are often at sea for many months at a time, it would be unreasonable for them to carry ice from a shore-based plant. Some fishing vessels have ice plants installed where it may not be economical to have a permanent shore-based plant; for example, because demand for ice is only seasonal due to the type of fishery.

Other fishing vessels operate their own ice plant because of difficulties in getting regular supplies without incurring unacceptable delays in port

There are other ways of chilling fish besides using ice. For example, they can be immersed in chilled water or cold air can be blown over them. Sea water, cooled by mechanical means, RSW or by the addition of ice, Chilled Sea Water (CSW), is a suitable alternative means of rapidly chilling large quantities of whole small fish, especially on board a fishing vessel. (Graham, 1992)

A2.2.3 Freezer trawlers

Freezing facilities are generally only installed on larger stern trawlers; these are 65m to 80m in length and have a freezing capacity of between 30 and 60t each day and a cold storage capacity of 300 to 800t.

Once the fish are aboard it is important to process and freeze them before rigor mortis sets in which, if it occurs, will result in a degradation of quality. The onset depends on time and temperature.

The first operation is to gut the fish. If they are not gutted, when the fish are thawed they produce bloodstained fillets with off flavours. It is possible to freeze them with guts but only after bleeding which solves some flavour issues but can lead to other spoilage problems.

If fish are gutted, then they still need to be bled for about 15-30 minutes and then washed before being frozen in chilled seawater. If this is not done, the blood is forced into the flesh by the freezing process, resulting in staining. Also, if the time before gutting is in excess of six hours, the blood becomes thicker and harder to wash away.

White fish should be frozen as quickly as possible but if there are limitations to freezing capacity, it is possible to store cod in ice for 3 days, haddock 2 days and hake just 1 day without serious deterioration in quality.

The layout of each factory deck on a freezer trawler, favoured in the Atlantic, will vary depending on its shape and also whether filleting takes place or white fish are frozen. However, the basic configuration will remain the same: a hatch to supply caught fish, a pound to store the fish, a gutting area, a washing area, freezing equipment and a cold store.

A freezer trawler is usually fitted out with a number of vertical plate freezers. Vertical plate freezers are hollow plates made up of sections of extruded alloy and are connected via flexible hoses to the refrigerant supply header. The cooling liquid, refrigerant or heat transfer fluid, is circulated by a pump; there is also a system for heating in order to release the plates once the fish are frozen.

Fish are packed between the plates head to tail, without gaps, any gaps make freezing slower and make fish susceptible to breakage.

Large fish should not be forced between the plates but placed into an air blast freezer. The freezing time will be dependent on the air temperature and velocity.

Plate freezers should be loaded in rotation or the freezing time will be longer due to cooling capacity limitations. If they are loaded at the same time, initially the plant demand will be very high but when the freezing is nearly complete the cooling plant will have little load.

Freezing times should never be cut short: if the blocks are removed too early they may appear hard but the middle of the fish will be soft. When they are placed in the cold store, they are likely to stick together and, worse, the store temperature will rise and the fish freeze slowly with a consequent reduction in quality. Another negative aspect is that if the fish stick together they are liable to being broken when removed.

Once the fish are frozen they are transferred to the cold store via a hoist. The cold storage temperature on trawlers is normally -40°C. (Awira, 2015)

A2.2.4 Ultra-low temperature freezing

Even if it represents a niche within the fishing industry, the catch to be forwarded to sashimi and sushi markets deserves a mention here because it poses a technological challenge to the refrigeration industry: tunas to be consumed as sashimi or sushi must in fact be brought down to at least -60°C, after removing gills and guts, to maintain the quality grade needed for raw consumption. (The Pacific Community)

The technological challenge lies in the fact that most of the systems and refrigerants used in traditional freezing plants are not able to go down to -60°C, so particular refrigeration systems and/or refrigerants have to be implemented to achieve this goal.

Tuna is quickly bled, processed and frozen before rigor mortis sets in which is why it is said to be "fresher than fresh". Approximately 80% of tuna sold in the Japanese market is in this category and commands a high price. Only certain fish are suitable for sushi. Only if "they have the special look and glow in the eyes" are they are sent to the -60°C blast freezer. Much of the remainder goes for canned tuna production.

