MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MAY 2018

VOLUME 3

PROGRESS REPORT

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

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Date:	May 2018

Under certain conditions, printed copies of this report are available from:

UNITED NATIONS ENVIRONMENT PROGRAMME
Ozone Secretariat, P.O. Box 30552, Nairobi, Kenya

This document is also available in portable document format from the UNEP Ozone Secretariat's website:

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ISBN: 978-9966-076-40-3

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Acknowledgements

The Technology and Economic Assessment Panel, its Technical Options Committees and the TEAP Task Force Co-chairs and members acknowledges with thanks the outstanding contributions from all of the individuals and organisations that provided support to Panel, Committees and TEAP Task Force Co-chairs and members. The opinions expressed are those of the Panel, the Committees and TEAP Task Forces and do not necessarily reflect the reviews of any sponsoring or supporting organisation.

Foreword

The May 2018 TEAP Report

The 2018 TEAP Report consists of five volumes:

Volume 1: *Decision XXIX/9: Hydrochlorofluorocarbons and decision XXVII/5 – March 2018*
Volume 2: *Decision XXIX/4: Destruction technologies for controlled substances – March 2018*
Volume 3: *TEAP 2018 Progress report – May 2018*

TOC Progress Reports
TEAP administrative issues and lists of TEAP and TOC members at May 2018
Matrix of expertise

Volume 4: *MBTOC interim CUN assessment report – May 2018*
Volume 5: *Decision XXIX/10: Issues related to energy efficiency while phasing down hydrofluorocarbons – May 2018*
Supplement to the April 2018 Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances – May 2018.

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MAY 2018 PROGRESS REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL
VOLUME 8

TABLE OF CONTENTS

1 Introduction

This is volume 3 of 5 of the May 2018 Technology and Economic Assessment Panel (TEAP) Report and contains Progress Reports from the five Technical Options Committees (TOCs) composing the TEAP: Flexible and Rigid Foams TOC (FTOC), Halons TOC (HTOC), Methyl Bromide TOC (MBTOC), Medical and Chemicals TOC (MCTOC) and Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC).

The TEAP and TOC membership lists, as at 31st May 2018, which includes each member's term of appointment, and a matrix of needed expertise for the TEAP and its TOCs appear in annexes at the end of this document. Specific organisational issues relating to each TOC and to TEAP are also discussed in Chapter 9 and in the relevant annexes.

1.1 Key TEAP messages

TEAP presents the main findings contained in each of the TOC progress reports below.

1.1.1 FTOC

- Regulations continue to evolve regarding the use of hydrofluorocarbons (HFCs) as foam blowing agents. Significant transitions to low global warming potential (GWP) alternatives have occurred in many regions and especially in non-Article 5 parties (non-A5 parties) in the last two years.

- There have been significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations and the availability of low GWP blowing agents enabling the successful commercialization of foam systems containing lthese agents especially for nonA5 parties where regulations related to GWP have been implemented. For some foam-types, conversions to zero ODP/low GWP alternatives are nearing completion (e.g. appliance foams, flexible foams, integral skin etc.).

- Article 5 parties (A5 parties) face common challenges in phasing out hydrochlorofluorocarbons (HCFCs) and phasing down high GWP HFC blowing agents.

    - HCFC Phase-out Management Plans (HPMPs) continue to drive transitions in foams.

    - In general, HCFCs are about one third of the cost of high-GWP HFCs and hydrofluorolefin / hydrochlorofluoro-olefin (HFO/HCFOs). HFO/HCFO blown foams remain more expensive than HFC foams due to the total cost of blowing agent and the required additives.

    - In some A5 parties, import of HCFC-141b itself is controlled or under license, but polyols containing HCFC-141b can be imported without controls. To counter this, some A5 parties are implementing regulations that would ban or restrict import of HCFC-containing polyol systems.

- Decisions on transition for some segments of use (e.g. spray foam and extruded polystyrene (XPS)) may be delayed because the cost of transition is still being optimised for some applications and regions.

- Matching the capacity to produce low-GWP alternatives to HCFCs, to the demand for use in foam blowing, will require continued communication between regulators, producers and users to ensure smooth transitions.

- Total global production of polymeric foams is projected to grow (3.9% per year) at a slightly lower rate than noted last year (4.0%), from 24 million tonnes in 2017, to 29 million tonnes by 2023. Production of foams used for insulation is expected to grow in line with global construction and continued development of refrigerated food processing, transportation and storage (cold chain).

1.1.2 HTOC

- HTOC is of the opinion that although research to identify potential new fire protection agents continues, it could be five to ten years before a viable agent might have significant impact on the fire protection sector.
- In response to Decision XXIX/8, the International Civil Aviation Organization (ICAO) has formed an informal working group, including an HTOC co-chair and a TEAP co-chair, to determine the uses and emissions of halon 1301 within civil aviation fire protection systems.
- The HTOC has re-engaged with the International Maritime Organization (IMO). This will enable HTOC to update the Decision XXVI/7 report on future availability of halons by assessing the quantity of halons installed on merchant ships, and the quantity and quality of halons being recovered from ship-breaking activities. The Parties may wish to consider if a more formal relationship, such as developing a joint Memorandum of Understanding (MOU) to formalize this and other ozone-related activities is worth pursuing.
- Civil aviation appears to be on schedule to meet the ICAO requirement to use only alternative agents to halon for all hand-held extinguishers on new production aircraft after 31 December 2018. The agent is 2-bromo-3,3,3-trifluoro-prop-1-ene (2-BTP), and this is. replacing halon 1211.

1.1.3 MBTOC

- Methyl Bromide (MB) phase-out for reported controlled uses is almost complete.
- A5 Parties have critical use requests for less than 1% of the A5 baseline for controlled consumption of MB.
- Alternatives to MB (both chemical and non-chemical), including technologies which altogether avoid the need for MB (e.g. heat, soil-less culture, resistant varieties and rootstocks), exist for almost all controlled uses of MB (both for pre-plant, commodities and structures).
- Recapture technologies are continually developing and being adopted in some countries because of human safety concerns
- Phase-out for the remaining methyl bromide critical uses will be greatly influenced by the registration of sulfuryl fluoride and methyl iodide, the use of some non-chemical options like soil-less culture and by consideration of specific Integrated Pest Management schemes.
- Improved reporting of production and trade for controlled uses and quarantine and pre-shipment (QPS) may assist understanding global movements of MB and uses.
- Pre-2015 stocks (an estimated 2000 tonnes) appear to be used for critical uses but are not being reported.
- An estimated 31 to 47% of present QPS uses could be replaced immediately with available alternatives.
- MBTOC is aware of continuing discrepancy (in the thousands of tonnes) between top-down and bottom-up comparisons of emissions and reported production/consumption.

1.1.4 MCTOC

- The global transition away from chlorofluorocarbon (CFC) metered-dose inhalers (MDIs) is complete.
- Based on the information reported by parties on the use of controlled substances under exemptions as process agents, parties may wish to consider the recommended changes to Table A of Decision XXIX/7 and Table B of Decision XXII/7.
- Based on Article 7 data reported by parties, total production of controlled substances (ozone-depleting substances (ODS)) for feedstock and process agent uses was 1,189,536 tonnes in 2016. Estimated associated emissions can be calculated as 5,948 tonnes, or 2,194 ozone depletion potential (ODP) tonnes.
- The use of HCFC-141b and HCFC-225 for solvent cleaning in non- 5 parties has been phased out, with the exception of aerospace and military applications. In A 5 parties, HCFC use for solvent cleaning has declined. There is a reported solvent use of HCFC-225 for syringe/needle coating in Japan. Several manufacturing processes use HCFCs as solvents in processes that might be considered similar to process agent uses.
- In 2017, China announced its commitment to phase out the use of carbon tetrachloride for the testing of oil in water by 2019 and, accordingly, no essential use nomination for this laboratory and analytical use was received.
- In response to decision XXVI/5(2) on laboratory and analytical uses, MCTOC plans to report in time for the 30th MOP.

1.1.5 RTOC

- The development of hydrocarbons (HCs), R-717 (ammonia), and R-744 (carbon dioxide) in relevant sectors has continued. Recently, unsaturated fluorochemicals (especially HFOs), and blends of HFOs with HFCs have become the main option to replace high GWP refrigerants. Since the publication of the RTOC 2014 Assessment Report, 33 new refrigerants, most of them blends, have received standard designations and safety classifications in ASHRAE Standard 34. Of these 33 new refrigerants, 23 have been previously listed in the 2017 RTOC progress report, and 10 are new since that report. Among the 10 new fluids there are two single-compound refrigerants and eight blends.
- The majority of medium- and low-GWP alternatives are flammable and require the development of new safety standards. There has been significant progress, although it is unclear when the A2/A3 amendment to standards IEC 60335-2-40 and IEC 60335-2-89 will be published.
- The phase down of high-GWP HFC’s is underway in all refrigeration, air conditioning and heat pump (RACHP) sectors.
    - Some sectors have identified possible long-term solutions for a majority of applications (e.g., domestic refrigeration with HC-600a and commercial refrigeration with R-744) while some other sectors are investigating different alternatives (e.g., air-to-air air conditioners with HFC-32 and HC-290, and motor vehicle air conditioning (MAC) with HFO-1234yf and R-744).
    - In almost all sectors, testing of lower-GWP blends is under way in order to find a suitable alternative to high-GWP fluids in the near or medium term.
- Energy efficiency is being taken into account in all decisions regarding which low-GWP alternatives are to be introduced. Over 90% of energy efficiency improvements accompanying the transition to low-GWP refrigerants, are due to improvements in equipment efficiency (with 5-10% attributable to the working fluid itself).
- The risk assessment of flammable refrigerants in different applications in different regions

is subject to special safety considerations. For example, in high ambient temperature (HAT) conditions, the elevated refrigerant charge and the capability of technicians in the service sector to manage safety risk, are both important factors.

2 Flexible and Rigid Foams TOC (FTOC) Progress Report

Executive Summary

- Regulations continue to evolve regarding the use of controlled HFCs in foams driving transitions to low GWP alternatives in several regions and especially in non-A 5 parties in the last two years.
- There have been significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations and the availability of low GWP blowing agents enabling the successful commercialization of foam systems containing these agents especially for non A5 parties where regulations related to GWP have been implemented. For some foam-types, conversions to zero ODP/low GWP alternatives are nearing completion (e.g. appliance foams, flexible foams, integral skin etc.).
- A 5 parties face common challenges in phasing out HCFCs and phasing down high-GWP HFC blowing agents.

    - HPMPs continue to drive transitions in foams.
    - In general, HCFCs are ~30% of the cost of high GWP HFCs and HFO/HCFOs. HFO/HCFO-blown foams remain more expensive than HFC foams due to the total cost of blowing agent and required additives.
    - In some A5 parties, import of HCFC-141b itself is controlled or under license, but polyols containing HCFC-141b can be imported without controls. To counter this, some A5 parties have implemented regulations that would ban or restrict import of HCFC-containing polyol systems.
    - Decisions on transition for some segments (e.g. spray foam and XPS) may be delayed because the cost of transition is still being optimized for some applications and regions.
    - Matching the capacity to produce low-GWP alternatives to HCFCs, to the demand for their use in foam blowing, will require continued communication between regulators, producers and users to ensure smooth transitions.

- Total global production of polymeric foams is predicted to grow (3.9% per year) at a slightly lower rate than noted last year (4.0%), from 24 million tonnes in 2017 to 29 million tonnes by 2023. Production of foams used for insulation is expected to grow in line with global construction and continued development of refrigerated food processing, transportation and storage (cold chain).

2.1 Global Markets for Foams

The market size of polymer foam is projected to grow at a Compound Annual Growth Rate (CAGR) of 3.9% from 2017 to 2023 in volume from just over 24 million tonnes to 29 million tonnes. The rate of growth is estimated to be slowing due to concerns about plastics in the environment and legislation regarding disposal of polymeric foams.[1]

[1] Market & Market Global Polymeric Foam Report 2017-2022

Table. 2.1 Estimated Global Polymer Foam Production (tonnes)

	2017	**2023**	**CAGR%[2]**
Polyurethane			
Rigid	5,900,000	7,530,000	5.00%
Flexible	6,100,000	7,455,100	4.09%
Total PU Foam Production	**12,000,000**	**14,985,100**	**4.54%**
Polystyrene			
EPS	8,523,575	9,890,000	3.02%
XPS	1,750,000	1,850,000	1.12%
Total Polystyrene Foam Production[2]	**10,273,575**	**11,740,000**	**2.70%**
Phenolics, Polyolefins, EVA, ENR	**1,613,000**	**2,150,000**	**5.92%**
Total Estimated Polymeric Foams[3]	**23,886,575**	**28,875,100**	**3.87%**

[1] Compound Annual Growth Rate
[2] Sources: Market & Market, IAL Consultants, Industry Report

2.2 Global Drivers for Foams

The increasing disposable incomes of the growing global, urban middle class remain the main drivers of the global polymeric foam market. Demand is driven by its wide range of end-use industries, building & construction, the cold chain, furniture & bedding, packaging and automotive industries. Rigid polymeric foams are often used for thermal insulation and packaging. These foams historically have used blowing agents controlled by the Montreal Protocol.

