MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

UNEP

DECISION XXVI/9 TASK FORCE EXTRACT
ADDITIONAL INFORMATION ON ALTERNATIVES TO ODS

APRIL 2015

(ExTRACT FOR OEWG-35)
ADDITIONAL INFORMATION ON ALTERNATIVES TO ODS
(Extract for OEWG-35)
Montreal Protocol
On Substances that Deplete the Ozone Layer

Extract of the
XXVI/9 TEAP Task Force

April 2015

DECISION XXVI/9 TASK FORCE EXTRACT:
ADDITIONAL INFORMATION ON ALTERNATIVES TO ODS

The text of this report is composed in Times New Roman.

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In light of the fact that there will be two OEWGs in 2015, the first much earlier than anticipated, the XXVI/9 Task Force is providing an extract to assist the Parties in their discussions at OEWG-35. This is “work in progress” that has not been systematically reviewed by the Technology and Economic Assessment Panel co-chairs and members. Information will change as work proceeds towards the finalisation of the draft XXVI/9 report in time for consideration at OEWG-36.
Preface

The April 2015 TEAP XXVI/9 Task Force Extract

Parties, in Decision XXVI/9, in November 2014, have, among other tasks, requested a report updating information on alternatives to ozone-depleting substances, to be made available for consideration by the Open-ended Working Group at its thirty-sixth-meeting and an updated report to be submitted to the Twenty-Seventh Meeting of the Parties.

That Decision also called for convening a two-day workshop, back to back with an additional three-day meeting of the Open-Ended Working Group to continue discussions on all issues in relation to hydrofluorocarbon management. This workshop and the additional OEWG-35 will be held back-to-back in Bangkok, 20-24 April 2015.

In light of the fact that there will be two OEWGs in 2015, the first much earlier than anticipated, the XXVI/9 Task Force is providing an extract to assist the Parties in their discussions at OEWG-35. This is “work in progress” that has not been systematically reviewed by the Technology and Economic Assessment Panel co-chairs and members. Information will change as work proceeds towards the finalisation of the draft XXVI/9 Task Force report in time for consideration at OEWG-36.

This draft XXVI/9 Task Force report is planned for completion by the TEAP Task Force before the end of May 2015 and it will subsequently be submitted to the Parties for further discussion at the OEWG-36.
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1 Scope

Decision XXVI/9 is the next in a series of Decisions on alternatives to ozone depleting substances to request TEAP to develop and assess -on the basis of latest information on alternatives to ODS- the impact of specific mitigation scenarios as part of its reporting back to the Parties. In responding to this mandate, TEAP is seeking to draw from its earlier evaluations of alternatives (Decisions XXIII/9, XXIV/7 and XXV/5 and the TOC assessment reports). The information is being updated where appropriate, although the principle changes are generally expected to be minor because of the short time period between the finalisation of the TEAP Report on XXV/5 (October 2014), the finalisation of the TOC 2014 Assessment reports and the publication of the draft XXVI/9 report (foreseen for late May 2015).

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

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

The XXVI/9 Decision contains a specific request related to high ambient temperature countries in para 1(b) in the Decision. The draft Task Force report will contain information on refrigerants for high ambient temperature conditions, plus an elaboration on the design of equipment as well as experimental information obtained in various demonstration projects.

Work is ongoing on the draft XXVI/9 report, which should be available for review by Parties by the end of May. This extract reports on parts that are already available for that draft XXVI/9 report as well as on the plans to expand the now available information. This extract contains for informational purposes:

- The updated technical information on alternatives in the various sectors and a determination of further updates to be done;
- First summaries on refrigerants and other design and operation conditions of equipment under high ambient temperature conditions;
- For the refrigeration and air conditioning sector, a first revision of BAU and MIT-2 scenarios and the consequence of manufacturing conversion periods on the demand profiles; this information is being further refined;
- Updates of technical information on alternatives in the fire protection and the medical uses sectors.

This extract has been specifically composed for the information of Parties at the OEWG-35 meeting in Bangkok, 22-24 April 2015.
2 Introduction

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

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

2.2 Scope and coverage

The text of Decision XXVI/9, as it relates to this report is as follows:

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

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

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

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

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

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

2. To convene a two-day workshop, back to back with an additional three-day meeting of the Open-Ended Working Group in 2015, to continue discussions on all issues in relation to hydrofluorocarbon management, including a focus on high-ambient temperature and safety requirements as well as energy efficiency, taking into account the information requested in the present decision and other relevant information;

3. To encourage parties to continue to provide to the Secretariat, on a voluntary basis, information on their implementation of paragraph 9 of decision XIX/6, including information on available data, policies and initiatives pertaining to the promotion of a transition from ozone-depleting substances that minimizes environmental impact wherever the required technologies are available, and to request the Secretariat to compile any such submissions received;
4. To request the Executive Committee of the Multilateral Fund to consider providing additional funding to conduct inventories or surveys on alternatives to ozone-depleting substances in interested parties operating under paragraph 1 of Article 5 upon their request;

2.3 Composition of the Task Force and extract report structure

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

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

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

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

Chapter drafts are (still) being prepared by sub-groups of the Task Force, for Task Force and TEAP review by the end of May, whereafter the final draft report will be submitted to the OEWG-36, for discussion by Parties.

For an update of the progress on the XXVI/9 report, it was decided to put together an extract of the material so far available, for information of the Parties at the OEWG-35 in Bangkok, 22-24 April 2015. The contents of this extract give an impression of which type of information is being dealt with and it also gives an impression of what can be expected in the final draft report by late May 2015. No TEAP review was foreseen before the publication of the Task Force extract by UNEP. Undoubtedly a substantial amount of material has to be added, other material may be adjusted and/or changed after review and before the submission of the final draft report.

The structure of the future TEAP XXVI/9 Task Force Report was preliminary considered by the Task Force and will be considered again by TEAP prior to a final formulation of the Report. The factors to be considered include:

- The relatively short period between the delivery of the final XXV/5 Report (October 2014) and the preparation of the draft XXVI/9 Report (February-May 2015).
- The publication of the various TOC Assessment reports with a large amount of updated and well-reviewed technical information by January-February 2015.
The similarity of the criteria set out within Decision XXV/5 and Decision XXVI/9 (and within the earlier Decision XXIV/7), already noted in the XXV/5 Task Force report.

The importance of avoiding too much repetition and bringing focus on what is either new or of growing importance.

Recognition that some sectors (specifically refrigeration, air conditioning and foam) have data which allow for the characterisation of a Business-As-Usual (BAU) case and related mitigation scenarios. Recognition that other sectors (specifically fire protection, solvents and medical uses) do not have reliable data from which relevant mitigation scenarios can be derived or for which mitigation scenarios were not derived.