Varieties of fish other than tuna are also sold for sushi, and are frozen at very low temperatures before consumption (Pachai, 2013). Such treatment ensures the flavor and texture of the flesh stays at its best. However, not all fish are suitable and are also dependent on seasonal variations. In some cases such low-temperature freezing causes physiological disorders to develop within the fish. Therefore an in-depth knowledge is essential for the correct processing for the species being caught.

A2.3 Refrigerants currently used

A2.3.1 Refrigerants used on board

From the field experience and estimates, it is known that in 2016 about 70% of the fleet still used HCFC-22 as their main refrigerant; this is a global phenomenon and includes all seagoing vessels. Ammonia (R-717) is the second refrigerant of choice. An EU report (Faber, 2009) shows that this is also the case in Europe.

A number of different refrigerants were used on board ships in the past including ammonia. Examples of these were CFC-12, R-502 and in some cases CFC-13, this is of significance when bearing in mind the age of some of the fishing vessels (30 years old). HCFC-22 came after the above refrigerants.

Low temperature air blast coolers are either cascade or two-stage sub-atmospheric systems. Cascade systems are likely to use R-23 in their low stage.

From reported data (Awira, 2015), it is known that refrigerant charges are estimated to be about 230 to 250 metric tonnes of HCFC-22 for fish carriers, long line and purse seiner vessels chartered and flagged in FFA member Countries.

The same report states that the total HCFC refill for flagged and chartered vessels amounts to 714 metric tonnes, while the Montreal Protocol HCFC baseline (consumption) for the 14 Pacific Islands Countries amounts to 271.69 metric tonnes.

A2.3.2 Refrigerants used on land operations

In land based industrial systems for food processing, including the fishing industry, R-717 is already the dominant refrigerant in non-Article 5 Parties while HCF-C-22 is the refrigerant mostly used by Article 5 Parties, both for process cooling and large ice plants. (de Larminat, 2015).

In recent years, non-Article 5 Parties have seen an increasing use of R-404A, especially in small and medium systems including those used for producing ice.

A3.3.3 Refrigerant leakage

In the maritime sector, the emission factor due to leakage in air conditioning and refrigeration systems with direct expansion are very high, estimated at 40% of the charge per year. Even when indirect systems are utilised, a loss of 20% per year is common. This is due to a combination of the age, the technology and the constant vibration and racking that a ship endures (FRDC, 2013)

As already mentioned, many vessels have licenses to operate in Article 5 Parties even though their flag is not Article 5. It is then not uncommon that the systems are refilled with refrigerant origining from an Article 5 Party. This refrigerant should be reported as export and import in the flag country and not, as currently occurs, as used by the Article 5 Party. For European flagged ships it would basically be illegal to top up the charge even if operating in an Article 5 Party.

A2.3.4 High ambient temperatures (HAT)

The issue of High Ambient Temperatures (46-52°C) is less likely to apply to fishing vessels and land based fisheries as refrigeration systems are generally cooled by sea water. Therefore, this is not very often a problem in open sea, but can become an issue in more slow moving rivers and lakes and potentially in ports where the water temperature can increase. For the refrigeration system it means that you can reach the limits of the operational envelope with the risk of the safety valve opening blowing out the refrigerant. This is mainly a problem if the ship is designed for colder water and is migrated to warmer waters for any reason. It is primarily a design topic more than a refrigeration issue.

High ambient temperatures are only significant as fish have inherently a high bacterial loading and can spoil quickly if not subject to the correct storage conditions.

A2.4 Low-GWP alternatives to ODS refrigerants

The most important information that can be drawn from the background analysis of the fishing industry is that, currently, the existing fishing fleet is dominated by HCFC-22 and R-717.

R-717 is a non ODS substance with a low GWP and is perfectly satisfactory for continued use, once the safety issues are taken into account (R-717 is a B2L fluid according to ASHRAE 34 standard).

HCFC-22 is an ODS and must be phased-out. Substitution of HCFC-22, considering its ubiquitous presence throughout the industry, is the real challenge facing the fishing industry.

Considering also that 70% of the global fishing fleet is based in Asia/Pacific, this challenge becomes even more important for Asia/Pacific Parties and specifically for Pacific islands, whose economy is heavily dependent on their fishing industry.

Table A2-2 provides the main characteristic of all the refrigerants that can play an interesting role in HCFC-22 substitution.

A2.4.1 Alternatives to HCFC-22

Traditionally, trawlers operate with direct expansion and have relatively high refrigerant charges and high leakage rates; this makes the choice for the transition from HCFC-22 a difficult one.