Polyurethane, polystyrene and phenolic foams contribute to the energy consumption in buildings. Global construction is forecast to increase by US$ 8 trillion by 2030, creating a global annual growth in demand for thermal insulation of 4-5 %[4]. The main drivers for thermal insulation are legislation and building standards to reduce heat loss. The EU and North America are currently leading proponents of building codes to improve energy efficiency in the construction industry. Emerging countries in Asia Pacific are fast growing markets for polymeric foams that offer thermal insulation.[5]

[3] Sources: Market & Market, IAL Consultants, Industry Reports

[4] Oxford Economics – Global Construction Trends to 2030
[5] Ialconsultants.com – EU Thermal Insulation Markets 2018

Rigid polyurethane foam accounts for 30 % of the total estimated polymeric foam produced, the major drivers being regulation and energy efficiency, especially in construction and the cold chain.[6]

An estimated one third of global food production requires refrigeration. Food and Agricultural Organization estimates that food production needs to increase globally by 70% to feed an additional 2.3 billion people by 2050, therefore refrigeration has an increasing role to play.[7]

2.3 Regulations & Codes

For A5 parties, developing regulations require foam producers to transition to zero-ODP blowing agents. In some parties, use of HCFCs is limited to applications where hydrocarbons are not suitable, such as spray foam. In others, HCFCs are still widely used. Some parties are working to limit imported HCFC-141b pre-blended polyol and manufacture of foam using HCFCs. Globally, the controlled availability and increasing price of HCFCs may drive faster transition to zero-ODP blowing agents.

2.3.1 HCFC Transition and 2016 Kigali Amendment

The FTOC has discussed and will monitor the Kigali Amendment implementation with the HCFC-141b phase out. There are a number of variables which may influence the rate of transition out of HCFC-141b into low-GWP and zero-ODP blowing agents directly, or as a second conversion via high GWP HFCs. These variables include: the cost and availability of HFOs/HCFOs and the cost and availability of high GWP HFCs (e.g., HFC-245fa, HFC-365mfc/HFC-227ea). A5 parties are working on enabling activities to support the ratification of the Kigali Amendment (e.g. translation of the Kigali Amendment into local language, stakeholder consultation, HFCs inventory surveys in the industry sectors to countries base line, review of socio-economic impacts, etc.); however, many have not yet considered specific regulations related to the use of controlled HFCs in foams.

Under HPMPs, projects that transition from HCFC-141b used in polyurethane foam to low GWP alternatives have been funded and many have been completed or are in progress. However, unfunded companies (e.g., companies that were established after September 2007, multi-national companies and companies in unfunded countries) operating in A5 parties may convert from HCFCs to high-GWP HFCs to meet HCFC phase-out deadlines rather than converting directly to low-GWP alternatives.

Article 5 parties face common challenges in phasing out of HCFC and phasing down of high GWP HFC blowing agents. In general, HCFCs are ~30% of the cost of high GWP HFCs and HFOs/HCFOs which are in some cases currently comparably priced. Decisions on transition may be delayed because the final formulations to optimise performance and cost are still not clear for all applications and geographies.

Some Southeast Asian parties with funded HPMPs have proposed to establish or amend regulations to phase out HCFC-141b in polyurethane foam through a quota system, with a permit for the import of bulk HCFC-141b. Additional regulations in development in these parties include a restriction on the import of HCFCs and polyols containing HCFC-141b after conversion projects are completed and a prohibition of the expansion of existing HCFC-based

[6] JRC Technical Report on the Competition Landscape of Thermal Insulation
[7] Cooling and refrigeration sector: the centre of the EU's energy system, CORY ALTON MAY 2017, PUBLISHED IN BLOG

manufacturing capacities or building new facilities. HCFC-141b in spray foam is still in use because of cost concerns and to optimize formulations with replacement products.

In **China**, the national fire code for buildings GB50016 has been in effect since 1 May 2015. This has changed the use of thermal insulation in the construction sector. The stringent fire performance criteria in the standard limit the use of organic foam materials such as rigid polyurethane and polystyrene foams in thermal insulation and ban the use of organic material such as the core of metal-faced sandwich panels for industrial applications. This creates a challenge for China's efforts to reduce energy consumption. There is an indication that foam insulation may be allowed in metal faced sandwich panels for cold storage applications. While stringent but achievable fire standards have been enacted, building code enforcement and construction site management also impact fire safety. Fire safety codes and standards in other regions may also be upgraded due to recent incidents.

In the **United States (US)**, in July 2015 the Significant New Alternatives Policy (SNAP) program implemented by the US Environmental Protection Agency (USEPA) made significant changes in the list of acceptable foam blowing agents eliminating the use of HFCs in a number of applications. The 2015 Rule was subsequently challenged and a court decision vacated the rule "to the extent it requires manufacturers to replace HFCs" and remanded the rule to EPA for further proceedings.[8] On 27 April, 2018, the USEPA published guidance addressing aspects of the court's decision stating that the USEPA would "not apply the HFC use restrictions or unacceptability listings in the 2015 Rule for any purpose before completion of a rulemaking" and, further, that the USEPA would "move forward with a notice-and-comment rulemaking and…seek input from interested stakeholders prior to developing a proposed rule." [9]USEPA held a subsequent stakeholder meeting on 4 May, 2018. Independently, the state of California has adopted several of the provisions from the 2015 SNAP rule related to HFC use in foams.

In **Canada**, regulations establishing a phase-down of HFC consumption from an established baseline came in to force in April 2018. Regulations have been implemented that eliminate the use of blowing agents with GWP greater than 150 by 2021. As producers in the US export foam and foam systems to Canada, US manufacturing facilities may need to convert a portion of facilities exporting to Canada to comply with the regulations.

In the **European Union (EU) or European Economic Area (EEA),** fluorinated gases are controlled according to (EU) No 517/2014 on Fluorinated Greenhouse Gases (F-Gas Regulation). The F-Gas Regulation establishes a phase-down in the total supply of HFC gases across the EU. This phase-down is implemented using a system of quotas allocated to companies involved in the production or import of HFC gases. In addition to this EU-wide phasedown in the availability of HFCs, the F-Gas Regulation also imposes a number of "product bans", which apply to particular gases and applications. In 2015, all HFCs with GWP greater than 150 were banned for foam use in domestic appliances. By 1 January, 2023 all HFCs with GWP greater than 150 will cease being used in all foam manufacturing.

The F-Gas Regulation operates on the supply side through a quota system. In 2018, only 62.5% of the baseline was available for allocation through quota which is now significantly impacting supply of blowing agents to the foam sector since much of the quota has been

[8] https://www.cadc.uscourts.gov/internet/opinions.nsf/3EDC3D4817D618CF8525817600508EF4/$file/15-1328-1687707.pdf

[9] https://www.epa.gov/snap/snap-regulations#other

supplied as refrigerants. This market access restriction has happened well before the phase-out dates noted above. As a result, low GWP foams are now commercial in significant quantities.

The production, import and export of HFOs/HCFOs above 100 tonnes of carbon dioxide equivalent (CO_2-eq) needs to be reported. Entities placing products and equipment on the EU market containing HFO/HCFO in quantities exceeding 500 tonnes of CO_2-eq over a year also need to report those uses, unless the gases were bought on the EU market or imported as bulk.

In **Denmark.** HFOs/HCFOs are covered by the same laws as HFCs and therefore, in theory, are banned. However, amendment to the law allows producers/importers to ask for exemption, based on the low-GWP value of HFO and their benefit in energy efficiency,

In **Japan**, a voluntary target on HFC phasedown was set based on “the Act on Rational Use and Proper Management of Fluorocarbons”, which itself entered into force in April 2015. As the result of the 2015 Paris Agreement, additional voluntary targets for the HFC phaseout programme for all applications of rigid polyurethane foam are required. HFOs/HCFOs have been used commercially for various rigid foam applications since mid-2015. In December 2017, the Japan Urethane Foam Association published the voluntary “Non-F-gas Declaration” that require HFCs to be replaced with low-GWP blowing agents by 2020 for polyurethane spray foam used in residential buildings.

2.3.2 Regulations Impacting Extruded Polystyrene

Regulations affecting the use of blowing agents in extruded polystyrene (XPS) have driven the point of sale replacement of HFC-134a foams by low GWP alternatives in the EU due to the reduction in allocation of F-gases and will drive the transition in Canada by 1 January, 2021. Manufacturing conversion will completely remove higher GWP HFCs in early 2019 from the supply chain in Europe. Blends of carbon dioxide ($CO_{2,}$), hydrocarbon (HCs)s, dimethyl ether (DME), and HFOs/HCFOs have been commercialized as replacements for HFCs in Europe. HFO-1234ze (E) is currently only available from a single supplier and may have higher costs when used as a pure, unblended replacement for HFC-134a. Consequently, HFO/HCFO blends are being tested and have been commercialized by some companies as a lower cost option with similar performance characteristics compared to foams containing HFC-134a.

Code changes in Japan may require another transition for XPS producers to meet new thermal requirements (Class 3 requirements). Some conversion from HCs to HFO-1234ze (E) and/or HCFO-1233zd (E)/hydrocarbon (HC) blends have been commercialized to meet these new thermal requirements.

Some A5 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 still used because of 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. Even though HFC-134a has low solubility in foam systems, it is often used as the main blowing agent in XPS foams to achieve better thermal performance. Blends with the aforementioned alternatives are used to better balance XPS foam performance. HFOs/HCFO’s are being evaluated either individually or in blends as a replacement for HFC-134a.

2.4 Status of Blowing Agents in Current Use

In some A5 parties, HCFC-141b is still a widely used blowing agent for rigid foams, although its use is declining. In some cases, import of HCFC-141b itself is restricted or under license, but polyols containing HCFC-141b can be imported without restriction creating a difficulty for verification of HPMP compliance. Some parties have enacted or are developing regulations that would prevent the import of polyol systems containing HCFCs. Transition away from HCFCs is occurring, and it may be possible for some remaining foam manufacturers to transition directly to a low GWP alternative.

In India and many parts of Asia, small and medium-sized enterprises (SMEs) form the largest number of HCFC-141b consumers, and the commercially available HFOs/HCFOs may be the best technical option for phase-out of HCFCs because they are non-flammable[10], but they are more expensive than HCFCs. Demonstration projects are needed to develop methods to reduce the amount of HFOs/HCFOs needed in foams (loading) and costs through blending with other blowing agents or by other means which could slow these transitions Lessons learned from cost-reduction efforts in non-A5 parties may address some of these concerns.

HCFC-142b in combination with HCFC-22 is predominantly used in XPS production especially in thousands of SMEs in Asian parties. China has proposed a direct phase out of HCFCs to CO_2 based formulations. There can be technical difficulties associated with the implementation of this technology including poor processability of these formulations, limited machine design, and the inherent challenge of using high levels of recycled foams from multiple sources that may contain different blowing agents. The implementation of this technology may be a significant challenge for such diverse, installed equipment within the phase down deadlines.

High-GWP HFCs are still widely used in non-A5 parties in specific foam types especially in North America. For example, HFC-134a is often blended with HFC-152a to enhance product properties as an alternative to HCFC-142b/HCFC-22 blends in XPS foams. HFC-152a enhances physical characteristics of certain foams and has high solubility in XPS foam, enabling the molecules to diffuse out of the foam matrix very quickly. HFC-134a has lower solubility in XPS foams and a lower diffusion rate, which means that it provides consistent, long-term thermal performance. Finding an economically viable alternative to HFC-134a for use in polystyrene foam remains a challenge with installed equipment especially for SMEs in A5 parties.

Another example is the HFC-134a that is sometimes used with HFC-245fa in low pressure PU spray applied and pour-in-place insulation foam. These two blowing agents work together to form a froth during spray application which helps reduce foam leakage from loosely fitting structures or moulds and serves to help expel the system from the dispensing container. The use of HFCs are due to be phased out in many non-A5 parties by 2022. In addition, producers in A5 parties may need to transition to these chemicals, or to blends containing these chemicals, in order to meet HCFC phase-out targets.

Hydrocarbons (HCs) are one of the most widely used blowing agents for a number of types of insulating foams globally and will continue to be a major replacement for HCFCs and

[10] Currently commercial HFO/HCFO blowing agents are considered non-flammable by ASTM test method E-681, ASTM D1310-86, ASTMD-3828-97 (no flashpoint). At least one company treats HFO-1234ze(E) as a flammable product using safety precautions because of the humidity and temperatures of their operation which differ from the temperature and humidity conditions required in the test procedures

HFCs in the future (e.g. in appliances and insulating boards). Large- and medium-sized foam producers, in many countries, have installed safety equipment and are consequently able to safely handle flammable materials. In some countries and regions, local regulations limit the use of HCs or require additional safety and emission abatement equipment because they are flammable and are also volatile organic compounds with the potential to create ground level ozone or smog. Pentanes are considered to offer a low incremental operating cost alternative to HFCs and HCFCs in polyurethane foams. HCs and HFOs/HCFOs are blended to optimize cost and foam properties especially energy efficiency.