Recognition that Decision XXV/5 sought to generate an analysis of the Article 5 and non-Article 5 implications of avoiding high GWP alternatives to ODS, and that this issue is further investigated in the XXVI/9 Task Force report.

As a result, and this for the time being, the following chapter layout has been followed for this extract of the (future) XXVI/9 Task Force report (this layout may change for the final draft):

Chapter 1 ‘Extract information’

Chapter 2 ‘Introduction’

Chapter 3 ‘Refrigerant alternatives’
…which gives first information on alternatives, including for high ambient application. The first part on alternatives needs quite a bit of further input.

Chapter 4 ‘Update of alternatives for ODS in Refrigeration, Air Conditioning and Heat Pumps applications’
…which provides information on the trends in alternative selection within the refrigeration, air conditioning sector. The foams sector is still investigating issues and will report in the final draft of the XXVI/9 TF report.

Chapter 5 ‘The BAU and MIT-2 scenarios in non-Article 5 and Article 5 regions’
…which considers in a preliminary way (in this extract) the revision of BAU and MIT-2 scenarios from the XXV/5 report for the RAC sector (to BAU+ and MIT-2+ scenarios). Further information will be added in the final draft report, late May 2015. The scenarios for foams should again be considered in the final draft XXVI/9 report. They are currently still under investigation and there will be a more comprehensive approach in the final draft XXVI/9 TF report.

Chapter 6 ‘High ambient temperature issues’
…which provides information on design and energy efficiency of equipment in high ambient temperature conditions. The summary given in this extract reflects what is being dealt with at present and looks forward to what can be prepared for the final draft XXVI/9 TF report.

Chapter 7 ‘Information on alternatives to ODS in the fire protection sector’
…which provides information on the trends in alternative selection within the fire protection sector with reference to information previously contained in the Decision XXV/5 Report.

Chapter 8 ‘Information on alternatives to ODS in medical uses’
…which provides information on the alternatives available for medical uses and the implications of technology choices.
3 Refrigerant alternatives

3.1 Refrigerant developments

At this moment, many low GWP refrigerant developments are taking place. The Task Force is listing new developments, but cannot yet present a complete update in this extract, compared to the information provided in the XXV/5 Task Force and the RTOC 2014 Assessment report.

All new candidates generally are unsaturated HFCs or blends, which may contain HFCs, HCs, and/or unsaturated HFCs. The parameters to be sorted out require balancing energy efficiency, flammability (including application standards and regulations), GWP, cost, worldwide availability, retrofit considerations, and level of system design complexity that is required to use the new candidates successfully. Since it is expected that, by mid-2015, information has become available on various new issues, the Task Force should be able to report more facts in this subchapter in the final draft XXVI/9 report.

3.2 Refrigerant alternatives for high ambient temperatures

Three major projects have been launched to evaluate refrigerant alternatives for high ambient temperatures. All three projects are focused on air conditioning equipment, both residential and commercial. They are briefly described below.

- **UNEP PRAHA Project (Middle East)**

  The main objective is to evaluate Window AC, mini-splits and Packaged Rooftops. Several local manufacturers are currently testing refrigerants provided by major equipment producers.

- **UNEP EGYPRA Project (Egypt)**

  Dedicated to the valuation of mini-splits and packaged rooftops with the participation of Egyptian manufacturers, and with refrigerants provided by major chemical manufacturers.

- **AHRI High Ambient Project (Article 5 countries)**

  Sponsored by AHRI and with UNEP experts participating, this project aims to test alternatives for HFCs suitable for high ambient regions. Evaluations were performed on mini-splits and packaged rooftop units. Systems tests will soon begin and results are expected by the end of July.

All refrigerants proposed in these projects are listed in tables 3-1 and 3-2. Some of them have already an ASHRAE designation. Others are developmental refrigerants with limited information about their components and composition.

### Table 3-1: HCFC-22 alternatives

<table>
<thead>
<tr>
<th>Ref</th>
<th>ASHRAE Name</th>
<th>AREP-II HAT</th>
<th>UNEP PRAHA</th>
<th>UNEP EGYPT</th>
<th>GWP (AR4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCFC-22</td>
<td>R-22</td>
<td>ü</td>
<td>ü</td>
<td>ü</td>
<td>1810</td>
</tr>
<tr>
<td>HC-290</td>
<td>R-290</td>
<td>ü</td>
<td>ü</td>
<td>ü</td>
<td>20</td>
</tr>
<tr>
<td>L-20A</td>
<td>R-444B</td>
<td>ü</td>
<td>ü</td>
<td>ü</td>
<td>295</td>
</tr>
<tr>
<td>N-20B</td>
<td>ü</td>
<td></td>
<td>ü</td>
<td>ü</td>
<td>988</td>
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<tr>
<td>DR-3</td>
<td>ü</td>
<td>ü</td>
<td>ü</td>
<td>ü</td>
<td>148</td>
</tr>
<tr>
<td>DR-93</td>
<td>ü</td>
<td></td>
<td>ü</td>
<td>ü</td>
<td>1230</td>
</tr>
<tr>
<td>ARM-20B</td>
<td>ü</td>
<td></td>
<td>ü</td>
<td>ü</td>
<td>250</td>
</tr>
<tr>
<td>ARM-32c</td>
<td>ü</td>
<td></td>
<td>ü</td>
<td>ü</td>
<td>1412</td>
</tr>
</tbody>
</table>
Tables 3-3 and 3-4 depict basic thermodynamic performance of the refrigerants that have basic properties available. Preliminary calculations were performed by Task Force members, using the following assumptions:
- Evaporation temperature: 7°C
- Superheat at evaporator outlet: 5°C
- TD at condenser: 10°C
- Degree of sub-cooling at condenser outlet: 5°C
- Isentropic efficiency: 70%
- Volumetric efficiency: 100%

Both HC-290 and R-444B show similar efficiencies with not significant degradation at high ambient when compared to HCFC-22. One would expect that they can replace HCFC-22 with no major redesign of the system. In the case of the higher pressure refrigerant R-410A, this shows significant drop of efficiency. Still, this drop can be partially offset by adequate design of both heat exchangers and compressors, exploiting its good thermal properties. In some cases, this may imply additional costs.
Both HFC-32 and R-447A show better thermodynamic performance than R-410A. Still, they will probably need improvements in heat exchangers and compressor to match the performance of HCFC-22. In some cases, this may imply additional costs.

Although thermodynamic calculations are useful for preliminary evaluations, they have to be taken with caution. The ultimate performance will be demonstrated in real system testing, which should come from these three projects. Preliminary results should be available by mid-2015.