An obvious retrofit replacement for HCFC-22 is R-404A which is a very popular and widely used blend. However, due to its high GWP value, it is now being phased out in Europe by 2020, as well as in certain sub-sectors in the USA; in other regions R-404A is under pressure. Analysing the options left after the HCFC phase-out and considering that high GWP is an issue as well, one presently stands with a limited number of potential alternatives even without considering the cost implications. A non-exhaustive list of potential alternative refrigerants is shown in Table A2-2 (UNEP, 2014; UNEP, 2016).

The (unsaturated - olefin type) HFO refrigerants are not suitable to replace HCFC-22 or R-404A for low temperatures. More promising are those refrigerant mixtures obtained by blending HFC and HFO in suitable proportions to make them a low-GWP fluid and, at the same time have the properties needed for a refrigerant in this application.

Ammonia (R-717) is very competitive but requires a refrigeration plant change and cannot be considered as a retrofit.

As the situation of HCFC-22 substitutes showing low-GWP properties is rapidly and positively evolving towards the development of suitable alternatives for most of the terrestrial applications (UNEP, 2015; UNEP, 2016), one can expect that those alternatives will be suitable also for on board applications of the fishing industry.

When evaluating the substitution of HCFC-22 for on board refrigeration, the decision must take into account several variables; in principle it is possible to distinguish among the following cases:

Table A2-2 Potential HCFC-22 alternatives, their GWPs and safety class

Refrigerant	Normal Boiling Point (°C)	GWP 100 years	Safety Class**
HCFC-22	-40.8	1810	A1
HFC-23	-82,0	12500	A1
R-404A	-46.6/-45.8	4200	A1
R-407A	-45.2/-38.7	2100	A1
R-407C	-43.8/-36.6	1700	A1
R-407F	-46.1/-39.7	1800	A1
R-428A	-48.3/-47.5	3700	A1
R-448A	-45.9/-39.8	1300	A1
R-449A	-46.0/-39.9	1300	A1
R-507A	-47.1	4300	A1
R-717 (NH_3)	-33.3	0	B2L
R-744 (CO_2)	-78*	1	A1

*Sublimation point in atmosphere of CO_2. Triple point is -56.2°C@5.2 bar.
** Even if it classified of lower-toxicity (A1), alternatives can present human health hazards when operating in enclosed spaces such as vessels: such risks have to be prevented with specific safety measures.

- If the entire vessel is approaching the end of its operating life and is going to be retired soon, then no refrigeration plant upgrade is worthwhile. Before going to the scrapyard, proper recover of remaining refrigerant is the most important operation to be scheduled for the refrigeration plant.
- If the ship has a long life ahead but the refrigeration plant needs a major overhaul, then the change of refrigerant is a reasonable operation to be implemented. The new refrigerant has to be chosen with care. Change of refrigerant may involve a complete refurbishment of the refrigeration plant: converting an halocarbon plant to ammonia, for example, will require disposing of all copper-nickel equipment and substitution with steel (often with stainless steel because of sea water).
- If the HCFC-22 equipped refrigeration plant is relatively young (less than 10-15 years) then retrofitting it with a drop-in solution can be the right option. Rapidly evolving situations in the development of low-GWP HFO/HFC blends makes it highly probable that in a few years a satisfactory solution also for this specific problem could be at hand.
- For new ships, several options are available nowadays: all of them are environmentally benign in terms of ozone depletion and climate change and are also economically feasible.

In the following a number of feasible options for the main applications of fishing vessels refrigeration will be described and critically analysed. At the end of the paragraph a summary table (FRDC, 2013) is provided to allow for comparisons. A separate paragraph will then be devoted to Ultra-low temperature applications, which require particular technology.

A2.4.2 Option 1 – Non-halocarbon refrigerants (R-717 and R-744)

Ammonia (R-717) and carbon dioxide (R-744) (so called “natural” refrigerants) are fit, from a thermodynamic point of view, for the refrigeration plants aboard fishing vessels.

Ammonia is lower flammable and toxic: its application requires considerable safety requirements (sensors and alarms, ammonia concentration meters, extensive signage, training, breathing apparatus etc.) and the systems must be run by skilled personnel. Carbon dioxide is non-flammable, colourless, odourless and tasteless. Even if it classified of lower-toxicity (safety classification A1 according to ASHRAE standard 34) it can present human health hazards when operating in enclosed spaces such as vessels: such risks have to be prevented with specific safety measures (it should be noted though, that these risks are present also with HCFC and HFC refrigerants) (FRDC, 2013).