However, converting SMEs (often located in urban areas) over to HCs, will require additional capital for safety equipment and training. Also, hydrocarbons are not used in some foam applications, in particular spray foam, due to the application method. In these cases, non-flammable alternatives, including HFO/HCFO options or CO_2 (water) are used.

Methyl formate use as a low-GWP blowing agent is slowly increasing around the world in pour-in-place applications. It has been noted that methyl formate has been used in integral skin and other foams in some A5 parties. A project is ongoing in Mexico evaluating methyl formate and methyl formate blends for spray foam and analysing flammability of pre-blended polyols containing methyl formate. There is also ongoing testing of blends of methyl formate with HFO/HCFOs in a variety of foam types.

CO_2 (Water) blown foam is used for applications where insulation requirements are less critical. CO_2 (Water) blown foam usage is growing in applications where fluorocarbons have traditionally been used in (e.g., spray foams, pipe insulation, portable coolers, water heater insulation). Physical properties of foams are an important consideration in this development.

HFOs/HCFOs provide an alternative to HCs which can eliminate or reduce the flammability for polyurethane, polyisocyanurate, phenolic, and extruded thermoplastic foam production eliminating the capital investment required to address safety when using HCs as a blowing agent. In addition, the use of HFOs/HCFOs often result in improved foam insulating values compared to HC blown foams. There have been significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations enabling the successful commercialization of foams containing low GWP blowing agents. The transition to HFOs/HCFOs amongst polyurethane foam SMEs is challenged by their greater expense and limited, but improving, supply of some HFO/HCFOs in A5 parties. HFO/HCFOs are commercially blended with other blowing agents to reduce costs in both A5 and non-A5 parties.

Manufacturers of HFO/HCFOs have current capacity and have also announced plans to increase manufacturing capacity to meet the demand for low GWP blowing agents that is expected to result from the implementation of low GWP regulations. A new HFO/HCFO plant can take 18 months to several years to achieve business planning consent, construct and reach full production rates. The timing of regulations for HFCs in non-A5 parties has enabled the planning of HFO/HCFO manufacturing capacity to meet demand. Continued coordination could be helpful to ensure that there is adequate supply as regulations are implemented.

The demand for HFOs/HCFOs will be influenced by the formulations that are developed. Significant work is on-going by system houses to reduce HFO/HCFO loading in final foam products. Preliminary results obtained within the framework of a Multilateral Fund demonstration project on discontinuous panels in A5 parties have shown the possibility of developing 40 to 60% HFO/HCFOs reduced formulations with a promising improvement of the cost/performance balance. The complete report will be ready later this year.

At least two additional HFO/HCFOs are under development in US and Japan. Additional information about their performance will likely be available later this year.

Other Blowing Agents and Co-blowing Agents continue to be used in small quantities. There are no significant updates since the 2017 Progress Report.

2.5 Conclusion

There have been significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations enabling the successful commercialization of foams containing low-GWP blowing agents. The foam industry continues to optimise costs and performance parameters determined by national and regional agencies concerned with improving energy efficiency.

3 Halons TOC (HTOC) Progress Report

Executive Summary

HTOC is of the opinion that although research to identify potential new fire protection agents continues, it could be 5 to 10 years before a viable agent will have a significant application in the fire protection sector.

The HTOC is engaged with the Refrigeration, Air Conditioning and Heat Pump Technical Options Committee (RTOC) and the general industry on the issue of flammability of refrigerants.

In response to Decision XXIX/8, the International Civil Aviation Organization (ICAO) has formed an informal working group, including an HTOC co-chair and a TEAP co-chair, to determine the uses and emissions of halon 1301 within civil aviation fire protection systems.

Civil aviation appears to be on schedule to meet the ICAO requirement to use only halon alternative agents for all hand-held extinguishers on new production aircraft after 31 December 2018 to replace halon 1211. The agent is 2-bromo-3,3,3-trifluoro-prop-1-ene (2-BTP).

The HTOC has also re-engaged with the International Maritime Organization (IMO). This will enable HTOC to update the Decision XXVI/7 report on future availability of halons by assessing the quantity of halons installed on merchant ships and the quantity and quality of halons being recovered from ship breaking activities. The Parties may wish to consider if a more formal relationship, such as developing a joint Memorandum of Understanding (MOU) between the Ozone Secretariat and the IMO to formalize this and other ozone related activities is worth pursuing.

3.1 2018 Meeting

The HTOC met from 20-22 March, 2018, in London, United Kingdom at IMO Headquarters. Attending members were from Australia, Brazil, Canada, Denmark, Egypt, India, Japan, Kuwait, Russia, Sweden, the United Kingdom, and the United States of America.

3.2 Possible Change of HTOC Name

Following the Kigali amendment, the role of the HTOC is now broader than just assessing technical options to halons, as options to high GWP HFCs need to be considered as well. During its 2018 meeting, the HTOC discussed at length whether its name needed to be changed to better represent this increased scope. Several options were discussed: The Fire Protection TOC (FPTOC) the Clean Agent TOC, the Fire Extinguishing Agent TOC and several others. The name Fire Protection TOC was not favoured as the HTOC felt that this was too broad.[1] During the discussion there was also a rather strong view that the HTOC is somewhat of a brand; people throughout the fire protection and environmental communities know the term HTOC and know what it does. There was a concern that changing its name would reduce or dilute its recognition. Therefore, it is desirable to retain the acronym HTOC, and the HTOC is considering requesting the Parties to consider retaining the acronym HTOC

[1] Strictly speaking the term fire protection covers much more than fire extinguishing or fire suppression using gaseous agents. However when used in the context of TEAP, TSB and HTOC reports, the terms fire protection, fire suppression and fire extinguishment are not meant to convey different meanings and therefore are considered to be synonymous and interchangeable.

but changing its full name to the "Halons and Other [Gaseous] Fire Extinguishing Agents" or "Halogenated Fire Extinguishing Agents" TOC. There are precedents for this in that the Refrigeration, Air Conditioning & Heat Pump Technical Options Committee is referred to as the RTOC and the Flexible and Rigid Foam TOC is referred to as the FTOC.

3.3 Halon Replacement Agents

Since the withdrawal of HCFO-1233zd(E) for consideration as a total flooding alternative fire protection agent as a potential replacement for halon 1301, HFC-227ea, HFC-125 or HFC-23 last year, no further progress on potential alternatives has been reported. The HTOC is of the opinion that although research to identify potential new fire protection agents continues, depending on where a possible alternative is in the development process, it could take five to ten years before a viable agent could possibly have significant impact on the fire protection sector. This timescale is consistent with the 2005 assessment in the Fire Protection Chapter (Chapter 9) of the Intergovernmental Panel on Climate Change (IPCC) / TEAP Special Report (IPCC TEAP, 2005) that due to the lengthy process of testing, approval / certification and market acceptance of new fire protection equipment types and agents, no additional agents were likely to be available in time to have appreciable impact by 2015 (i.e., ten years in the future at the time of writing). This is also broadly consistent with the 2015 recommendation of the civil aviation working group on cargo bay halon alternatives, that the earliest possible date to set a mandate for non-halon systems in new aircraft designs was 2024 (i.e., nine years in the future when the recommendation was made). However, there is also no assurance that any additional viable agents will be introduced at that time since the most promising chemical groups have already been thoroughly evaluated.

3.4 Civil Aviation

In March 2018, an HTOC co-chair, a TEAP co-chair and the International Civil Aviation Organization (ICAO) Secretariat met with industry partners and civil aviation Non-Governmental Organizations (NGOs). It was decided that the ICAO would form an informal working group to determine the current and projected future quantities of halon installed in civil aviation fire protection systems, the associated uses and releases of halon from those systems and any potential courses of action to minimize unnecessary halon emissions as requested by Decision XXIX/8: Future availability of halons and their alternatives. The working group initially consists of representatives from airframe manufacturers Boeing, Airbus and Bombardier, civil aviation fire protection cylinder manufacturers Meggitt and United Technologies, the civil aviation non-governmental organizations the International Air Transport Association (IATA) and the International Coordinating Council of Aerospace Industry Associations (ICC AIA), the ICAO secretariat, and an HTOC, and TEAP co-chair. The working group has prepared a survey that ICAO has agreed to send officially as an ICAO State Letter to all of the States with civil aviation halon 1301 service providers. The results of the survey will provide a more accurate estimate of the annual amount of halon 1301 emitted in civil aviation worldwide. The timetable agreed by ICAO and HTOC has been set to meet the Decision XXIX/8 deadlines to report back to the 30th Meeting of the Parties of the Montreal Protocol and to the 40th ICAO General Assembly in 2020.

In addition, the HTOC has re-engaged with the IMO to update the potential amount and quality of halon 1301 that could be recovered from ship breaking activities. The Parties may wish to consider if a more formal relationship, such as developing a joint Memorandum of Understanding (MOU) between the Ozone Secretariat and the IMO to formalize this and other ozone related activities is worth pursuing.

The updated information from ICAO and IMO will be used to re-assess the potential quantities of halon 1301 that could become available to support civil aviation and to update the analysis originally provided in the Decision XXVI/7 report

The halon 1211 alternative, 2-bromo-3,3,3-trifluoro-prop-1-ene (2-BTP), has been certified for use in portable extinguishers used in civil aviation applications, meaning that this sector is on course to meet the ICAO requirement to use only halon alternative agents for all hand-held extinguishers on new production aircraft after 31 December 2018 to replace halon 1211.

3.5 Refrigerant Safety Standards

The HTOC is working with the RTOC and the overall refrigerant sector on the issues of flammability of the latest generation of refrigerants. The HTOC continues to express concern with the potential under-assessment of the inherent risks associated with refrigerants that are assessed as non-flammable or lower flammability under typical tests used to assess flammability of refrigerants but exhibit actual flammability when assessed using other methods or in practice.

3.6 Reference

IPCC TEAP, 2005: IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues related to Hydrofluorocarbons and Perfluorocarbons. Prepared by Working Group I and III of the Intergovernmental Panel on Climate Change and the Technology and Economic Assessment Panel under the Montreal Protocol (Metz, B., L. Kuijpers, S. Solomon, S.O. Andersen, O. Davidson, J. Pons, D. de Jager, T. Kestin, M. Manning, and L.A. Meyer (editors), available at https://www.ipcc.ch/report/sroc/

4 Methyl Bromide TOC (MBTOC) Progress Report

Executive Summary

The 2018 MBTOC Progress Report provides an overview on the production, consumption of methyl bromide (MB) for both controlled and exempted (quarantine and pre-shipment (QPS)) uses, and on recent developments with MB alternatives particularly for sectors for which critical uses have been nominated this year for 2019 or 2020 use.

MB phaseout for reported controlled uses is almost complete. The original global baseline for controlled consumption of MB for was about 72,000 tonnes. A5 Parties have critical use requests for less than 1% of the A5 baseline for controlled consumption of MB.

MBTOC is aware of continuing discrepancy (in the thousands of tonnes) between top-down and bottom-up comparisons of emissions and reported production/consumption. MBTOC estimates that 15-20,000 tonnes of MB might still be being used annually. This consists of unreported consumption for controlled use in A5 Parties, use in QPS (up to half of which is avoidable), and possible illegal trade. This is supported by the gap between emissions vs production/consumption data.

The volume of MB in remaining controlled uses of MB is now small, with a combined total being sought by parties in 2018 in A5 and non-A5 parties of less than 150 t. A wide range of non-chemical and chemical fumigant options, and technologies which avoid MB, are being successfully adopted to continue phase out of MB. Phase-out for the remaining methyl bromide critical uses will be greatly influenced by the registration of sulfuryl fluoride and methyl iodide, the use of some non-chemical options like soil-less culture and by consideration of specific Integrated Pest Management schemes.

Under Article 7:

- The reported consumption provided for controlled uses amounted to 554.3 metric tonnes in 2016.
- Total reported production for controlled uses in 2016 in China, Israel and US, amounted to 900 metric tonnes, almost double the controlled consumption.
- Since 2005, reporting by parties demonstrates a cumulative gap between consumption and production of about 8,200 MB produced for controlled uses.

MBTOC estimates that up to 2000 tonnes of MB are being used by A5 parties from pre-2015 stocks for critical use sectors (e.g. strawberries), but are not seeking exemptions, and therefore avoid the need for reporting.

MBTOC believes that use of large amounts of MB (many thousands of tonnes) may be unreported for controlled uses as a result of illegal trade in some regions.

MBTOC estimates that 31-47% of current use for QPS could be replaced immediately with available alternatives.

Action on the large and largely avoidable remaining uses of MB would be the most certain measure to have an early impact on ozone layer recovery.

4.1 Global MB production and consumption

In 2016, the reported consumption provided under Article 7 for controlled uses amounted to 554.3 metric tonnes or less than 1% of the global baseline, which was about 56,000 tonnes for non-A5 and 16,000 tonnes for A5 parties. Phase-out of remaining controlled uses of MB has continued under the Critical Use Exemption, in both A5 and non-A5 parties. This reflects successful development and adoption of alternatives in the vast majority of sectors where MB was once used, both as a soil fumigant and as postharvest or structural treatment, however challenges remain, particularly in certain critical use sectors.