The three projects listed above, in section 3.2 (UNEP-PRAHA, UNEP-Egypt and AHRI HAT), will test refrigerants at typical test conditions listed in ANSI/AHRI Standard 210/240, and also at ISO T3 condition (46°C) and the extreme of 52°C. Table 3-5 below gives additional details of such test conditions.

Table 3-5: Additional details for test conditions AHRI / ISO T3 and HAT 52

<table>
<thead>
<tr>
<th>Condition</th>
<th>Outdoor (DB/WB)</th>
<th>Indoor (DB/WB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHRI A</td>
<td>35°C / 23.9°C</td>
<td>26.7°C / 19.4°C</td>
</tr>
<tr>
<td>AHRI B</td>
<td>27.8°C / 18.3°C</td>
<td>26.7°C / 19.4°C</td>
</tr>
<tr>
<td>AHRI C</td>
<td>27.8°C / -</td>
<td>26.7°C / &lt;13.9°C</td>
</tr>
<tr>
<td>ISO T3</td>
<td>46°C / -</td>
<td>29°C / 19°C</td>
</tr>
<tr>
<td>High Temp. 52°C</td>
<td>52°C / -</td>
<td>29°C / 19°C</td>
</tr>
</tbody>
</table>

Initial results of these evaluations are expected by mid-2015 with complete reports by the end of 2015.
4 Update of alternatives for ODS in Refrigeration, Air Conditioning and Heat Pumps applications

Since much of the material presented in the Decision XXV/5 Report has remained largely unchanged, an extract of what will be eventually presented in the final draft of the XXVI/9 report has been given here, which is mainly based on the XXV/5 Task Force report and the 2014 RTOC Assessment report. A more complete and detailed overview will be presented in the final XXVI/9 Task Force draft report due late May 2015.

Note: The following sections briefly describe the trends in refrigerant selection by specific sector. A number of the new refrigerant candidates have an A2L safety rating which is associated with flammability (i.e., a low flame velocity, distinguishing them from more flammable chemicals). Since the foams expert group of the Task Force is still developing update material, it has not been available for this extract. The updated foam material will be available in the May 2015 final draft TF XXVI/9 report.

4.1 Domestic appliances

Globally, new refrigerator production conversion from the use of ODS was essentially completed by 2008. HC-600a or HFC-134a continue to be the main choice of refrigerant for new production. No other new refrigerant has matured to become an energy-efficient and cost-competitive alternative. Refrigerant migration from HFC-134a to HC-600a is expected to continue, driven either by local regulations on HFCs or by the desire for reduced global warming impact from potential emissions. Excluding any influence from regulatory interventions, it is still projected that by 2020 about 75% of new refrigerator production will use HC-600a (possibly with a small share by unsaturated HFC refrigerants) and the rest will use HFC-134a.

According to some industrial sources, initial developments to assess the use of HFC-1234yf in domestic refrigeration have begun, but it is not being pursued with high priority, as in automotive applications.

4.2 Commercial refrigeration

On a global basis, HCFC-22 continues to represent a large refrigerant bank in commercial refrigeration and is used at all temperature levels. The most widely used HFC is R-404A and this for all temperature levels. Over the last decade, HCs --for low refrigerant charge systems-- and CO2 --for supermarkets-- have taken significant market share, especially in Europe. In parallel, progress has been made to improve energy efficiency and leak tightness especially for centralized systems. The progressive phase-out of HCFC-22 in developing countries requires making informed choices on the best replacement options.

Stand-alone Equipment: Even if they have very different GWPs, HFC-134a and R-404A can be expected to be phased-out progressively in developed countries. Lower GWP HFC and HFC blends, hydrocarbons and CO2 are replacing R-404A and HFC-134a in new stand-alone equipment. Minimum energy standards have been issued or updated in many countries increasing competition between manufacturers to reach higher energy efficiency in stand-alone systems.

Condensing Units: For new systems, R-404A is still the leading choice, and intermediate blends such as R-407A or R-407F are proposed as immediate options to replace R-404A. Global companies are now offering hydrocarbon condensing units for smaller capacities. One can also expect lower GWP HFC and HFC blends and CO2 to grow in acceptance in this application in future.

Supermarket systems: In Article 5 countries, HCFC-22 is still the dominant refrigerant used in centralised systems. In Europe, new systems have been mainly charged with R-404A; R-744 is now taking a significant market share with improved energy efficiency by using two-stage systems,
options well known from industrial refrigeration. For small and medium size supermarkets, the so-called “booster system” has been designed to use CO\textsubscript{2} at the low and the medium temperature levels. For large supermarkets, the cascade system is preferred with CO\textsubscript{2} at the low temperature level and CO\textsubscript{2} or HFC-134a at the medium temperature level. Distributed systems are also quite common, gaining market share with improved energy efficiency, lower charge levels and lower emission rates. Indirect systems are also popular in order to limit the refrigerant content by more than 50% and to drastically lower refrigerant emission levels. For developing countries, the important issue remains the replacement of HCFC-22, either for retrofit or for new installations. Blends such as R-407A or R-407F as well as lower GWP HFC and HFC blends constitute options offering significantly lower GWP than R-404A and R-507A.

4.3 Industrial systems
The majority of large industrial systems use R-717 as the refrigerant. When R-717 is not acceptable in direct systems in these countries, options include R-744 or glycol in secondary systems or HCFCs or HFCs in direct systems. In countries where R-717 has not been the preferred solution, or in market segments with smaller systems, the transition from HCFC-22 is not straightforward. It requires acceptance of higher cost fluorocarbons in systems similar to the types used with R-22 or the adoption of more expensive systems with the cheaper refrigerants R-717 and R-744. HFC-T234ze(E) has been demonstrated in large district heating systems as a possible replacement for HFC-134a, however its performance is not any better than HFC-134a which is already limited in application and efficiency compared for example with R-717.

4.4 Transport refrigeration
For new systems, hydrocarbons offer high energy efficiency, but the safety risks in transport refrigeration applications appear significant and must be mitigated. On the other hand, R-744 has been tested in the field since 2011. Its non-flammable characteristics make R-744 attractive, but the gap in efficiency in high ambient temperatures and the limited component supply base are limiting its penetration into the market.

HFC blends are likely to play a role as a retrofit to R-404A and (possibly) HFC-134a systems: their GWP is significantly lower than R-404A and performances are relatively close. Candidates include but are not limited to R-407A, R-407F, R-448A, R-449A and R-452A. One also sees “non-conventional” solutions such as open loop systems or eutectic systems. These solutions offer specific advantages in some transport routes, furthermore, the fact that vehicles are HFC free and that the supporting installation can be HFC free will continue making them attractive.