When the safety issues can be properly addressed and skilled personnel is available, then a R-717 plant can be the right choice, from both technical and economical points of view.

When safety may become an issue, the main priority is to reduce the mass of R-717 charged in the plant: confining ammonia only in one machine room, for example, can reduce the safety requirements considerably. This can be done by adopting a $NH_{3/}CO_2$ (R-717/R-744) cascade system: ammonia is the high-temperature fluid and carbon dioxide is the low-temperature fluid. The high-temperature side of the plant is confined to the machine room while the low temperature fluid is sent to all the plant terminals throughout the ship (Kawamura, 2015).

One of the first $NH_{3/}CO_2$ (R-717/R-744) cascade systems was presented in 2003 at the IIAR conference (Nielsen, 2003). The paper describes a 75m long purse seiner with a freezing capacity of 210 tons of fish per day. The system consists of 11 vertical plate freezers, a vertical flake ice freezer, and CO_2 air-coolers for 3 cargo holds.

A cascade system is very efficient for low temperature operations (down to -48°C). It is also cost effective, as compressors and piping are small if compared to those needed for other fluids. Moreover, sending to the plant terminals R-744 instead than R-717 reduces the risks due to flammability and toxicity (de Larminat, 2015).

Also on board ships, the use of R-744 as the sole refrigerant can be a technically feasible option. Recently a trawler using only R-744 as a working fluid has been built and put into operation (Hafner, 2016). Systems using only R-744 as a refrigerant could potentially have a challenge to maintain the high energy efficiency when sea water temperatures are high. It is however expected that ejector-assisted systems can be utilised to overcome this challenge, in the same way as the ongoing development within commercial refrigeration systems using R-744 as refrigerant. Some such systems are already installed and under testing.

One of the advantages of the lower evaporation temperature (-48°C) obtained with R-744 as a refrigerant is a quicker freezing time and less damage to the fish at the surface due to softening of the surface during defrosting of the plate freezers. These benefits in fish quality are very much appreciated and therefore many ships are now converted to this solution especially in Europe, but now also in the US.

Hydrocarbons are also technically feasible refrigerants for on-board refrigeration, but the strict safety concerns and large refrigerant charge required make the practical application of flammable refrigerants aboard vessels unlikely.

The use of R-717 or R-744 in one of the three plant options analysed here is viable also in terms of overall climate change impact: when considering both the direct and indirect GHG emissions involved with the use of such plant alternatives (through TEWI, Total Equivalent Warming Impact) the assessment gives an impact reduction with respect to the existing situation (FRDC, 2013).

In any case, R-717 cannot be considered a viable solution for the replacement or retrofit of refrigeration plants on existing vessels without rebuilding. On the contrary, its choice is probably the right one when new ships are involved. R-744, on the contrary, can be a viable solutions both for new ships and for plant refurbishment in existing vessels, as some recent experiences have demonstrated (Hafner, 2016)

Just for sake of reference, the cost of an on-board R-717/R-744 cascade plant is estimated at 500k AUS$ for a new ship whose cost is 2.5M AUS$ or more (FRDC, 2013). In the markets where these plants are sold, the cost is on the same level as for HFC plants.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
Option 1 – Non-halocarbon refrigerants				
R-717 system	Medium	Medium	High	Nil
	Requires new ship with separate machine room or rebuilding	Potential improvement in efficiency. Require competence, but inexpensive refrigerant	Highly complex relative to on-board capabilities. Additional safety risk of ammonia (lower flammable and toxic). Training required in new markets	No environmental policy risk throughout expected life of equipment.
R-717/R-744 cascade system	Medium	Medium	High	Nil
	Requires new ship with separate machine room or rebuilding	Potential improvement in efficiency. High maintenance cost due to complexity. Require competence, but inexpensive refrigerant	Highly complex relative to on-board capabilities. Additional safety risk of ammonia (lower flammable and toxic), Training required in new markets	No environmental policy risk throughout expected life of equipment.
R-744 system	Medium	Low-to-Medium	Medium	Nil
	Suitable for existing vessels with replacement of system	Potential improvement in efficiency at the expenses of complexity. Require competence, but inexpensive refrigerant	Some complexity relative to on-board capabilities. Training required in new markets	No environmental policy risk throughout expected life of equipment.