MB use for pre-plant and postharvest uses (excluding QPS and feedstock uses) has reportedly been replaced with alternatives (or re-categorised to QPS by one Party). In some A5 parties, stocks prior to 2015 may be being used for potential critical use sectors. MBTOC estimates this use at around 2000 tonnes.

MBTOC is aware of continuing discrepancy (in the thousands of tonnes) between top-down and bottom-up comparisons of emissions and reported production/consumption.

By the end of 2016 (the most recent date for which officially reported data is available) controlled uses (in addition to any stocks used) in A5 parties amounted to 377.5 metric tonnes and in non-A5 parties to 176.8 metric tonnes, all of which were granted under the Critical Use Exemption by the Meeting of the Parties.

Production for controlled uses presently takes place in only three countries: China, Israel and the United States. Total reported production in 2016 amounted to 900 metric tonnes, almost double the controlled consumption. Since 2005 reporting by parties under article 7 has shown that about 8,270 t of MB produced have not been shown as consumption.

Total world production of MB for QPS amounted to about 8,715 metric tonnes in 2016. Five parties, two A5s (China, India) and three non-A5s (US, Israel and Japan) presently produce MB for QPS. In the same year, reported global consumption for QPS was lower than production for that purpose, amounting to 8,370 metric tonnes.

Information on consumption and production of MB for QPS purposes (presently exempted under the Protocol) has become more complete since 2015, when India updated production information.

4.2 Update on alternatives for remaining critical uses

As stated above, technically and economically feasible chemical and non-chemical alternatives to MB have been found for virtually all soils, structural and commodity applications for which MB was used in the past with comprehensive information available for these uses.

MBTOC considers that in spite of active research and some promising results of late, progress in phasing out certain critical uses, such as for strawberry runners and to control some soil borne pathogens such as false root-knot nematode (*Nacobbus aberrans)* on tomato, has been slow, mainly due to difficulties in identifying technically economically feasible alternatives and regulatory issues.

Some A5 parties have provided limited research data from trials within their own country for the specific circumstances of the nomination and this is making assessment of critical use exemptions difficult. The assessment is reliant on other published information from other countries where it exists.

4.2.1 Alternatives for remaining CUNs in the soil sector

4.2.1.1 False root knot nematode of tomato

False root- knot nematode (*Nacobbus aberrans)* is a key reason for the need for a critical use application from Argentina as it is difficult to control in protected cultivation of tomato (i.e. in plastic greenhouses) in Argentina, where it causes severe damage. This nematode, has a very wide host range and variable behaviour between populations (Costilla, 1990; Doucet and Gardenal 1992; Boluarte and Jatala 1999; Lax *et al*., 2011), plus several pathotypes have been reported (Lax *et al*., 2011). These factors led to methyl bromide treatment in the past and critical use nominations after 2015 in Argentina only. Detailed information on this CUN can be found in MBTOC's interim CUN evaluation report (volume 4 of the TEAP report).

No commercial tomato cultivars with full resistance to *N. aberrans* are yet available, but recent research is showing encouraging results (Lax *et al*., 2016), particularly by use of grafted tomato cultivars on resistant rootstocks (Martínez, 2013; Bucco and Berardo, 2017) .

An Integrated Management Program to control *Naccobus* was developed by Cristobal-Alejo *et al*., (2006) in Mexico, comprising fertilization, nematicide applications (ethoprop) and biofumigation with chicken manure. Mycorrhizae have recently been shown to reduce the penetration capability of *N. aberrans* into tomato roots (Marro *et al*, 2018), possibly adding a biocontrol tool to the integrated management approach.

Recently, Hidalgo *et al.* (2015) reported significant reduction of population density, reproduction rate, and root galling of *N. aberrans* in tomato crops with fluensulfone (Nimitz®) a contact nematicide. Fluensulfone, which poses less risk to human health and the environment than fumigants, is potentially a good alternative to MB for tomato and cucumber crops affected by *N. aberrans*. When combined with Pic-Clor 60 (Pic + 1,3-D), this nematicide showed lower galling index as compared to Pic-Clor 60 alone (Castillo *et al.*, 2016; Gilma *et al*, 2017).

4.2.1.2 Alternatives for strawberry runner production

Two parties are requesting MB for critical use of MB for strawberry runners. Detailed information on this CUN can be found in MBTOC's interim CUN evaluation report (volume 4 of the TEAP report). In the past, many strawberry runner nurseries around the world relied on MB soil fumigation to produce disease-free transplants, however most have phased-out this fumigant by avoiding the need for MB by use of soilless substrate production or successfully implementing alternatives chemical compounds (metham sodium (spading), 1,3 D and/or 1,3 D + Chloropicrin, Dazomet) (García-Sinovas *et al*., 2014; López-Aranda, 2016). and in some cases, including non-chemical options such cover/catch crops, soil solarisation, anaerobic soil disinfestation (ASD), crop rotation.

In some countries, certification schemes are in place which restrict implementation and adoption of alternatives, making MB use under the CUE still necessary. One party (US) has classified this use, together with other nursery production, under the QPS exemption.

Production in substrates has been adopted by many countries for at least a proportion of the runner production and has also given promising results for strawberry runners in Australia, at least for some stages of the production process. Although cost constraints exist, soilless culture is emerging as a suitable alternative in the remaining two nominations from non-A5 parties (Australia and Canada) particularly when combined with an integrated approach including alternative fumigants and herbicides (Mattner *et al*, 2017; Milinkovic *et al*, 2017).

4.2.2 Alternatives for remaining critical uses in the structures and commodities sector

Only one Party (Republic of South Africa, RSA) is still requesting a CUE for further use of MB for pest control in empty grain mills and wood buildings (dwellings, churches).

Chemical alternatives for the nominated uses, e.g. sulfuryl fluoride (SF), ethylene dinitrile (EDN), HCN are in use in many countries. South Africa has recently announced registration of SF, and it is anticipated that this will contribute to phasing out MB. MBTOC nevertheless notes that this fumigant has a very high GWP and encourages the party to look at non-chemical options, such as heat.

Biological control, is increasingly considered as a feasible alternative for commodity treatments. Commercial scale trials have demonstrated the effectiveness of the release of parasitoids in combination with mating disruption for the control of moths in food processing facilities (Trematerra *et al*., 2017, Riudavets, 2018).

4.3 MB use for QPS purposes

As stated in previous sections, QPS is by far the main use of MB and as nearly all the MB used for QPS is emitted to the atmosphere and MB has a very short half-life (0.7 years), it is the major contributor to the remaining methyl bromide in the stratosphere. Increase in use for QPS has the potential to offset the benefits gained by phasing out MB for controlled uses.

Despite the ability of recapture systems being available for MB they are not widely adopted as they are presently uneconomical compared to venting directly to the atmosphere or impractical for all uses. Recapture systems however are being implemented due to other environmental and human safety concerns outside of Montreal Protocol regulations. For example, the New Zealand Environmental Protection Agency requires mandatory recapture or destruction of all available methyl bromide left in the enclosures after QPS fumigation from October 2020. Four ports in NZ have implemented recapture prior to this date including a major log export port where large quantities of emissions from under cover fumigations are being recaptured via a liquid scrubber.

Recapture from ship holds is still under development. Smaller recapture units utilizing activated carbon are being used for shipping container recapture.

Parties to the Montreal Protocol are encouraged to minimize and replace MB for QPS whenever possible. Considering that MBTOC has identified opportunity for replacing between 30 and 40% of QPS uses with immediately available alternatives, it is suggested that parties may wish to consider controlling QPS uses to any extent possible.

Chemical alternatives currently under research in the QPS sector include Ethyl Formate (EF) alone or combined with Phosphine, CO_2 or N_2 (Yang *et al.* 2016; Jamieson *et al.* 2016; Grout and Stoltz, 2016), Ethanedinitrile (EDN) (Pranamornkith *et al.* 2014; Park *et al.* 2014; Bong-Su *et al*. 2015).

Promising non-chemical alternatives include irradiation (Hallman 2016), heat and cold treatment, bark removal and vacuum/ controlled atmospheres (UNEP, 2016).

4.4 International Plant Protection Convention (IPPC)

On the basis of a Memorandum of Understanding (MOU) subscribed between the International Plant Protection Convention (IPPC) and the Ozone Secretariat, MBTOC maintains regular communication with relevant bodies of IPPC dealing with phytosanitary measures and standards where MB is of interest.

During the 13th Session of Commission on Phytosanitary Measure (CPM-13) held from 16 to 20 April 2018 in Rome, Italy, a revision to ISPM (International Standard for Phytosanitary Measure) No. 15 dealing with treatment of wood packaging materials was adopted. Valid treatments under ISPM No. 15 are presently limited to either MB fumigation or heat (including microwaves), but a revision is expected to include other options, namely sulfuryl fluoride.

4.5 Remaining challenges

- Some parties continue to express concerns over difficulties in interpreting the categories of MB uses between controlled and exempted uses.
- MBTOC has indicated that there may be a discrepancy of around 15,000 tonnes between top down and bottom up comparisons of emissions and production/consumption. Addressing this discrepancy could have early benefit for the ozone layer.
- Parties may wish to investigate this discrepancy and improving mechanisms of reporting for both production and consumption, would be important. For example, parties may wish to invite all parties to report on stocks of MB, irrespective of whether they are applying for CUNs or not.

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5 Medical and Chemicals TOC (MCTOC) Progress Report

Executive Summary

The global transition away from chlorofluorocarbon (CFC) metered-dose inhalers (MDIs) is complete. CFCs are no longer being used to manufacture MDIs. Around 2,500 tonnes or less of HCFCs are used to manufacture medical aerosols.

MCTOC reviewed the information submitted by parties in relation to their use of controlled substances under exemptions as process agents, and the consumption/make-up and emissions for those uses. Based on the information reported, parties may wish to consider the recommended changes to Table A of Decision XXIX/7 and Table B of Decision XXII/7.

Based on Article 7 data reported by parties, total production of controlled substances (ozone-depleting substances (ODS)) for feedstock and process agent uses was 1,189,536 tonnes in 2016. Estimated associated emissions can be calculated as 5,948 tonnes, or 2,194 ODP tonnes.

The use of HCFC-141b and HCFC-225 for solvent cleaning in non-A5 parties has been phased out, with the exception of aerospace and military applications. In A5 parties, HCFC use for solvent cleaning has declined and will continue to reduce further. There is a reported solvent use of HCFC-225 for syringe/needle coating in Japan. HCFC-141b is used for this purpose in A5 parties. Several manufacturing processes use HCFCs as solvents in processes that might be considered similar to process agent uses.

In 2017, China announced its commitment to phase out the use of carbon tetrachloride (CTC) for the testing of oil in water by 2019 and, accordingly, no essential use nomination for this laboratory and analytical use was received. In response to decision XXVI/5(2) on laboratory and analytical uses, MCTOC plans to report in time for the 30th MOP. Information is currently being collected about ODS uses of laboratory and analytical uses, and possible alternatives. For analytical procedures, investigations are proving to be challenging.

5.1 Metered dose inhalers

The global transition away from chlorofluorocarbon (CFC) metered-dose inhalers (MDIs) is complete. CFCs are no longer being used to manufacture MDIs. No CFCs have been produced for MDI manufacture since 2014. About 11,000 tonnes of HFCs were used to manufacture MDIs in 2017.

Proprietary alternatives in development and on the market have continued to diversify and multiply, and companies are investing in their own unique delivery technologies. Nevertheless, the MDI remains a mainstay of inhaled therapy.

Alternate propellants with lower GWP than the currently used propellants, HFC-134a and -227ea, are being considered for MDIs. Research and development for any new therapeutic inhalational product is a lengthy and resource-intensive process, especially when this involves a propellant not previously used in an inhalational medicine. One chemical company has recently reported research and development to investigate HFC-152a as a possible MDI propellant, with initial toxicology studies completed and MDI formulation studies underway. Another chemical company has also started research and development to investigate HFO-1234ze as a possible propellant for use in MDIs. A pharmaceutical company has submitted an application for approval to the Argentinian regulatory agency (ANMAT) for a salbutamol isobutane MDI.

More information on these and other developments in inhaled therapy will be reported in the 2018 MCTOC Assessment Report later this year.

5.2 Medical Aerosols

Available information indicates that HCFC use in China for medical aerosols for Traditional Chinese Medicines could be about 2,000-2,500 tonnes HFCF-22 or HCFC-22/HCFC-141b blend (HCFC-22: 1,500-2,000 tonnes and HCFC-141b: 500 tonnes). Flammability safety concerns with some economically feasible alternatives, such as DME or LPG, are currently a barrier to their use in this application. Other potential technical alternatives, such as HFC-134a, currently present an economic impediment in this particular application. Around 500 tonnes HFC-134a is already used in other medical aerosols in China.