4.5 Air-to-air air conditioners and heat pumps
R-410A is the dominant alternative to HCFC-22 in air-conditioners and is being used in manufacturing in most non-Article 5 and several Article 5 countries. Except for R-744, all of the medium and low GWP alternatives are flammable and should be applied in accordance with appropriate regulations and/or safety standards (that are continuously under development), considering refrigerant charge amount, risk measures and other special construction requirements. Some safety standards limit the system charge quantity of any refrigerant within occupied spaces.

HC-290 and HC-1270 are mainly considered for systems with smaller charge sizes, whilst the operating pressures and capacities are similar to HCFC-22 and the efficiency is higher than HCFC-22. Split air conditioning systems using HC-290 have been available in Europe and Australia, are in production in India and HCFC-22 equipment production capacity is being converted to HC-290 in China (however, with limited output at present). R-744 is considered to have limited applicability for air conditioning appliances in Article 5 countries, due to the reduced efficiency when the ambient temperature approaches or exceeds about 31°C. There is continuing research on cycle enhancements.
and circuit components, which can help improve the efficiency under such conditions, although they can be detrimental to system cost.

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

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

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

4.6 Water heating heat pumps

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

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

4.7 Chillers

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

The new candidates generally are unsaturated HFCs or blends, which may contain HFCs, HCs, and/or unsaturated HFCs. The parameters to be sorted out require balancing energy efficiency, flammability (including application standards and regulations), GWP values, cost, worldwide availability, retrofit considerations, and level of system design complexity that is required to use the new candidates successfully.
4.8 Vehicle air conditioning

In spite of existing regulations in the US (supporting the use of low-GWP refrigerants) and legislation in Europe (banning the use of refrigerants with GWP > 150), the overwhelming majority at present of the newly sold passenger cars and light trucks worldwide are still equipped with air conditioning systems, which use HFC-134a as refrigerant.

It looks likely that more than one refrigerant will be used in the coming years for car and light truck air conditioning: HFC-134a will remain largely adopted worldwide, HFC-1234yf will continue its growth in new models at least in the near future, other new low GWP synthetic refrigerants or refrigerant blends (e.g. R-445A) may be implemented and R-744 is expected to be implemented on a commercial scale by 2017. All options have GWPs below the EU threshold and can achieve fuel efficiencies comparable to modern HFC-134a systems. Currently it cannot be forecast whether or not all these refrigerants will see parallel use in the market for a long period of time. It is also unclear whether the bus and train sector will follow these trends.

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

At present, no regulations exists that control the use of fluorinated greenhouse gases as refrigerants for MAC systems in buses and trains. It is likely that the choice of refrigerant of passenger car air conditioning systems, as well as developments in the stationary heat pump market, will influence the choice of refrigerant for air conditioning systems in buses and trains.
5 The BAU and MIT-2 scenarios for Article 5 and non-Article 5 regions

5.1 Introduction

In the XXV/5 Task Force report, BAU scenarios were developed for RAC and foams for non-Article 5 and Article countries. The consumption (demand) for RAC was estimated to be 5 times larger than for foams in the year 2010, and extrapolation to 2030 showed that the consumption (demand) for RAC would rise exponentially and would be more than 95% of the total demand for RAC and foams.

Mitigation measures were investigated in a MIT-1 and MIT-2 scenario. Bans on the use of certain high GWP chemicals were assumed to enter into force in new manufacturing as of 2020. The MIT-1 scenario in non-Article 5 countries resulted in a very moderate growth up to the year 2030 for the RAC sector, MIT-2 resulted in a decrease of 40% compared to 2015. The MIT-2 scenario for Article 5 countries resulted in a decrease from 2400 to 800-1000 Mt CO2-eq., a reduction of about two thirds.

5.2 Revision of scenarios

Decision XXVI/9 asks to revise the scenarios in paragraph 1 (c): “Taking into account the uptake of various existing technologies, revise the scenarios for current and future demand elaborated in the October 2014 final report on additional information on alternatives to ozone-depleting substances of the Technology and Economic Assessment Panel’s task force on decision XXV/5, and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and stage II of HCFC phase-out management plans”. Regarding the text of this paragraph, the Task Force is so far not aware that the uptake of various technologies has changed that much that it would ask for a revision of the mitigation scenarios developed. The mitigation scenarios in the XXV/5 Task Force report already assumed a phase-out date of 2020 for high GWP substances in the manufacturing in most RAC subsectors, which date was, and is, still challenging. One could consider a slower phase-in of the conversions in manufacturing, because that would be a better way to consider various other consequences. Some further work will be reported here on costs and benefits.

The Task Force has not been able to change BAU and MIT scenarios for the foams sector in both non-Article 5 and Article 5 countries, due to the fact this part is still being worked on and will be more fully reported in the late May draft report.

As mentioned above, the Task Force did not see a reason to revise the BAU and MIT (MIT-1 and MIT-2) scenarios for the RAC sector for non-Article 5 countries. However, in the case of the BAU scenario for Article 5 countries (small) changes were made for certain subsectors in the growth percentages (downward) assumed for the period 2015-2030, based upon more information having become available on recent growth patterns and also concerning expectations on future growth in larger Article 5 countries. In particular, this had major consequences for the demand in the commercial refrigeration sector. For this extract, the Article 5 MIT-1 scenario was not further investigated; the focus has been on the Article 5 MIT-2 scenario. The new scenarios looked at in this extract are defined as the BAU+, MIT-1+ and MIT-2+ scenarios.

One of the issues that needs attention when revising the XXV/5 scenarios is the following. In the MIT scenarios, bans are assumed for certain RAC subsectors as of 2020 (in most cases). The conversion of new manufacturing could in principle happen overnight, but this seems not realistic at all. A certain period for conversions has to be built in. For this extract (and also for the final May 2015 draft) a certain conversion period has therefore been assumed. This period has been 3 years for non-Article 5 countries before a ban on a certain refrigerant would become effective, and has been 6 years in Article 5 countries after a ban on a refrigerant would become effective. In fact, the latter case is the same as if a ban would become effective 6 years later than given, and the conversion would start 6 years before that date (of the ban). This period has been chosen (and the length of the period has been varied) for
reasons of the distribution of funding, i.e., if the complete conversion of manufacturing would have to be funded, it would cost a certain period before all conversion projects would have been designed, and projects would have been approved by a certain funding authority. It will be clear that, the slower the conversion of manufacturing, the longer the servicing tail will be (assuming that no equipment will be retrofitted, this based on experience so far with the CFC phase-out and the HCFC phase-down under the Multilateral Fund).

As in the XXV/5 report, the calculation method used is a bottom-up method, where one has to define a starting point (i.e., the year 1990) where there is still a large amount of equipment (the installed base) in operation from the period 1975-1990. This amount will gradually disappear over the years, so that estimates for the demand after the year 2005 are dealing with estimates of numbers of equipment that have been manufactured after 1990. Choices for certain refrigerants made will therefore gradually increase in the total demand, consisting of both the new manufacturing (charging) and the servicing demand.