A2.4.3 *Option 2 – Refrigerant replacement with plant adjustments*

For systems with more than 10 to 15 years' service life, it will generally not be feasible to perform just a refrigerant drop-in retrofit. Experience shows that compressors and other parts tend to break down shortly after a refrigerant retrofit. Replacement installations are therefore safer and more reliable. Reliability is usually one of the biggest concerns to ship owners as loss of cooling can be costly.

The most fundamental conversion is when the total system is converted to a NH_3/CO_2 solution. This type of conversion requires a major overhaul, because the safety conditions change when ammonia is involved. Also material compatibility is different when transiting from halocarbon refrigerants to ammonia.

A conversion from HCFC-22 to R-744 is a possible option as well, even if it requires a plant replacement.

Experience from the markets where these conversions to R-717 and R-744 have been done is that they can be done to the same cost as for a conversion to HFC.

A conversion to a halocarbon refrigerant could be feasible. As a matter of fact, the conversion from HCFC-22 to R-507A is investigated in (FRDC, 2013). This conversion would require the change of some components and other adjustments in the refrigeration systems in order to improve the efficiency and, necessarily, would require measures for leak containment. A conversion of this type is estimated to cost in the range of 250k to 280k AUS$ for the Northern Prawn Fishery fleet. But, R-507A (together with its companion R-404A) is not a low-GWP HFC (actually, its GWP is 4300 (UNEP, 2014)) and it cannot be considered a viable substitute anymore.

According to (UNEP, 2016) R-404A and R-507A are now being substituted for commercial refrigeration applications by blends such as R-448A and R-449A, which contain some HFOs and whose GWP is <1500. As is well known, the situation is evolving rapidly so it is not possible, at this stage, to name a refrigerant that will certainly be the definitive low-GWP substitute for R-507A or R-404A.

It may be reasonable, nevertheless, to expect in the medium term a solution that will make feasible the above-suggested type of conversion. The economics of the operation will, of course, depend on the cost of the new refrigerant. Most likely, the possible alternatives will be flammable in category A2 or A2L, thus requiring adequate safety considerations and precautions.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Medium	Unknown	Unknown	Unknown
Option 2 – Refrigerant replacement with plant adjustments				
Conventional refrigeration plant system operating with low-GWP HFC blend	Suitable for existing vessels with change of components and adjustments	Cost of refrigerants at present unknown Flammability must be addressed	No significant change in type of technology and components	Environmental policy risk throughout expected life of equipment unknown at present

A2.4.4 *Option 3 – Refrigerant drop-in*

For systems with less than 10 to 15 years' service life, then a refrigerant drop-in retrofit becomes a feasible option, provided there is such a drop-in. At present, actually, there is no low-GWP HFC available on the market that can be used as drop-in for on-board systems.

Some low-GWP HFC alternatives to HCFC-22 are proposed by the chemical industry as a drop-in for land-based applications (UNEP, 2015; UNEP 2016). When these alternatives become commercially available, they could be used also as HCFC-22 substitutes for on board applications. Considering the rapidly evolving situation in the development of low-GWP HFCs it may be probable that in a few years-time a satisfactory solution will also be available for this specific problem.

One aspect to be considered in cases concerning a step-by-step transition from HCFC-22 to HCF (both high-GWP and low-GWP) is how to meet regulatory requirement of product importers, especially when non-flagged vessels are involved.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Unknown	Unknown	Unknown	Unknown
Option 3 – Refrigerant drop-in				
Conventional refrigeration plant system operating with low-GWP HFC blend	Requires improvement of refrigerant containment	Cost of refrigerants at present unknown Flammability must be addressed	No significant change in type of technology and components	Environmental policy risk throughout expected life of equipment unknown at present

A2.4.5 Option 4 – Maintaining HCFC-22

Considering the current problems in finding proper solutions for the retrofit of on-board systems equipped with HCFC-22, one reasonable option could be keeping it in the system for a further few years, until the end of the system or ship life.

The time horizon for this type of option should be no more than 4-5 years and the target should be those on-board plants with more than 10-15 years' service life.

Maintaining HCFC-22 would require the contextual execution of the following operations: i) comprehensive upgrade for improved refrigerant containment, ii) increased focus on preventive maintenance regime, iii) securing sufficient stock of gas to be held in reserve, iv) planning for an inevitable capital equipment replacement program at the end of the period to a newly released low-GWP fluid to be assessed closer to the equipment replacement date. The literature source estimates the costs for this option at 30k-50k AUS$ plus the cost of gas reserves (FRDC, 2013).