In the Russian Federation, a topical medical aerosol application also uses HCFC-22 and -141b as propellant and solvent, respectively, in quantities of around 20 tonnes per year. The product is an aerosol foam used to provide local anti-inflammatory and antiseptic action, and to stimulate healing.

5.3 Chemicals

5.3.1 Status of CTC authorised for production under EUE for laboratory and analytical uses ("testing of oil, grease and total petroleum hydrocarbons in water") in China

Decision XXIII/6 specifies that after 31 December 2014, the use of carbon tetrachloride (CTC) for the testing of oil in water would only be allowed under an essential use exemption. In accordance with this Decision, parties authorised essential use exemptions for China for 80 tonnes, 70 tonnes, 65 tonnes, and 65 tonnes of CTC for 2015, 2016, 2017, and 2018 respectively. In 2017, China announced its commitment to phase out this use by 2019 and, accordingly, no essential use nomination was received. China stated in its reporting accounting framework that it produced and used the entire 65 tonnes CTC that was authorised by parties for 2017.

The oil in water test, which is a fundamental requirement in monitoring water quality in China, observes the national standard "*HJ 637-2012 Water quality- Determination of petroleum oil, animal and vegetable oils- Infrared photometric method*", in which CTC is used as the extracting agent to extract oil substances that are then determined with the infrared oil monitoring instrument. This method is capable of testing petroleum oil, animal and vegetable oils and total petroleum hydrocarbons, including long chain petroleum hydrocarbons, fatty acids, and aromatic hydrocarbons. Over years of tests, research and analyses, the technical route to replace CTC with tetrachloroethylene (PCE) has now been determined, which required the revision of the standard *HJ 637-2012*. China has now finished its standards development and is planning to implement the new standard. China has also been promoting and implementing other non-ODS standards to replace other uses of CTC in laboratory and analytical uses.

5.3.2 Status of CFC-113 authorised for production under EUE for use as a solvent in aerospace applications

The Russian Federation was authorised an essential use exemption of 75 tonnes of CFC-113 for 2015 for solvents used in aerospace applications. In the last reporting accounting framework received from Russia, it reported that aerospace applications used 85 tonnes of CFC-113 in 2015, with 75 tonnes of CFC-113 remaining at the end of that year. The Russian Federation has reported previously that it would phase out the use of CFC-113 as a cleaning solvent in aerospace applications when its stockpile was depleted. It is also understood that Russia is recycling solvent and destroying any contaminated material.

The Russian Federation is eliminating CFC-113 by using a variety of alternative solvents and cleaning agents in its aerospace applications, including aqueous detergents, organic solvents including chlorinated solvents, and HCFC-141b (currently 20 tonnes per year, with expectation of growth). MCTOC understands that alternatives to HCFCs, including HFCs, are being considered and tested. Based on current information, HCFCs are likely to be required in the Russian Federation after the 2020 HCFC phase out date in non-Article 5 parties. Any HCFC production for these uses from 2020 onwards would need to satisfy the essential use criteria established in Decision IV/25 and be authorised by parties.

5.3.3 Decision XVII/6(7) and (8): Review of information submitted by parties on the use of controlled substances as process agents

Parties are requested under decisions X/14(4) and XVII/6 to submit information on their process agent uses as follows:

Decision X/14(4):

"*That all Parties should:*

(a) Report to the Secretariat by 30 September 2000 and each year thereafter on their use of controlled substances as process agents, the levels of emissions from those uses and the containment technologies used by them to minimize emissions of controlled substances. Those non-Article 5 Parties which have still not reported data for inclusion in tables A and B are urged to do so as soon as possible and in any case before the nineteenth meeting of the Open-Ended Working Group;

(b) In reporting annual data to the Secretariat for 2000 and each year thereafter, provide information on the quantities of controlled substances produced or imported by them for process agent applications;"

Decision XVII/6:

"To request Parties with process-agent uses to submit data to the TEAP by 31 December 2007 and 31 December of each subsequent year on opportunities to reduce emissions listed in table B…"

Parties were also requested under decision XXIX/7(2) to submit information on process agents, in relation to a report from TEAP requested in time for the 41st Open-ended Working Group Meeting, as follows:

"*To urge parties to update their information on the use of controlled substances as process agents and to provide the Secretariat, by 31 December 2017, with information on the implementation and development of emissions reduction techniques;*"

China, the European Union, Israel, and the United States submitted information about their process agent uses for the year 2016, in accordance with decisions X/14(4) and XVII/6, and China, the European Union and the United States submitted information in relation to decision XXIX/7(2).

Parties have requested TEAP to review the information submitted by parties under decisions XVII/6(7) and XVII/6(8) (with a report due this year and in every even year), and decisions XVII/6(6) and XXII/8(5) (with a report due next year and in every odd year). This report responds to decisions XVII/6(7) and XVII/6(8), which state:

Decision XVII/6(7) *"...the TEAP to review the information submitted in accordance with this decision and to report and make recommendations to the Parties at their Twentieth Meeting in 2008, and every other year thereafter, on process-agent use exemptions; on insignificant emission associated with a use, and process-agent uses that could be added to or deleted from table A of decision X/14;"*

Decision XVII/6(8) *"…and for the TEAP to review in 2008, and every other year thereafter, emissions in table B of decision X/14, taking into account information and data reported by the Parties in accordance with that decision, and to recommend any reductions to the make-up and maximum emission on the basis of that review. On the basis of these recommendations, the Parties shall decide on reductions to the make-up and maximum emissions with respect to table B."*

MCTOC has reviewed the information submitted by these parties, quantities produced or imported for process agent applications, on make-up, levels of emissions, and containment technologies to minimise emissions for those uses. Tables A and B summarise the data submitted.

Furthermore, it is noted that the reported emissions from the reported processes are considerably lower than the maximum emission limits that are given in Table B of Decision XXIII/7 (see Table B below). This can be seen as either resulting from the ceasing of use of controlled substances as process agents in certain processes, or a reduction in emissions through improvements in the processes, or a combination of both.

Table A: List of uses of controlled substances as process agents[1]

No.	Process agent application Decision XXVII/7	Substance	Permitted Parties Decision XXIII/7	Parties that reported data for 2016	Parties no longer requiring ODS for process agent application
1	Elimination of NCl_3 in chlor-alkali production	CTC	European Union, Israel, United States of America	European Union, Israel, United States of America	
2	Chlorine recovery by tail gas absorption in chlor-alkali production	CTC	European Union, United States of America	European Union, United States of America	European Union
3	Production of chlorinated rubber	CTC	European Union	European Union	
4	Production of chlorosulfonated polyolefin (CSM)	CTC	China	China	
5	Production of aramid polymer (PPTA)	CTC	European Union	European Union	
6	Production of synthetic fibre sheet	CFC-11	United States of America	United States of America	
7	Photochemical synthesis of perfluoropolyetherpolyperoxide precursors of Z-perfluoropolyethers and difunctional derivatives	CFC-12	European Union	European Union	
8	Preparation of perfluoropolyether diols with high functionality	CFC-113	European Union	European Union	European Union
9	Production of cyclodime	CTC	European Union	European Union	
10	Bromination of a styrenic polymer	BCM	United States of America	United States of America	
11	Production of high modulus polyethylene fibre	CFC-113	United States of America	United States of America	

[1] Table A was last updated in 2017 with Decision XXIX/7: Use of controlled substances as process agents. The table shows Dec. XXIX/7 Table A alongside the reported information received from parties for the year 2016.

Table B: Limits for process agent uses (in metric tonnes[2] per year)[3]

Party	**Make-up or consumption Decision XXIII/7**	**Maximum emissions Decision XXIII/7**	**Reported make-up or consumption for 2016**	**Reported emissions for 2016**
China	1,103	313	177.42	105.05
European Union	1,083	17	365.28	3.808
Israel	3.5	0	0	0.0143
United States of America	2,300	181	Not reported	[31.2 ODP tonnes]
Total	4,489.5	511	*[542.70]**	*[108.8723]**

*Nominal totals for 2016, which exclude data not reported or data reported in ODP-weighted metric tonnes.

[2] Except for the United States, which is given in ODP-weighted metric tonnes.

[3] Table B was last updated in 2011 with Decision XXIII/7: Use of controlled substances as process agents. The table shows Dec. XXIII/7 Tables B alongside the reported information received from parties for the year 2016.

Table 5.1 Data reported by parties on process agent applications on associated make-up or consumption

Party	Reported make-up or consumption (metric tonnes)							
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Brazil	0	-	-	-	-	-	-	-
China	313	179.3	179.92	179.24	88.92	178.44	179.84	177.42
Colombia	-	0.64	-	-	-	-	-	-
European Union	669	1116.231	954.42	547.178	622.101	508.741	283.313	365.28
Israel	2.4	3.3	2.1	3.6	2.4	2.4	1.8	0
Mexico	-	40.9954	-	-	-	-	-	-
United States of America	NR	NR	NR	NR	NR	NR	NR	NR
Nominal Total	984.4*	1340.4664*	1136.44*	730.018*	713.421*	689.581*	464.953*	542.70*

*Nominal totals exclude data not reported by parties, as indicated by NR.
The United States reports emissions data and does not report make-up/consumption data.

Table 5.2 Data reported by parties on process agent applications on emissions

Party	Reported emissions in metric tonnes *[ODP tonnes given in square brackets]*							
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Brazil	0	-	-	-	-	-	-	-
China	-	179.3	179.2	179.24	52.64	105.63	106.46	105.05 *[115.56]*
Colombia	-	-	-	-	-	-	-	-
European Union	1.6	1.287	116.428	27.192	15.808	7.338	6.414	3.81 *[4.15]*
Israel	0	-	-		0.000038	0.1794	0.0617	0.0143 *[0.016]*
Mexico	-	40.9954	-	-	-	-	-	-
United States of America	*[47.1]*	*[59.79]*	*[44.35]*	*[34.63]*	*[34.5]*	*[34.1]*	*[33.2]*	*[31.2]*
Total	1.6*	221.5824*	295.628*	206.432*	68.448038*	113.1474*	112.9357*	108.86* *[150.92]*

*Nominal totals in metric tonnes exclude data reported in ODP-weighted metric tonnes by the United States. This table updates a similar table presented in the 2017 TEAP Progress Report, which incorrectly attributed ODP-weighted emissions quantities reported by the United States in metric tonnes. This table also presents the 2016 data for parties other than the United States in metric tonnes and ODP-weighted tonnes for comparison purposes.

5.3.3.1 Associated make-up quantity of controlled substances

The information reported in Table 5.1 demonstrates that the total reported make-up or consumption quantities of ozone depleting substances used for the reported processes has decreased from its peak in 2010. This excludes information on make-up or consumption in the United States, which is not reported. For the parties reporting (China, the EU and Israel), there is a significant reduction in the quantities of make-up/consumption of controlled substances from the maximum quantity of make-up/consumption contained in Decision XXIII/7. These reductions could be the result of a reduction in the number of processes using ozone-depleting substances as process agents or implementation of improvements in the processes.

5.3.3.2 Progress made in reducing emissions from process-agent uses

The information reported in Table 5.2 demonstrates that the quantities of ozone depleting substances emitted from the reported processes have stabilised over the past two years and have decreased significantly from the maximum quantity of emissions contained in Decision XXIII/7. These reductions could be the result of a reduction in the number of processes using ozone-depleting substances as process agents or/and implementation of improvements in the processes to further reduce emissions.

5.3.3.3 Implementation and development of emissions-reduction techniques

Israel has noted in its submission that it uses compression and purification systems obtained from Krebs Swiss and has continuous chlorine analysers that activate the safety interlockers system when the chlorine concentration in the air is 0.5 ppmv.

The United States has provided a list of containment technologies that are used to minimise emissions of controlled substances. These are as follows: continuous air monitoring of stacks; fugitive emission monitoring and repair; vent emission recycling back into process; bio-treatment and carbon bed filtration; stack gas sent to vent incineration; nitrogen used to clear the transfer lines; used material sent to THROX incineration unit; solvent recovery system; carbon absorption system; wastewater treatment system; emergency discharge system routed through a blow-down collection tank; air sweep to a carbon absorption system from suspected leak areas; redundant process controls to minimize mis-operation; full system drainage and vapour purge prior to maintenance; refrigerated vent condensers to minimize BCM emissions; multi-disciplined conservation team overseeing leak detection technology and process optimization; mechanical seal pumps replaced by seal-less pumps for CTC transfer lines; compressor suction automation valves and heat exchangers to improve recovery control; recycling and recovery operations to maximize material re-use; internal mechanisms for rapid-response to threshold shifts in daily emission values.

5.3.3.4 Alternative processes and products not using ODS

The European Union provided information on its process agent applications and the availability of alternatives. It reported that a company has introduced a process to remove the ammonium impurity using NaClO, putting an end to the use of CTC for the elimination of nitrogen trichloride in the production of chlorine and caustic soda at one production unit in France. It has also noted that the use of CTC in the recovery of chlorine in tail gas from the production of chlorine has been eliminated through the introduction of gas burners, through which the tail gas circulates. Work is also underway to eliminate the use of CFC-12 in the photochemical synthesis of perfluoropolyetherpolyperoxide precursors of Z-perfluoropolyethers and di-functional derivatives within the European Union, and HFE-7100 has replaced the use of CFC-113 in the preparation of perfluoropolyether diols with high functionality.