A number of considerations substantially complicate the calculations including a preference to apply certain alternatives in specific equipment (and often under certain conditions), combined with the fact that the amounts in the RAC banks (which is the amount present in the equipment) need recharging (i.e., servicing) over their entire lifetime (assumed to be 15-20 years in Article 5 countries).

5.3 **BAU+ scenarios**

In the figures below the BAU+ scenarios are shown:
- Non-Article 5 BAU+ with subdivision for refrigerants.
- Non-Article 5 BAU+ with subdivision for the various RAC subsectors.
- Article 5 BAU+ with subdivision for refrigerants.
- Article 5 BAU+ with subdivision for the various RAC subsectors.

![Figure 5-1: Non-Article 5 BAU+ scenario with subdivision for refrigerants.](image)

Figure 5-1 shows the Non-Article 5 refrigerant BAU+ demand, with a subdivision for the commonly used high GWP refrigerants and low GWP refrigerants. The demand is given in tonnes and in GWP weighted terms (in CO\textsubscript{2}-eq.).

In the year 2010, the importance of R-410A and R-407C are not really dominant. However, when extrapolating the BAU scenario towards 2030, the demand doubles and the relative importance of R-410A and R-407C in the total increases enormously.
Figure 5-2: Non-Article 5 BAU+ scenario with subdivision for the various RAC subsectors.

Figure 5-2 again shows the Non-Article 5 refrigerant BAU+ demand, with a subdivision for the different subsectors. The demand is given in tonnes and in GWP weighted terms (in CO$_2$-eq.).

In the year 2010, the importance of the stationary AC sector is not really dominant. However, when extrapolating the BAU scenario towards 2030, the demand doubles and the relative importance of the stationary AC sector in the total increases enormously.

Figure 5-3: Article 5 BAU+ scenario with subdivision for refrigerants.

Figure 5-3 shows the Article 5 refrigerant BAU+ demand, with a subdivision for the different high GWP refrigerants and the low GWP group. The demand is given in tonnes and in GWP weighted terms (in CO$_2$-eq.).

In the year 2010-2012, all types of refrigerants have a certain share; the respective shares do not change that much in tonnes. However, expressed in GWP weighted terms, the commercial refrigeration subsector with its use of the high GWP R-404A becomes dominant in 2020-2030.

Figure 5-4 again shows the Article 5 refrigerant BAU+ demand, with a subdivision for the different subsectors. The demand is given in tonnes and in GWP weighted terms (in CO$_2$-eq.).

In the year 2010, the importance of the stationary AC sector is not really dominant. However, when extrapolating the BAU scenario towards 2030, the demand doubles and the relative importance of the stationary AC sector in the total increases quite a bit in tonnes. However, expressed in CO$_2$-eq., the BAU+ scenario shows the importance of the commercial refrigeration subsector in 2030, with the use of the high GWP R-404A.
5.4 MIT-2+ scenarios

In the figures below the MIT-2+ scenarios are shown:
- Non-Article 5 MIT-2+ with subdivision for refrigerants.
- Non-Article 5 MIT-2+ with subdivision for the various RAC subsectors.
- Article 5 MIT-2+ with subdivision for refrigerants.
- Article 5 MIT-2+ with subdivision for the various RAC subsectors.

Figure 5-5 shows the Non-Article 5 refrigerant MIT-2+ 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 CO₂eq.).

In the year 2010, the importance of R-410A and R-407C are not really dominant. However, with bans on use as of 2020, the amounts of high GWP refrigerants decrease, the amounts of low GWP refrigerants increases sharply towards the year 2030 (when about 90% in the total demand is taken by low GWP refrigerants. The GWP weighted curves show that the peak is reached in 2015-2017, after which the total amount in GWP weighted terms is about 50% of that value in the year 2030.

Since the low GWP refrigerants are assumed to have an average GWP of 300 (note: this is a change compared to the MIT-2 scenario in the XXV/5 TF report, where a GWP of 7000 was chosen), the relative importance of these refrigerants is much lower in the GWP weighted graph.

The importance of R-410A in the year 2030 has changed completely from the BA+ demand curve.
Figure 5-6: Non-Article 5 MIT-2+ scenario with subdivision for the various RAC subsectors.

Figure 5-6 again shows the Non-Article 5 refrigerant MIT-2+ demand, with a subdivision for the different subsectors. The demand is given in tonnes and in GWP weighted terms (in CO₂-eq.).

In the year 2010, the importance of the stationary AC sector is not really dominant. However, when extrapolating the BAU scenario towards 2030, the demand doubles and the relative importance of the stationary AC sector in the total increases enormously. However, where in the BAU+ demand curves the demand in GWP weighted terms was huge in 2030, this has now decreased substantially in that year. One can also observe that the importance of commercial refrigeration decreases gradually towards the year 2030.

Figure 5-7: Article 5 MIT-2+ scenario with subdivision for refrigerants (manufacturing conversion 6 years).

Figure 5-7 shows the Article 5 refrigerant MIT-2+ demand, with a subdivision for the different high GWP refrigerants and the low GWP group. The demand is given in tonnes and in GWP weighted terms (in CO₂-eq.).

In the year 2010-2012, all types of refrigerants have a certain share, the respective shares do change substantially once conversion starts in the year 2020. Also here, low GWP refrigerants have taken 90% of the share in tonnes by the year 2030. Expressed in GWP weighted terms, importance of all the refrigeration subsectors has decreased substantially, with also a moderate contribution, it seems, of the low GWP refrigerants. However, please note that the scales in these Article 5 demand curve figures are really different from those used for the non-Article 5 demand curves.

Figure 5-8 again shows the Article 5 refrigerant MIT-2+ demand, with a subdivision for the different subsectors. The demand is given in tonnes and in GWP weighted terms (in CO₂-eq.).
As of the period 2015-2020, the importance of the stationary AC sector is dominant. However, when looking at the MIT-2+ scenario towards 2030, even when the demand doubles between 2020 and 2030 (including the tonnes of low GWP refrigerant), expressed in CO$_2$-eq., the MIT-2+ scenario shows the decrease in the demand (by more than a factor two between 2020 and 2030).

**Figure 5-8: Article 5 MIT-2+ scenario with subdivision for the various RAC subsectors (manufacturing conversion 6 years).**

For the demand curve during the period 2020-2030, it is important which period will be chosen for the refrigerant manufacturing conversion period. A slow conversion will lead to a large demand for servicing in the intermediate period, where in the end, by about 2035, the demand curves for the various conversion periods will not be that much different. This effect is being demonstrated here, but will be investigated more in depth for the final draft report.