Also for this option, one aspect to be considered is how to meet regulatory requirement of product importers, especially when non-flagged vessels are involved.

	Financial considerations		Technology risk (Complexity and performance)	Regulatory and environmental risk (10 years horizon)
	Capital investment	Operating expenses		
	Low	High	Low	Very high
Option 4 – Maintaining HCFC-22				
Existing plant, operating with HCFC-22, with improved containment Short term solution (max 4-5 years) May not be practical for all vessels	Requires improvement of refrigerant containment	HCFC-22 price expected to increase	No change in technology Availability of HCFC-22 will decrease	HFC-22 phase-out in advanced stages

A2.4.6 Ultra-low temperature solutions

Blast freezers for low temperature operations (-60°C and below) needed for sushi or sashimi grade tuna must use a cascade or two-stage compressor.

Table A2-3 (UNEP, 2014; UNEP, 2016) shows the situation of available refrigerants for cascade systems to be used on board ships.

Table A2-3 Refrigerants used on board ship in cascade systems

Refrigerant	Normal Boiling Point (°C)	Cascade stage	GWP 100 years
HCFC-22	-41	1	1780
R-404A	-46.6/-45.8	1	4200
R-407F	-46.1/-39.7	1	1800
R-507A	-47.1	1	4300
R-717	-33.3	1	0
HFC-23	-82	2	12500
R-508A	-87.4	2	12000
R-508B	-87.4	2	12000
R-744	-56.2*	2	1
HC-170	-89	2	5.5

*CO_2 triple point is -56.2°C @ 5.2 bar

There are no viable low-GWP HFC alternatives to HFC-23, R-508A and R-508B, which are the refrigerants currently used in the low-temperature stage in cascade systems.

The new (unsaturated HFC) HFO compounds do not offer any low temperature solutions.

A possible alternative could technically be HC-170 (ethane, flammable, class A3), but its A3 flammability makes it unfeasible for on board systems.

A viable low-GWP alternative with evaporation down to -55°C, but requiring an equipment exchange, is an R-717/R-744 cascade system.

Another option could be a cascade system using NH_3 in the high stage and HFC-32 in the low stage (the normal Boiling Point for HFC-32 is -52.0°C). The disadvantage is that the system will go to negative pressure at -70°C. This is a potential risk because air that enters can cause the refrigerant to explode.

It is possible to use a two-stage compressor to achieve low temperature blast freezing. The lowest evaporating temperature is -65°C @+35°C condensing temperature. Evaporation will then happen at a sub-atmospheric pressure. Below is shown the possible operating envelop for such a system operating with R-407F. Also R-410A could be used in a two-stage compressor system.

In the medium term, a very interesting solution for the Ultra-Low temperature freezing can be the air-cycle (also known as Joule-Brayton reverse cycle). This is a non-vapour compression technology and fits better in the Not-In-Kind section, where it will be described and evaluated.

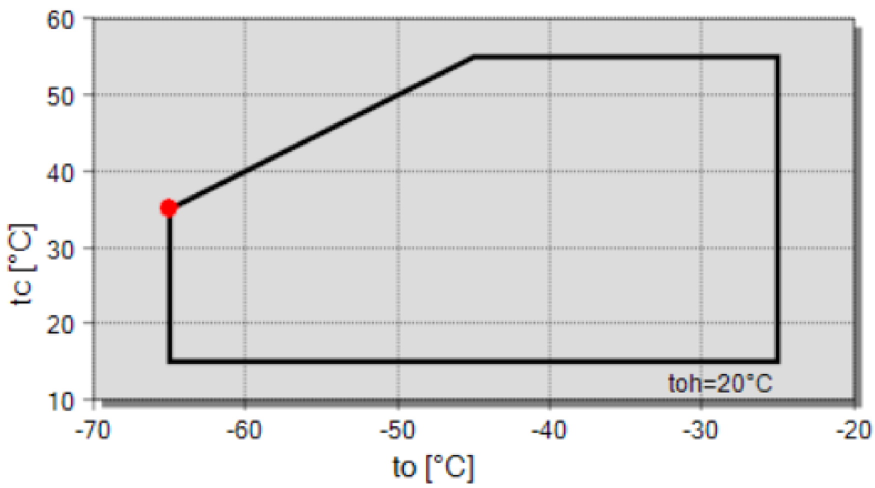


Figure A2-5 Limits for two stage compressor operating on R-407F

A2.4.7 Land based equipment

Land based equipment for the fishing industry faces the same transition problems faced by other industrial refrigeration applications. Information on how to handle transition can be retrieved in the most recent reports produced by RTOC and TEAP Task Forces (UNEP, 2014; UNEP, 2015; UNEP, 2016).