5.3.3.5 Recommendations on process agents

In response to the decisions XVII/6(7) and XVII/6(8), the TEAP has prepared the following recommendations.

Based on the information reported, parties may wish to consider:

- Removing the following process agent uses from Table A of Decision XXIX/7:
  - Use of CFC-113 in the preparation of perfluoropolyether diols with high functionality; and
- Updating and removing previously permitted uses of controlled substances as process agents in certain parties from Table A of Decision XXIX/7:
  - European Union for chlorine recovery by tail gas absorption in chlor-alkali production;

Parties may also wish to consider reducing the quantities of make-up/consumption and maximum emission levels contained in Table B of decision XXIII/7 to take into account the currently reported process agent uses and emissions.

5.3.4 Decision XVII/6(4): Assessment of any new plant using controlled substances as process agents

Decision XVII/6(4) states, "*Where Parties install or commission new plant after 30 June 1999, using controlled substances as process agents, to request Parties to submit their applications to the Ozone Secretariat and the TEAP by 31 December 2006, and by 31 December every subsequent year or otherwise in a timely manner that allows the TEAP to conduct an appropriate analysis, for consideration subject to the criteria for essential uses under decision IV/25, in accordance with paragraph 7 of decision X/14;*"

No applications were submitted under this decision for TEAP assessment.

5.3.5 Use of controlled substances for chemical feedstock

ODS feedstocks are chemical building blocks that allow the cost-effective commercial synthesis of other chemicals. The use of ODS, such as CTC, 1,1,1-trichloroethane (TCA) (also referred to as methyl chloroform), CFCs, HCFCs and several others, as feedstock allows incorporation of chlorine and fluorine atoms into molecular structures. The resulting products find important uses such as refrigerants, blowing agents, solvents, polymers, pharmaceuticals and agricultural chemicals. Emissions from feedstock use consist of residual levels in the ultimate products and fugitive leaks during production, storage and/or transport processes.

Feedstock is selected by commercial producers to be the most technologically and economically viable at the time to yield the final products. These facilities can require large initial capital investments over US$100 million, not including the supporting and required infrastructure. Properly designed and maintained chemical manufacturing facilities using ODS feedstock can operate for as long as 50 years.

The Montreal Protocol specifies those ODS that are controlled substances, including those that are also used for chemical feedstock, according to Article 1, clause 4, which states: *" "Controlled substance" means a substance in Annex A, Annex B, Annex C or Annex E to this Protocol, whether existing alone or in a mixture. It includes the isomers of any such substance, except as specified in the relevant Annex, but excludes any controlled substance or mixture which is in a manufactured product other than a container used for the transportation or storage of that substance."*

The definition of production under the Montreal Protocol excludes the amount of controlled substances used as feedstock, according to Article 1, clause 5: *"Production means the amount of controlled substances produced, minus the amount destroyed by technologies to be approved by the Parties and minus the amount entirely used as feedstock in the manufacture of other chemicals. The amount recycled and reused is not to be considered as Production."*

5.3.5.1 How the ODS feedstock is used

When used as feedstock, ODS are fed directly into the process as a raw material stream or as an intermediate in the synthesis of another product. Emissive losses can occur during production, storage, transport, if necessary, and transfers. Intermediates are normally stored and used at the same site thereby reducing fugitive leaks. Efforts are made to minimize such losses for both environmental and economic reasons.

Table 5.3 shows common feedstock applications, although the list is not exhaustive. Parties report amounts of ODS used as feedstock to the Secretariat but not how they are used. Processes are proprietary and there is no official source to define the manufacturing routes followed and their efficacy. The table provides some examples and is the product of the collective experience and knowledge of MCTOC members. Products included are both intermediates as well as final products, including fluoropolymers.

Table 5.3 Common feedstock applications of ODS (this list is not exhaustive)

Feedstock ODS	**Product**	**Further conversion**	**Comments**
CFC-113	Chlorotrifluoroethylene	Chlorotrifluoroethylene based polymers	Polymers include poly-chlorotrifluoroethylene (PCTFE), and poly-fluoroethylenevinyl ether (PFEVE).
CFC-113, CFC-113a	Trifluoroacetic acid and pesticides	HFO-1336mzz	Production processes in China and India. CFC-113a is as an intermediate in this process.
CFC-113, CFC-113a	HFC-134a and HFC-125		High-volume use. The sequence for production of this refrigerant may begin with CFC-113, which is converted to CFC-113a and then to CFC-114a.
CFC-114, -114a	HFC-134a		The sequence for production of this refrigerant gas may begin with CFC-113, which is converted to CFC-113a and then to CFC-114a.
CTC	CFC-11 and CFC-12		Production and consumption of these CFCs have fallen to zero based on recent data.
CTC	Perchloroethylene		High volume use.
CTC	Chlorocarbons	Feedstocks for production of HFCs, such as HFC-245fa, HFC-365mfc, HFC-236fa	
CTC	Chlorocarbons	Feedstock for production of HFOs and HCFOs, such as HFO-1234yf, HCFO-1233zd	HFOs are low-GWP fluorocarbons used in refrigeration, air conditioning and insulation.
CTC	Intermediates (DVAC)	Pyrethroid pesticides.	CCl_3 groups in molecules of intermediates become $=CCl_2$ groups in pyrethroids.
1,1,1-trichloroethane	HCFC-141b, -142b, and HFC-143a		Note that an alternative feedstock is 1,1-dichloroethylene (vinylidene chloride), which is not an ODS.
HCFC-21	HCFC-225		Product used as solvent.
HCFC-22	Tetrafluoroethylene	Polymerized to homopolymer (PTFE) and also co-polymers	Very high-volume use. Work has been done for decades to find an alternative commercial route, without success.
HCFC-123	HFC-125		
HCFC-123, HCFC-133a and Halon-1301	Production of pharmaceuticals, TFA and agrochemicals		
HCFC-124	HFC-125		
HCFC-141b	HFC-143a		
HCFC-142b	Vinylidene fluoride	Polymerized to poly-vinylidene fluoride or co-polymers.	Products are fluorinated elastomers and a fluororesin.
HCFC-225		HFO-1234yf	

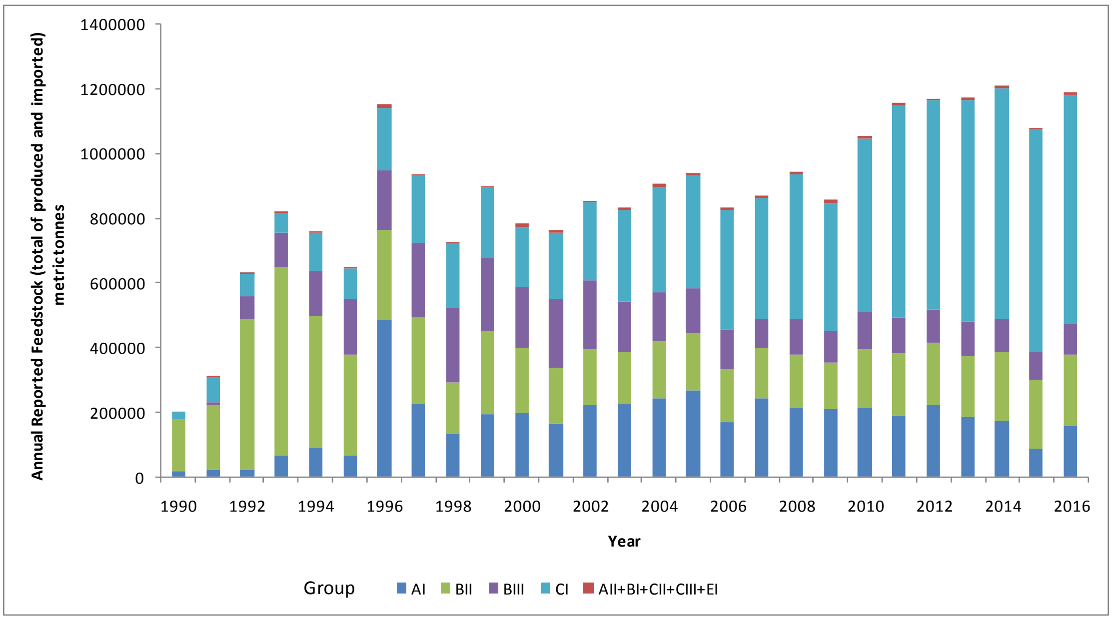
5.3.5.2 Trends in ODS feedstock uses

Parties report the use of ODS as feedstock to the Ozone Secretariat. Data have been provided to the MCTOC by the Ozone Secretariat on production, import and export of ODS used as feedstock for the year 2016. These also include quantities used as process agents because parties are required to report such consumption in a manner consistent to that for feedstock. Detailed information can be found in Table 5.2, as provided by the Ozone Secretariat.

For 2016, a total of 17 parties reported use of ODS as feedstock, while 12 of these parties were also producers of ODS for these uses. In 2015, 17 parties reported use of ODS as feedstock.

In 2016, total production for feedstock uses was 1,189,536 tonnes (2015: 1,084,101 tonnes)[15]. Use of ODS as feedstock grew significantly between 1990 and 2011, although not at a uniform rate (see Figure 5.1). Since 2011, use has been roughly constant, fluctuating around a mean total of 1,116,000 (±44,000) tonnes/year.

Figure 5.1 Annual use of ODS for feedstock, categorised by Montreal Protocol Group[16]



The largest feedstock uses currently are HCFC-22 (45% of the total mass quantity), CTC (19%), and HCFC-142b (11%). The quantity of HCFCs, in total, used as feedstock has been growing since the record began in 1990, mainly as a consequence in the growth of fluoropolymers. HCFC-22 is used to produce tetrafluoroethylene (TFE), which can be both homo- and co-polymerized to make stable, chemically resistant fluoropolymers with many applications. Polyvinylidene fluoride is made from HCFC-142b. The growth in fluoropolymers can be expected to continue for the near future. CTC use is growing slowly;

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[15] This represents a total of 438,712 ODP tonnes (2015: 375,488 ODP tonnes)

[16] Annex AI CFCs -11, -12, -113, -114, -115; Annex BII carbon tetrachloride; Annex BIII 1,1,1 trichloroethane; Annex CI HCFCs. Annex AII Halons -1211, -1301, -2402; Annex BI CFCs -13, -111, -112, -211, -212, -213, -214, -215, -216, -217; Annex CII HBFCs; Annex CIII bromochloromethane; and Annex EI methyl bromide.

from a minimum in 2009, use is now growing at an average of 6,700 tonnes/year due to growing demand for low GWP hydrofluoroolefins (HFOs) and perchloroethylene.

CFCs, mainly CFC-113, have shown a long-term decline in use. The reasons for this are complex – a reduction in the fluoropolymers produced from CFC-113 is possible, but unlikely in view of the increased demand for other fluoropolymers, however, changes in the production technology for HFCs can impact use of CFC-113, as can changes in the reporting of in-house production and inventories.

Table 5.4 Amount of ODS used as feedstock in 2016

Substance	ODP	Tonnes	ODP Tonnes[17]
HCFC-22	0.055	539,473	29,671
Carbon tetrachloride	1.1	221,554	243,709
HCFC-142b	0.065	129,692	8,431
CFC-113	0.8	104,122	83,297
1,1,1-trichloroethane (methyl chloroform)	0.1	93,036	9,304
CFC-114	1	51,755	51,755
HCFC-124	0.022	24,017	528
HCFC-141b	0.11	13,010	1,431
HCFC-123	0.02	4,822	96
Methyl bromide	0.6	4,248	2,549
Bromochloromethane	0.12	1,965	236
HCFC-133a	0.06	943	57
HALON-1301	10	753	7,535
HBFC-22B1	0.74	124	91
CFC-12	1	20	20
HBFC-31B1 (CH_2FBr)	0.73	3	2
Total		1,189,536	438,712

5.3.5.3 Estimated emissions of ODS

Emissions are not reported by parties and estimation of ODS emissions is inexact. The sophistication of the operating facility can heavily influence emission levels. Highly automated, tight and well-instrumented facilities with proper, closely observed, procedures can have ODS emission levels as low as 0.05% of the ODS amount used as feedstock. At the other extreme, batch processes of limited scale with less tight facilities, with less concern for operational excellence, could have emission levels up to 5% of the ODS amount used as feedstock. For example, estimates of emissions from feedstock use of CTC throughout the world varied according to the scale of the processes and were 0.3% for perchloroethylene and HFC production, rising to 4.8% of the quantity used to make the pesticide intermediate DVAC[18]. The largest volumes of feedstock use are likely to be at the least emissive end of the

[17] While ODP tonnes are presented, it should be noted that ODP is relevant to emissions. From the total amount of ODS used as feedstock, only an insignificant quantity will be released as emissions (see section 5.3.5.3 Estimated emissions of ODS).