**Figure 5-9: The Article 5 MIT-2+ commercial demand scenario for 6-8-10-12 conversion years**

**Figure 5-10: The Article 5 MIT-2+ industrial demand scenario for 6-8-10-12 conversion years**
In the figures above, the impact for the subsectors commercial, industrial and domestic refrigeration is shown. It is clear that the domestic refrigeration curves have a substantially different character, since the servicing aspect plays a very different role here (i.e., relatively low consumption).

Fig. 5-12 gives the 4 curves for 6, 8, 10 and 12 years conversion for all refrigeration and AC subsectors together.

A six years conversion in manufacturing for all subsectors results in a decrease by somewhat more than 40% by the year 2026, after which the servicing tail comes in, reductions go slower and the demand has been decreased by about 50% in ten years (2020-2030).

A twelve years conversion period does not show 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 been converted) causes this profile in the demand curve. After 10 years after the start of the conversion, a reduction in the demand can be observed of 20-25%.

It will be clear that there is a direct relation of the shape of the curves to the conversion period. However, one should realise that a 6 years conversion period would ask for twice the amount of funding in the first 6 years after 2020 (for these MIT-2+ scenario assumptions), compared to the 12 years conversion period.
5.5 BAU – global summary for both foams and RAC from XXV/5

The XXV/5 Task Force report considerations were that it could be important to bring some perspective to the BAU scenarios. In the report it is mentioned that “although comparisons can be made in both actual tonnages and ODP tonnes, the most meaningful from the perspective of this report is to assess the consumption (potential emissions) in climate terms (tonnes CO\textsubscript{2}-eq). Figure 5-13 does this and provides an assessment of the actual situation through to 2012 and then projections through to 2030 using the assumptions spelled out in earlier parts of this chapter. It can be seen that consumption of refrigerants in RAC applications dwarfs the consumption as taking place in the various foam sub-sectors. It is also evident that the growth in Article 5 parties, if left unchecked, will have significant climate impact by 2030, especially if emission rates from installed equipment cannot be significantly limited to reduce on-going servicing demand.” This important point is shown in the following graph from the XXV/5 report and reproduced here.

![Comparative BAU Scenarios for Foam & RAC Applications by Region](source: XXV/5 Task Force report, October 2014)

5.6 BAU+ and MIT-2+; current and future demand

The XXV/5 Task Force report gave a number of tables with current and future refrigerant demand in tables, for both the various refrigerant types and for the RAC sub-sectors. More data will be presented in the final draft XXVI/9 report than in this extract.

On the basis of the development of the demand for the various ODS replacements for the various sub-sectors (high GWP and of low GWP alternatives), the total demand in tonnes (and in GWP based CO\textsubscript{2}-eq. tonnes) can be calculated.

Below several tables are given with the Article 5 demand for refrigerants in tonnes and Mt CO\textsubscript{2} equivalent for the BAU+ and the MIT-2+ case, up to the year 2030. BAU+ values may be slightly different than for the BAU case given in Figure 5-13.

Table 5-1: Current and future refrigerant demand for (refrigerant) ODS alternatives
**Table 5-2: Current and future refrigerant demand for (refrigerant) ODS alternatives (BAU+ scenario) for the period 2010-2030 in Article 5 countries (Mt CO$_2$ equivalent)**

<table>
<thead>
<tr>
<th>Year/Refrigerant type</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-134a</td>
<td>70.7</td>
<td>98.0</td>
<td>134.6</td>
<td>171.6</td>
<td>218.0</td>
</tr>
<tr>
<td>R-404A/R-507</td>
<td>51.6</td>
<td>184.8</td>
<td>359.5</td>
<td>604.5</td>
<td>880.0</td>
</tr>
<tr>
<td>R-407C</td>
<td>26.8</td>
<td>89.6</td>
<td>164.0</td>
<td>282.6</td>
<td>462.5</td>
</tr>
<tr>
<td>R-410A</td>
<td>78.7</td>
<td>204.8</td>
<td>370.1</td>
<td>546.6</td>
<td>700.5</td>
</tr>
<tr>
<td>Low-GWP</td>
<td>0.06</td>
<td>0.12</td>
<td>0.21</td>
<td>0.32</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>227.9</td>
<td>577.3</td>
<td>1028.4</td>
<td>1605.6</td>
<td>2261.5</td>
</tr>
</tbody>
</table>

The following can preliminarily be observed for the Article 5 countries in the BAU and MIT-2 scenarios:

- There are differences in the BAU+ and MIT-2+ scenarios compared to the XXV/5 report; this is due to small changes in BAU+ assumptions, and different assumptions for the MIT-2+ scenario;
- The demand for various HFCs in Article 5 countries is still assumed to increase by a factor 3-4 in the BAU+ scenario between 2015 and 2030;
• The BAU+ scenario still shows a large growth in demand for the refrigerants R-404A, R-407C and R-410A mainly due to the external (growth) factors;

• Conversion to low GWP refrigerants as of 2020 (with a conversion period of 6 years) with a GWP<300 in commercial refrigeration, stationary and mobile air conditioning (GWP<150) manufacturing results in a reduction by about 80% over the period 2020-2030:

• It should be realised that this proposed MIT-2+ conversion will be very demanding and the assumptions used here are based on the fact that institutional and industrial capacities can completely deal with this conversion in this timeframe.

The above statements are preliminary; it will further elaborated upon in the XXVI/9 draft report.

5.5 Costs and benefits

The Decision XXVI/9 mentions “…and improve information related to costs and benefits with regard to the criteria set out in paragraph 1 (a) of the present decision, including reference to progress identified under stage I and stage II of HCFC phase-out management plans”.

New information on cost and benefits could not be presented in this extract. So far, the information available is not significantly different from the information presented in the XXV/5 Task Force report.

Where it concerns costs and benefits, also where it concerns the cost effectiveness factors for conversions in manufacturing, further work is being undertaken for the final draft report.
6 High Ambient Temperature issues

6.1 Introduction

Designing for high ambient needs special care to avoid excessively high refrigerant condensing temperatures in order to not getting close to the critical temperature for each type of refrigerant considered. Other issues like safety, refrigerant charge quantity, as well as improving the energy efficiency for both partial and full load have to be taken into consideration.

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

In some countries that experience high ambient temperatures, there is thoughtful concern relating to meeting the freeze and reduction targets where alternatives to HCFC-22 in small/medium size air-conditioning applications have not yet been introduced and verified by local markets.

An overview of theoretical thermodynamic cycle calculations done for a variety of refrigerants operated at high ambient temperature conditions can be found in chapter 3. Caution is needed here, since these are thermodynamic calculations only, further experimental results from the projects are not expected until mid-2015. This is maybe too late for inclusion in the draft XXVI/9 Task Force report, but could be included for the final XXVI/9 Task Force report.