One peculiar characteristic of fishing-industry-land-based installations is that all of them are inevitably connected to a water stream (sea, lake, river), which can be used as a machine coolant. This fact makes fishing industry less sensitive to high ambient temperatures (HAT) even when located in Parties with high ambient temperature conditions.

A2.4.8 Not-In-Kind technologies

Provided that with the definition of “Not-In-Kind technologies” one refers to those refrigeration techniques which do not use vapour compression reverse cycle, there are some interesting options under study that deserve to be analysed to check if there is any possibility for their application within the fishing industry in the short term.

For very low temperatures, air (R-729) can be used as a working fluid in the so called air cycle, or Joule-Brayton reverse cycle. It was first proposed for ice making in 1844 by Dr. John Gorrie. The cycle was used for some years and then abandoned for absorption systems and later for compression systems.

The main reason for not using air was that the efficiency at the working conditions of most of refrigeration applications is far lower than the vapour compression efficiency. With modern motors and technologies, however, the air cycle can be a good solution when temperatures below -55°C are to be reached, especially if the refrigerant has to be non-flammable. Some interesting attempts of air cycle applications at low temperatures are available in the literature (Gigiel, 2006; Machida, 2011; Giannetti, 2015). To be available at a commercial level the technology needs more development work and therefore it can be a feasible option only in the medium to long term.

Absorption systems could also be a viable alternative to vapour compression, down to temperatures of -55°C. Systems could use the water (R-718)/ammonia (R-717) pair where water acts as solvent and ammonia as refrigerant. The same safety problems encountered with the application of vapour compression ammonia systems are to be faced here. Technology is mature and consolidated: the main problem with the absorption systems is the size and space needed on-board and the sensitivity to roll and pitch of a ship.

An important challenge for on board applications comes from the fact that driving energy is waste heat from engine and therefore there is a possible lack of cooling capacity if the ship's engine is not working e.g. in harbour (Fernandez, 1998)

A lot of research in magnetic cooling is ongoing. The capacities with improving technology are increasing. It is a bit early in the development cycle to determine whether or not the cooling capacity will be sufficient and at the temperature differences needed on board modern fishing ships.

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Annex 3 - EU (F-gas, MAC Directive), USA (EPA SNAP Program) and Japan Regulatory Prohibitions (Ch. 6)

	European Union			United States			Japan		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
Mobile Air Conditioning									
HFC-134a	Mobile Air Conditioners	150	2013 (new types); 2017 (all)	Light-Duty Motor Vehicle Air Conditioners		MY 2021 (~1/6/2020)	Mobile Air Conditioners		2023
Stationary Air Conditioning and Refrigeration									
HFC-134a, HC-600a	Domestic refrigerators & freezers	150	2015	*Household refrigerators and freezers (Proposed)*		*2021*			
HFC-134a, R-404A	Commercial refrigerators and freezers (hermetically sealed systems)	2500	2020	Stand-alone Low-Temperature	R-404A (3922)	2020			
HFC-134a, R-404A				*Refrigerated Food Processing and Dispensing (Proposed)*		*2021*			
HFC-134a		150	2022	Stand-alone Medium-Temperature	HFC-134a (1430)	2019 (<0.64 kW); 2020 (rest)			

	European Union			United States			Japan		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
HFC-134a				Vending Machines	HFC-134a (1430)	2019			
R-404A, R-407A, R-507	Retail Food/ Supermarkets (Multipack centralized commercial refrigeration systems with a capacity 40kW or more)	150	2022	Retail food refrigeration (supermarket systems)	R-404A (3922), R-507A (3985)	2017	Condensing Unit and Refrigerating Unit (for separate type showcases, etc.)	1500	2025
R-404A	Retail Food/ Supermarkets (primary circuit of cascade systems)	1500	2022						
R-717	*Cold Storage*			*Cold Storage Warehouses (Proposed)*	*R-404A (3922),* *R-407A (2107),* *R-410A (2088),* *R-507 (3985)*	*2023*	Cold Storage Warehouses (>50,000 m^3)	100	2019
HFC-134a	*Chillers*			*Centrifugal Chillers (Proposed)*	*HFC-134a (1430)*	*2024*	Commercial Air Conditioning	750	2020