[18] Sherry D., A. McCulloch, Q. Liang, S. Reimann and P. A. Newman (2017) Current Sources of Carbon Tetrachloride (CCl4) in our Atmosphere, ***Environ. Res. Lett.*** (2018) 024004 https://doi.org/10.1088/1748-9326/aa9c87.

scale because large capacity plants have the most investment and are better able to control emission levels. The higher emissions levels are based on industry input and anecdotal experience, with no citable references.

Data compiled by the European Environment Agency (EEA) from reports by companies under the European ODS Regulation show that 164,992 metric tonnes of ODS were used as feedstock within the EU in 2016[19]. Total emissions of feedstocks were quoted as 82 metric tonnes, an emission factor of 0.06% (compared to a revised estimate of 0.05% in 2015). The emissions are less than half of the quantities reported in the European Pollutant Release and Transfer Register[20] from chemicals manufacture, which totalled 180 metric tonnes in 2015 (20 carbon tetrachloride, 0 methyl chloroform, 39 CFCs and 121 HCFCs) but these include *all* emissions from *all* chemical manufacturers. Nevertheless, the relatively low rate of emissions achieved illustrates the effectiveness of local regulation and oversight, and industrial diligence, in the management and control of ODS emissions in feedstock uses.
For the purpose of compiling national greenhouse gas inventories, the Intergovernmental Panel on Climate Change (IPCC) recommends a default emissions factor for HFCs from their manufacture of 0.5%.[21] There is no similar international technical consensus for estimating ODS emissions associated with ODS feedstock uses, however, the chemicals, operational processes, and emissions abatement technologies involved are very similar and can be considered technically analogous to those for HFC production. In order to generate some indicative estimations of ODS emissions, the IPCC emission factor of 0.5% for HFC production was applied as a surrogate emission factor uniformly across all Groups. For guidance purposes only, estimated emissions associated with ODS feedstock and process agent uses in 2016 can be calculated as 5,948 tonnes, or 2,194 ODP tonnes.

5.3.5.4 How to minimize ODS feedstock emissions

Both regulators and producers can act to assure that emissions from feedstock uses of ODS are kept at minimal levels. In the European Union, the United States, China, and several other countries, all new operations are required to be licensed for operation. These licences usually define specific maximum emission limits, as well as the methodology to quantify them.

Producers can follow specifically defined responsible use practices, which, *inter alia*, define equipment to control processes, closed-loop loading and recovery, and thermal destruction of vapour emissions. It is considered by MCTOC experts that, when strictly followed, these responsible use practices can limit ODS emissions to about 0.1% of the ODS amount used as feedstock in continuous processes. Less responsible operation, and batch processes, can lead

[19] Ozone-depleting substances 2016, Aggregated data reported by companies on the import, export, production, destruction, and feedstock and process agent use of ozone-depleting substances in the European Union, European Environment Agency Report No 12/2017, Luxembourg: Publications Office of the European Union, 2017, doi:10.2800/179166.

[20] European Pollutant Release and Transfer Register (E-PRTR), available at http://prtr.ec.europa.eu/ , accessed February 2018.

[21] This can be found in the 2006 IPCC Guidelines for National Greenhouse Gases Inventories Volume 3, Chapter 3.10, accessible at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_3_Ch3_Chemical_Industry.pdf , accessed March 2016. The Guidelines state, "*For Tier 1, in the absence of abatement measures, a default emission factor of 0.5 percent of production, not counting losses in transport and transfer of materials, is suggested for HFCs and PFCs, based on data supplied to AFEAS (2004).*"

to emissions as high as 5% of feedstock quantities. Close cooperation between producers and regulators can continue to make these operations safe and environmentally sustainable.[22]

5.3.6 Solvent uses of ODS

The use of HCFC-141b and HCFC-225 for solvent cleaning in non-Article 5 parties has been phased out, with the exception of aerospace and military applications. In Article 5 parties, HCFC use for solvent cleaning has declined and will continue to reduce further as more critical uses of HCFCs, such as in refrigeration, are given priority and as available quantities decline under the HCFC phase-out schedule of the Montreal Protocol. Alternatives to HCFCs for solvent cleaning are commercially available and are being used for automotive, aerospace, precision component and optical cleaning where high levels of cleanliness are required. These alternatives include low GWP HCFO-1233zd(E) and hydrofluoroethers (HFEs).

Aerospace or military applications might require small quantities of HCFCs, potentially to service existing equipment (e.g. HCFC-122, -122a, -141b, -225). For example, HCFC-225 replaced CFC-113 in precision cleaning and cleanliness verification of sensitive equipment, such as oxygen systems, in aerospace applications. HCFO-1233zd(E) has undergone successful laboratory testing for this application, but for at least one important user there is currently no on-going production of large systems that would allow the proving of the efficacy of this solvent in the actual conditions of use. If HCFO-1233zd(E) or other alternatives, such as HFEs, fail to demonstrate adequate performance, the application would need to continue to use HCFC-225 (or the original CFC-113). It is estimated that aerospace and military applications currently require small quantities of HCFCs globally, possibly less than about 50 tonnes annually. Such HCFC solvent uses are unlikely to exceed several hundred metric tonnes (i.e., several ODP tonnes) annually for the period 2020-2030. It is not clear whether quantities would be available or suitable from stockpiled or recycled sources. Although stockpiled sources can be infeasible due to the formation of chemical impurities unsuitable for these precision cleaning uses.

There is a reported solvent use of HCFC-225 for syringe/needle coating in Japan. HCFC-141b is used for this purpose in Article 5 parties. This solvent application coats silicone oil on the surface of the needle/syringe to reduce pain at injection. The solvent properties required are non-flammability, good solvency with the silicone oil, and quick evaporation after coating. Alternative non-ODS solvents are under investigation in Japan, and already used in Europe and the United States (e.g. HFEs). Topical creams are also available as pain relief for injections.

Several manufacturing processes use HCFCs as solvents in processes that might be considered similar to process agent uses. They are used either as reaction solvents, or as solvents for extractive distillation due to the unique affinities to certain chemicals. Known applications include processes using HCFC-141b and HCFC-225 as solvents. Alternative processes and/or solvents are under development. There is a small possibility that such HCFC use may remain after 2020 if alternatives cannot be found by then.

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[22] More information on requirements to minimise emissions from feedstock use can be found, for example, in European Chemicals Agency (ECHA) guidance on intermediates and the use of "*Rigorous containment of the substance by technical means, supported by procedural and control technologies in place, used to minimise emissions and resulting exposure during the whole life cycle of the intermediate*". See, for example, "*How to assess whether a substance is used as an intermediate under strictly controlled conditions and how to report the information for the intermediate registration in IUCLID Practical Guide 16*" at https://echa.europa.eu/view-article/-/journal_content/title/new-practical-guide-on-intermediates-launched, accessed March 2018.

5.3.7 *Decision XIII/7(3): Report on n-Propyl bromide use and emissions*

Decision XIII/7(3) requests TEAP to report annually on *n*-propyl bromide use and emissions. *n*-Propyl bromide (1-bromopropane, $CH_3CH_2CH_2Br$, *n*-PB, CAS No. 106 94 5) is being used as a solvent in a range of applications. Its boiling point, 71ºC, is comparable to that of CFC-113 (48ºC), hexane (69ºC), methyl chloroform (TCA, 74ºC) and trichloroethylene (87ºC), making it attractive as a solvent with similar physical properties. Its solvent properties are typical of those of lower molecular weight hydrocarbons and organohalogen compounds. *n*-Propyl bromide is used as an electrical cleaning agent, degreaser or carrier solvent, as an intermediate in chemical manufacture, in spray adhesives, dry cleaning, insulation, and as a refrigerant flushing agent. n-Propyl bromide has also appeared in consumer aerosol cans as electronics cleaning and degreasing products, as adhesive products, as textile spot removers, and as paintable mould release agents.

Due to the presence of bromine in the molecule, however, concerns have been expressed based both on its potential for ozone depletion and its toxicity. The atmospheric lifetime, and impact on ozone depletion, of *n*-propyl bromide have been evaluated in several studies, with derivations dependent on emissions location. In 2011, using a current-generation chemistry-transport model of the troposphere and stratosphere, Wuebbles *et al*. derived an atmospheric chemical lifetime of 19.6 days, and ODP of 0.011, for the global emissions case, and 24.7 days, and an ODP of 0.0049 at northern hemisphere mid-latitudes[23]. *n*-Propyl bromide is not a controlled substance under the Montreal Protocol.

Regarding its toxicity, the National Toxicology Program report (NTP TR 564, August 2011) and the American Conference of Governmental Industrial Hygienists (ACGIH®) (February 2012) established a threshold limit value (TLV®) for n-propyl bromide of 0.1 ppm. In 2013, a peer-reviewed Draft Report on Carcinogens prepared by the U.S. National Toxicology Program concluded that n-propyl bromide is reasonably anticipated to be a human carcinogen[24]. In 2014, ACGIH published a time weighted average exposure limit (TWA) of 0.1ppm for n-propyl bromide. The Japan Society for Occupational Health set a TLV of 0.5ppm for n-propyl bromide in 2013.

The European Chemical Agency (ECHA) has classified *n*-propyl bromide as a Substance of Very High Concern (SVHC) and it is included in the list of substances included in Annex XIV of REACH ("Authorisation List"). The substance is subject to authorisation, meaning it cannot be placed on the market or used after 04/07/2020 (the sunset date), unless an authorisation is submitted for specific use(s) by 04/01/2019 (the application date) and an authorisation is granted, or an authorisation application has been submitted before the application date but the Commission decision on the application for authorisation has not yet been taken, or the specific use is exempted from authorisation. There are no exempted (categories of) uses for *n*-propyl bromide[25].

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[23] Wuebbles, D. J., Patten, K. O., Wang, D., Youn, D., Martinez-Avile, M., and Francisco, J. S.: Three-dimensional model evaluation of the Ozone Depletion Potentials for n-propyl bromide, trichloroethylene and perchloroethylene, Atmos. Chem. Phys., 11, 2371–2380, 2011.

[24] National Toxicology Program, U.S. Department of Health and Human Services, Draft Report on Carcinogens Monograph for 1-Bromopropane, January 18, 2013, available at https://ntp.niehs.nih.gov/ntp/about_ntp/monopeerrvw/2013/march/draftroc1bpmonograph_508.pdf, accessed April 2017.

[25] European Chemicals Agency (ECHA) authorisation list entry for n-propyl bromide https://echa.europa.eu/authorisation-list/-/dislist/details/0b0236e1804d5364, accessed March 2018.

According to the harmonised classification and labelling (CLP00) approved by the European Union, *n*-propyl bromide "...*may damage fertility and may damage the unborn child, is a highly flammable liquid and vapour, causes serious eye irritation, may cause damage to organs through prolonged or repeated exposure, causes skin irritation, may cause respiratory irritation and may cause drowsiness or dizziness*". In addition, the classification identifies that *n*-propyl bromide "...*is suspected of causing cancer and is harmful to aquatic life with long lasting effects*".[26]

The Toxic Substances Control Act (TSCA) requires the US EPA to establish a risk evaluation process. In performing risk evaluations for existing chemicals, US EPA is directed to "*determine whether a chemical substance presents an unreasonable risk of injury to health or the environment, without consideration of costs or other non-risk factors, including an unreasonable risk to a potentially exposed or susceptible subpopulation identified as relevant to the risk evaluation by the Administrator under the conditions of use*." In December 2016, *n*-propyl bromide was identified as one of ten chemicals designated by US EPA for chemical risk evaluation, based on high hazard concerns due to its toxicity profile and high exposure concerns due to its use in consumer products.

TSCA requires that US EPA publish the scope of the risk evaluation to be conducted, as part of the public consultation process. The scope of risk document for *n*-propyl bromide was published in June 2017.[27] It included information about conditions of use, hazards, exposures, and potentially exposed or susceptible subpopulations, that US EPA expects to consider in the risk evaluation. The document presents the scope of the risk evaluation to be conducted for *n*-propyl bromide by US EPA, and the occupational scenarios in which workers and occupational non-users may be exposed during a variety of conditions of use. TSCA requires that these chemical risk evaluations be completed within three years of initiation (from December 19, 2016 for *n*-propyl bromide), allowing for a single 6-month extension.

The scope of risk evaluation states that in the United States *n*-propyl bromide is primarily used as a solvent cleaner in vapour and immersion degreasing operations to clean optics, electronics and metals. It has also been used as an alternative solvent carrier for other ozone-depleting substances and chlorinated solvents, e.g. in industries using spray adhesives such as foam cushion manufacturing. Past uses include as a solvent for fats, waxes or resins and as an intermediate in the synthesis of pharmaceuticals, insecticides, quaternary ammonium compounds, flavours and fragrances. *n*-Propyl bromide was also recently listed on the Toxics Release Inventory (TRI), with data on environmental releases of *n*-propyl bromide to air, landfills or water likely to become available in the near future.

In China, *n*-propyl bromide is identified as one of nearly 3,000 hazardous chemicals controlled under the Regulation on the Safety Management of Hazardous Chemicals. Based on this regulation, stakeholders handling *n*-propyl bromide must prevent and reduce hazardous chemical accidents and guarantee the use of *n*-propyl bromide will not impact the life and safety of the general public and the environment during its production, storage, use, dealing and transport.