6.2 Challenges

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

- An unclear global trend about refrigerant alternatives for each category of application particularly those suitable to operate in high-ambient conditions;
- The limited availability of components, mainly compressors, that are suitable for various low-GWP alternatives and designed for high-ambient temperature conditions; and
- The fact that the behavior of HVAC systems and their efficiencies has not been clearly determined when operated at high ambient temperatures.

These challenges were accentuated by the absence of national/regional codes/standards that can facilitate the introduction of low-GWP alternatives and deal with the new energy efficiency rating schemes and regulations, particularly for air conditioning (AC) systems, that were being introduced simultaneously with phasing out HCFC systems. Moreover, safety standards in high ambient countries have not yet been adapted or implemented. Standards, like ISO 5149, EN 378, IEC 60335-2-40 for air conditioners and heat pump systems need to be implemented and IEC 60335-2-89 for commercial refrigeration appliances, need to be adapted before the new refrigerants (that are mostly flammable) can be placed on the market. IEC standards are a de facto legal requirement in several countries as the Certification Body (CB) scheme is the actual requirement for import and sales of products.

The need for research into alternatives and assessment of equipment designs applied to high ambient conditions has become more urgent and some modelling and laboratory-based efforts – both internationally and within high ambient regions – has recently been carried out.
As discussed in chapter 3, UNEP and UNIDO recently launched a project to study and compare systems specifically built for and using selected refrigerants, operating at high ambient temperatures. The project, “Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries” (PRAHA) was launched in 2013 with a target completion in 2015. Building up on PRAHA and the linkage to country phase-out plans, Egypt adopted a similar initiative as part of the HPMP to test refrigerant alternatives for air-conditioning units built in Egypt. The initiative, “Promotion of Low-GWP Refrigerants for the Air-Conditioning Industry in Egypt” (EGYPRRA) proposes to test more blends in different applications. The initiative was launched in June 2014 and is expected to have the results by end 2015.

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

6.3 What is expected in the final draft XXVI/9 Task Force report

The final XXVI/9 report will include a listing of the available alternatives for the different air conditioning and refrigeration applications, their specific relevant properties, and their adaptability to high ambient conditions. The following is a list of some preliminary findings:

- R-407C is chosen as an alternative to HCFC-22 by some manufactures in the Middle East. R-407C has been demonstrated to be an acceptable retrofit refrigerant and has seen widespread use in some regions although there is some loss in capacity and efficiency compared to HCFC 22.

- The use of R-410A is getting more widespread. The lower critical temperature results in lower efficiency than HCFC-22 at same condensing temperatures. A larger condenser can resolve this issue, but relative cost increment is inevitable.

- HFC-32 is suitable for regions with high ambient temperatures in most types of split, multi-split and ducted ACs although necessary consideration is needed for the system design and to provide suitable training for the service sector to handle the lower flammability aspects.

- HC refrigerants are suitable for regions with high ambient temperatures in single split systems. In multi-split, split (ducted) and ducted split commercial and non-split air conditioners, both HC-290 and HC-1270 perform well at high ambient. However, due to charge amount limitations, they are not easily applicable and require expert consideration as to suitability of cases. Manufacturers in high ambient countries are experimenting with hydrocarbons in rooftop units.

- Both R-446A and R-447A have higher critical temperature of around 84°C and 83°C, respectively, compared to 71°C for R-410A. This higher critical temperature enables them to have a higher efficiency at high ambient temperature with cost implications comparable to R-410A.

- R-444B has a critical temperature similar to HCFC-22 and thus substantially higher than R-410A. Preliminary test results indicate that equipment using R-444B shows similar capacity and efficiency to HCFC-22 with comparable cost implications to HCFC-22.

- As highlighted in the 2013 XXIV/7 TF report, the use of single component unsaturated HFCs, such as HFC-1234yf and especially HFC-1234ze(E), have not been seriously considered for
multi-split and ducted ACs because their volumetric capacity is low, implying bulkier systems and – along with high anticipated refrigerant price.

- Due to its relative higher critical point compared to other refrigerants, R-447A performs well at high ambient temperatures in chilled water systems and its energy efficiency at high ambient temperatures is better than R-410A.

- The use of R-744 is not suitable for high temperature climates due to the inability or excessive cost necessary to achieve desired efficiencies. There is continuing research on cycle enhancements and circuit components, which can help improve the efficiency under such conditions, although they can be detrimental to system cost.

- R-717 chillers can and are used in regions with high ambient temperatures, although the very high discharge temperatures need to be accommodated for through inter-stage and oil cooling.

- For centrifugal chillers, R-718 (water) has been used in Europe and Japan in capacities of up to 350 kW using a special axial type compressor. In principle R-718 chillers should perform well under high ambient temperatures. Due to lower molar mass and lower saturation pressure, compression is not so easy and fouling can have a devastating impact on the performance.

The three projects listed in chapter 3 (UNEP-PRAHA, UNEP-Egypt and AHRI HAT) will test refrigerants at typical test conditions listed in ANSI/AHRI Standard 210/240, and also at ISO T3 condition (46°C) and the extreme of 52°C. Table below give additional details of such test conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Outdoor (DB/WB)</th>
<th>Indoor (DB/WB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHRI A</td>
<td>35°C / 23.9°C</td>
<td>26.7°C / 19.4°C</td>
</tr>
<tr>
<td>AHRI B</td>
<td>27.8°C / 18.3°C</td>
<td>26.7°C / 19.4°C</td>
</tr>
<tr>
<td>AHRI C</td>
<td>27.8°C / -</td>
<td>26.7°C / &lt;13.9°C</td>
</tr>
<tr>
<td>ISO T3</td>
<td>46°C / -</td>
<td>29°C / 19°C</td>
</tr>
<tr>
<td>High Temp. 52°C</td>
<td>52°C / -</td>
<td>29°C / 19°C</td>
</tr>
</tbody>
</table>

Initial results of these evaluations are expected by mid-2015 with complete reports by the end of 2015.
7 Information on alternatives to ODS in the fire protection sector

7.1 Introduction

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

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

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

7.2 Alternatives for Fixed Fire Protection Systems

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

a) Halocarbon agents:
   FK-5-1-12
   HFC-23
   HFC-125
   HFC-227ea

b) Inert Gas agents
   IG-01
   IG-100
   IG-55
   IG-541

c) Carbon dioxide (for use in unoccupied areas only)

d) Water Mist technologies

e) Inert Gas generators

f) Fine solid particles

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

Other halocarbon agents are in the early stages of testing and development. However, due to the lengthy process of testing, approval and market acceptance of new fire protection equipment types and agents, it is not anticipated that these agents can have any appreciable impact in the near-term. Phosphorous tribromide (PBr₃) has been commercialised for use as a fire extinguishing agent in one small
aircraft engine application but it is not being considered for any other application at this time owing to its toxicity and corrosiveness.