	European Union			**United States**			**Japan**		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
HFC-134a, R-407C R-410A				*Positive Displacement Chillers (Proposed)*	*HFC-134a (1430),* *R-407C (1744),* *R-410A (2088)*	*2024*	(for offices and stores) [chillers, rooftop units, larger split systems]		
R-410A	Rooftop Units, Larger Split Systems								
R-410A	Movable room air conditioning appliances (e.g. portable air conditioners, window units)	150	2020				Room Air Conditioning	750	2018
R-410A	Single split air conditioning systems containing < 3 kg of F-gases	750	2025						

	European Union			United States			Japan		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
Fire Protection									
HFC-227ea, CO_2, Water, Dry Powder	Fire protection systems & fire extinguishers	HFC-23	2016						
				Total flooding systems using C_3F_8 or C_4F_{10} (Proposed)	*PFC-218 (8830); PFC-3-1-10 (8860)*	*2018*			
HCs, HFC-134a	Tire Inflators	SF6, all HFCs	4/7/2007	Tire Inflators	HFC-134a (1430)	20/7/2016			
HFC-134a, HFC-152a	Consumer product aerosols for entertainment and decorative purposes	150	4/7/2009	Consumer aerosols, with some exceptions for technical and medical aerosols	HFC-134a (1430)	2016	Dust Blowers	10	2019
HFC-134a, HFC-227ea (MDIs)	Technical aerosols (unless required to meet national safety standards or	150	2018						

	European Union			United States			Japan		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
	medical applications)								
Foams									
HFC-134a, HFC-245fa, HFC-365mfc	XPS Foams with HFCs	150	2023	Polystyrene Extruded Boardstock and Billet (XPS)	HFC-134a (1430)	2021			
HCs, HFC-134a	One-component foams	150	4/7/2008	Polyisocyanurate Laminated Boardstock, Polystyrene Extruded Sheet, Phenolic Insulation Board and Bunstock, Polyolefin, and several types of Polyurethane foams	HFC-134a (1430), HFC-245fa (1030), HFC-365mfc (794)	2017-2020	Urethane Foam (house construction materials)	100	2020
HCs, HFC-134a, HFC-245fa, HFC-365mfc	Other Foams with HFCs	150	2020						

	European Union			United States			Japan		
Typical Historical Zero-ODP Option	**Applications and Products**	**GWP Max Limit, F-gas Prohibited**	**Effective Date of Prohibition**	**Applications and Products**	**Unacceptable examples (GWP)**	**Date of Prohibition**	**Designated Products**	**Target GWP**	**Target Year**
HFC-134a, HFC-245fa, HFC-365mfc	Other Foams (Rigid PU Spray Foam)	150	2020	*Rigid PU Spray Foam (Proposed)*	HFC-134a (1430), HFC-245fa (1030), HFC-365mfc (794)	*2020-2021*			

Notes:

- GWPs are AR4 values (IPCC, 2007)
- Prohibition dates January 1st unless otherwise noted and shown as day/month/year.
- Proposed USA prohibitions in *italics*; dates assume as proposed with a final rule published 1/1/2017.
- Exceptions include, *inter alia*, US mobile AC for export to markets lacking service infrastructure, EU stationary refrigeration products below -50 C, USA chillers for military vessels and human-rated spacecraft, EU foams where required to meet national safety standards, USA foams until 1/1/2022 (existing) or 1/1/2025 (proposed) for space- and aeronautics–related applications, and Japan exceptions to designated products.

Annex 4 - 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 6):

- 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 A4-1: 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 A4-2: 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 A4-3: 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 A4-4: 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 A4-5: 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 A4-6: 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 A4-7: 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 A4-8: 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: A4-9: 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 A4-10: 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 A4-11: 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 A4-12: 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 A4-1: 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 A4-2: 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 A4-3: 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 A4-4: 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 A4-5: 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 A4-6: 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 A4-7: 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 A4-8: 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: A4-9 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
	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
A5 BAU	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
	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
A5 MIT-3	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
	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
A5 MIT-5	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 A4-10: 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 A4-11: 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 A4-12: 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