7.3 Alternatives for Portable fire protection systems

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

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

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

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

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

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

For local, non-portable, applications such as the protection of floating roof tank rim seals, CF₃I (iodotrifluoromethane) has re-emerged as an acceptable alternative for halon 1211 or halon 2402.

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

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

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

A) HFCs

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

Sector Growth: HFC Sales for fire protection according to one manufacturer are:
- US: flat
- Middle East: growing
- Asia Pacific: growing
- Latin America: flat
- Europe: flat

B) Fluoroketone

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

Sector Growth: Fluoroketone sales for fire protection according to the manufacturer are:

Sales continue to grow substantially in Europe, the Middle East, Africa, North America and South East Asia. In addition, sales are increasing in Latin America.

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

8.1 Metered Dose Inhalers

CFC-propelled MDIs were historically the inhaled delivery device of choice in the treatment of asthma and COPD. They have been replaced with HFC MDIs, dry powder inhalers (DPIs, with two main types, single-dose and multi-dose, including reservoir and multi-unit dose devices), nebulisers, aqueous mist inhalers, and emerging alternatives, such as iso-butane propelled MDIs. The two main alternatives to CFC MDIs, HFC MDIs and DPIs, are now available for all key classes of drugs.

Industry data shows worldwide CFC MDI usage declining, and less than either DPI or HFC MDI usage, based on dose equivalence. Meanwhile there has been an increased overall use of inhalers due to the increased use of both MDIs and DPIs. The total consumption of all MDIs increased during the period 2007-2012 (2.1 per cent per annum), and the consumption of DPIs also increased (3.0 per cent per annum). In 2012, CFC MDIs accounted for about 16 per cent of all inhaled medication globally, based on dose equivalence, HFC MDIs for about 43 per cent, DPIs about 32 per cent, and nebulised solutions about 8 per cent.

Approximately 630 million HFC based MDIs are currently manufactured annually worldwide, using approximately 9,400 tonnes of HFCs in 2014. HFC-134a makes up the major proportion of MDI manufacture (~8900 tonnes in 2014), with HFC-227ea accounting for about 5 per cent (~480 tonnes in 2014). This corresponds to direct emissions with a climate impact of approximately 0.013 Gtonnes CO₂-e equivalents, which is about 3 per cent of global GWP-weighted emissions of HFCs used as ODS replacements in 2014. Under a business as usual model, for the period 2014 to 2025, the total cumulative HFC consumption in MDI manufacture is estimated as 124,500 tonnes (119,000 tonnes HFC-134a; 5,500 tonnes HFC-227ea), corresponding to direct emissions with a climate impact of approximately 0.173 Gtonnes CO₂-equivalent, which would be significantly less than the climate impact of CFC MDIs had they not been replaced.

DPIs are technically and economically feasible alternatives that could minimize the use of HFC MDIs. Nebulisers and emerging technologies may also be technically feasible alternatives for avoiding some use of HFC MDIs. The exception is for salbutamol; currently salbutamol HFC MDIs account for the large majority of HFC use in inhalers, and are significantly less expensive per dose than multi-dose DPIs, making them an essential and affordable therapy. At present, it is not yet technically or economically feasible to avoid HFC MDIs completely because there are economic and technical impediments in switching from HFC MDIs to multi-dose DPIs for salbutamol, and because a minority of patients (10-20 per cent or less) cannot use available alternatives to HFC MDIs. Nevertheless, DPIs may play an increasing role over the next decade. In about ten years, by about 2025, when patents expire, or even despite patent protection, there is likely to be more competition and more widespread DPI manufacture, such as in Article 5 Parties, and more affordable DPIs. These factors are likely to improve the cost effectiveness of DPIs compared with HFC MDIs.

8.2 Other medical aerosols

In 2010, the GWP-weighted HFC consumption for all aerosol products was estimated as 0.054 Gtonnes CO₂-equivalent, or 5 per cent of the total for global HFC consumption. Medical aerosols, including MDIs, are estimated as a small percentage of total aerosol production in terms of units, but are responsible for about 76 per cent of GWP-weighted HFC consumption used in aerosol production. Other medical aerosols, excluding MDIs, cover a wide range of uses from simple numbing of pain, nasal inhalation, to the dosage of corticosteroids for the treatment of colitis. Other medical aerosols are estimated to represent around 1 per cent globally of all aerosol products, with approximately 250-300 million cans per year. It is estimated that less than 10 per cent of other medical aerosols (excluding MDIs) use HFC propellants, or less than 1,000 tonnes per year.

Since 1978, when the aerosol market was the dominant source of all ODS emissions, CFCs used as aerosol propellants have gradually been phased out in response to concerns about ozone depletion. MDIs will be the last category to be phased out in 2015-2016. When the Montreal Protocol identified
essential uses of CFCs, allowing for exemptions from CFC production phase-out schedules, it differentiated oral inhalation into the lungs (MDIs) from other medical aerosols, for which CFCs were considered non-essential. Small quantities of CFCs and HCFCs are reportedly still used for other medical aerosol products such as topical anaesthetic sprays and coolants to numb pain respectively. HCFC use is estimated as about 100 ODP tonnes or less worldwide (HCFC-22 and HCFC-141b), with the majority used in China.

Technically and economically feasible alternatives to ozone-depleting propellants (CFCs and HCFCs) are available for all other medical aerosols. Most aerosols, including other medical aerosols, replaced CFC propellants with hydrocarbons and dimethyl ether (DME) propellants. HFCs are used where flammability and toxicity are an issue, or sometimes where there are regulatory requirements regarding volatile organic compounds (VOCs). The majority of other medical aerosols are for nasal inhalation, throat topical medication, and nitroglycerin sublingual application. Suitable alternatives to avoid using HFC propellants include nitrogen or “not-in-kind” metered pump sprays. Registration of new HFC-free formulations would be costly and would require time.

8.3 Sterilants

Considering the range of sterilization methods in routine application in healthcare and industrial facilities, the use of EO/CFC and EO/HCFC sterilants are no longer required and can be phased out. Existing capital equipment using EO/HCFC or, in very rare cases, EO/HFC sterilants could remain in use if a source of gas could be secured for perhaps the next ten years. However, there is no technical or economic reason for EO/HCFC or EO/HFC sterilants to be in used in non-Article 5 Parties beyond 2020, and in Article 5 Parties beyond 2030 or possibly earlier. Due to the wide variety of technically and economically feasible alternatives available in sterilisation, and the almost non-existent use of high-GWP alternatives, there are very few implications for the sterilisation sector in avoiding high-GWP alternatives to ODS.