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[26] European Chemicals Agency (ECHA), *Brief Profile of n-propyl bromide*, available at https://echa.europa.eu/brief-profile/-/briefprofile/100.003.133, accessed March 2018.

[27] United States Environmental Protection Agency, Office of Chemical Safety and Pollution Prevention, EPA Document # EPA- 740-R1-7009, *Scope of the Risk Evaluation for 1-Bromopropane*, CASRN: 106-94-5, June 2017, available at https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-1-bromopropane-1-bp, accessed April 2018.

The relatively low workplace exposure standards indicate that use of *n*-propyl bromide in solvent applications is likely to be problematic, and its use will likely be limited to applications where worker exposure is controlled and will require significant emission control. Nevertheless, *n*-propyl bromide continues to appear as a marketed solvent at trade exhibitions with demand in a number of markets (e.g. China, Japan and the United States).

Manufacture is occurring in a small number of countries, including China, Israel and the United States. Chemical manufacturers do not publicise their *n*-propyl bromide production data for commercial reasons. Parties to the Montreal Protocol are not required under Article 7 to report the production and consumption n-propyl bromide because it is not a controlled substance. China has previously estimated production capacity of about 10,000 tonnes per year, consumes (about 3-4,000 tonnes per year), and exports (about 5,000 tonnes) to other markets. The United States manufactured and imported about 8,500 tonnes in 2012, and nearly 12,000 tonnes in 2015 and 2016.[27,28.] Japan imported about 5,000 tonnes in 2015. The European Union imports about 2,000 tonnes, with maximum production of 3,600 tonnes. Information is not available for Israel.

Parties may wish to consider requesting TEAP to assess the global production of n-propyl bromide and invite parties to provide production quantities to be collated and reported to the 31st MOP'.

5.3.8 Carbon tetrachloride emissions

The World Climate Research Programme, under its Stratosphere-Troposphere Processes and Their Role in Climate (SPARC) project, published a 2016 report entitled "*The Mystery of Carbon Tetrachloride*"[29], which analysed potential sources of emissions of carbon tetrachloride and estimated their magnitudes. Globally, it is estimated that 25,000 tonnes/year are emitted; regional contributions are 4,000 tonnes/year from the United States and 2,200 tonnes/year from the European Union. It is apparent that most of the global emissions are unreported (23,000 tonnes, or more than 90%): either inadvertent emissions from activities involving chlorine and leakage from old landfill (estimated to total 10,000 tonnes/year) or unreported emissions from industrial processes, including waste treatment (estimated at 13,000 tonnes/year). A recent scientific publication, by a group of experts involved in the SPARC project, documents these findings in further detail.[30]

5.3.9 Laboratory and analytical uses

Decision XV/8(2) requests TEAP "...to report annually on the development and availability of laboratory and analytical procedures that can be performed without using the controlled substances in Annexes A, B and C (group II and group III substances) of the Protocol". A later decision XXVI/5(2) also requests TEAP "*...to report no later than 2018 on the*

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[28] U.S. EPA, Office of Chemical Safety and Pollution Prevention, *Preliminary Information on Manufacturing, Processing, Distribution, Use, and Disposal: 1-Bromopropane*, CASRN: 106-94-5, February 2017, Support document for Docket EPA-HQ-OPPT-2016-0741, available at https://www.epa.gov/sites/production/files/2017-02/documents/1-bromopropane.pdf, accessed April 2017.

[29] SPARC (2016), SPARC Report on the Mystery of Carbon Tetrachloride. Q. Liang, P.A. Newman, S. Reimann (Eds.), SPARC Report No. 7, WCRP-13/2016.

[30] David Sherry, Archie McCulloch, Qing Liang, Stefan Reimann and Paul A. Newman, Current sources of carbon tetrachloride (CCl4) in our atmosphere, *Environ. Res. Lett.* **13** (2018) 024004, https://doi.org/10.1088/1748-9326/aa9c87, accessed April 2018.

development and availability of laboratory and analytical procedures that can be performed without using controlled substances under the Montreal Protocol". In light of decision XXVI/5(2), and with the challenges of reporting annually on this topic, MCTOC will focus its resources and activity towards completing the decision XXVI/5(2) report, with plans to report on this topic in time for the 30th MOP (see chapter 8, **Error! Reference source not found.**).

5.3.10 Destruction technologies

At their 29th Meeting, parties to the Montreal Protocol requested the Technology and Economic Assessment Panel (TEAP) to report by 31st March, and if needed in a supplementary report to the 40th Open-ended Working Group (OEWG), on an assessment of destruction technologies, as instructed in decision XXIX/4. In response to decision XXIX/4, TEAP formed a temporary subsidiary body, in the form of a Task Force on Destruction Technologies, which is reporting on this decision separately.

Decision XXIII/12(2) requests the TEAP to continue to assess the plasma destruction technology for methyl bromide in the light of any additional information that may become available and to report to the parties when appropriate. A submission by SRL Plasma, reviewed in the 2014 CTOC Assessment Report, provided information on the plasma arc destruction of methyl bromide and reported a DRE of over 99.6%, but with 2-3% of methyl bromide recovered. No new information has been reported by parties. Additional information has become available from E.S.T. Ltd., Environmental Systems & Treatment[31], which reports on its website the plasma destruction of methyl bromide, a pharmaceutical production waste stream, achieving a conversion of 98.5%. Further information provided stated that this was carried out on a pilot plant process that would require further optimisation to achieve higher levels of conversion.

[31] http://www.est-systems.com/Application.html, accessed February 2018.

6 Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC) Progress Report

Executive Summary

The phase down of high-GWP HFC's is underway in all refrigeration, air conditioning and heat pump (RACHP) sectors. Some sectors have identified possible long-term solutions for a majority of applications (e.g., domestic refrigeration with HC-600a and commercial refrigeration with R-744) while some other sectors are investigating different alternatives (e.g., air-to-air air conditioners with HFC-32 and HC-290, and motor vehicle air conditioning (MAC) with HFO-1234yf and R-744).

In almost all sectors, testing of lower-GWP blends is under way in order to find a suitable alternative to high-GWP fluids in the near- or medium- term. Energy efficiency is being taken into account in all decisions regarding which low-GWP alternatives are to be introduced. Over 90% of energy efficiency improvements accompanying the transition to low-GWP refrigerants, are due to improvements in equipment efficiency (with 5-10% attributable to the working fluid itself).

The development of HCs, R-717 (ammonia), and R-744 (carbon dioxide) in relevant sectors has continued. In recent years, unsaturated fluorochemicals (especially HFOs), and blends of HFOs with HFCs have been the main option to replace high-GWP refrigerants.
Since the publication of the RTOC 2014 Assessment Report, 33 new refrigerants, most of them blends, have received standard designations and safety classifications in ASHRAE Standard 34. 23 of these refrigerants were listed in the 2017 progress report, and 10 are new since that report. Among the 10 new fluids there are two single-compound refrigerants, seven azeotropic blends (which behave as a pure fluid) and one non-azeotropic blend (which presents a temperature glide during evaporation and condensation).

The majority of medium and low GWP alternatives are flammable, and there has been significant progress with the development of new safety standards, although it is unclear when the A2/A3 amendment to standards IEC 60335-2-40 and IEC 60335-2-89 will be published.

Updates from the relevant RACHP sectors are as follows:

- The Association of Home Appliance Manufacturers of North America (AHAM) has announced a voluntary goal to phase down HFC-134a in household refrigerators and freezers after 2024.
- In supermarket refrigeration, non-halocarbon refrigerants such as R-744 (carbon dioxide) are increasingly being used worldwide, both in cascaded systems and in trans-critical systems. The components and systems for trans-critical systems are being optimized to reduce their energy cost at high ambient conditions. In Europe and US, a wide range of blends such as R-448A, R-449A, R-449B, R-452A, R-407H, R-450A, and R-513A is accelerating.
- Lower-GWP refrigerants are being introduced in transport refrigeration. R-452A has achieved market penetration in newly produced trucks and trailers in Europe. Several hundred refrigerated marine container units utilizing R-744 are in field trials. Safetystandards are in development for the implementation of flammable and semi flammable refrigerants in refrigerated containers. Fishing vessels built in Europe use all use R-717 or a R-717/R-744 cascade.
- Replacement of HCFC-22 in new air-to-air AC and heat pumps continues. HFC-32 is widely used in residential split air conditioners in Japan and increasing in certain countries in South East Asia and Europe. In India, production of HC-290 split air conditioners continues, with production line conversions underway in several other

countries. In China, although further conversion of production lines to HC-290 is underway for small and portable units, safety standards are limiting market introduction for larger units.

- Almost all new light vehicles in Europe and many in the United States and other countries use HFO-1234yf mobile air conditioners (MAC). The transition to HFO-1234yf for heavy vehicles and delivery vans is slower. R-744 is also an alternative, which some premium models have started using in 2017. R-744 is also under evaluation for use in heat pumps on electrified vehicles. Secondary loop systems are starting to appear on electrified vehicles. Counterfeit refrigerants are a major issue, and it will likely be even more significant as more expensive HFO-1234yf become available.
- Opportunities for improved sustainability through the lifecycle of a refrigeration system include the reduction of use of raw materials, and the establishment of codes of ethical conduct for suppliers along the value chain. Energy efficiency is being taken into account in decisions on transitions to low-GWP alternatives.
- Safety is a special consideration in risk assessment of flammable refrigerants in different applications in different regions. For example, in HAT conditions, the elevated refrigerant charge and the capability of technicians in the service sector are important factors in assessing risk.

6.1 Introduction

The RTOC met in Bruges, Belgium on October 2017 and in Delhi, India in March 2018. Attending members were from non-A5 Parties: Czech Republic, Croatia, Denmark, Germany, Italy, Japan, The Netherlands, Norway, UK, United States (US), and from Article 5 Parties: Brazil, China, Egypt, India, Jamaica, Jordan, Lebanon, Peru and Saudi Arabia. The membership of RTOC at the time of the Delhi meeting stood at 37 members.

During 2017, RTOC lost Paulo Vodianistakia, whose premature death was deeply regretted by RTOC members, who remembered him at the beginning of the Bruges meeting.

The main purposes of both meetings were: (1) to update the RTOC members on the discussions and outcomes of Montreal Protocol meetings, (2) to discuss the Energy Efficiency implication in the Kigali Amendment implementation within the RACHP sectors, (3) to discuss and complete the 2018 RTOC Progress Report and (4) to continue the work for the 2018 RTOC Assessment Report in terms of content and organization. The contents of the several chapters were reviewed as well the chapter’s membership.

The procedure for the preparation of the assessment report was analysed, with the first draft of the report to be released by the end of July 2018, followed by an extensive peer review to be completed before the December meeting of RTOC, to be held in Rome, Italy. During the Rome meeting the reviewer’s comments will be taken into account in order to have the final version of the Report ready to be released by the end of the year.

In the following sections, the status of the different sub-sectors (chapters in the RTOC assessment report) is reported, focusing on updates to the technology.

6.2 Refrigerants

The trend in recent years has been a focus on unsaturated fluorochemicals (and most of them HFOs (unsaturated HFCs) and blends of them with HFCs), to replace fluids with high-GWP. The use of HCs, R-717 (ammonia), and R-744 (carbon dioxide) continues. Interest continues for R-718 (water), already in very limited commercial use, and R-728 (air), but there has been no significant progress with either.

Since the publication of the RTOC 2014 Assessment Report, 33 new refrigerants, most of them blends, have received standard designations and safety classifications in American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 34 with anticipated adoption also in International Standards Organisation (ISO) 817. 23 of these refrigerants were listed in the 2017 progress report, and 10 are new since the 2017 progress report.

The 33 refrigerants are listed in table A, B, and C with the 10 fluids new since the 2017 progress report marked with yellow. The GWP values are calculated as in the RTOC 2014 Assessment Report.

Among the 10 new fluids are two single-compound refrigerants, HFO-1132a and HCFO-1224yd(Z). HFC-1132a is a flammable (safety class A2) high pressure fluid, with a boiling point of -86,7 °C it has potential to be used in cryogenic applications, as well as a component in new refrigerant blends, for instance to replace R-410A. HCFO-1224yd(Z) is a low-pressure fluid. Neither of these two new molecules is yet commercially produced in significant quantities.

The remaining 8 refrigerants are blends. Half are blends of traditional HFC's (R-407H, R-407I, R-461A, R-462A), while the other half are blends of traditional HFC's and either HFO-1234yf or HFO-1234ze(E) (R-460C, R-464A, R-465A, R516A).

Table A: Data summary for new single component refrigerants

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ppm)	GWP 100 Year	GWP 20 Year
HCC-1130(E)	CHCl=CHCl	trans-1,2-dichloroethene	96,9	47,7	B2				
HFC-1132a	$CF_2 = CH_2$	1,1-difluoroethylene	64,0	–86,7	A2	4,0 days	0,004	<1	<1
HCFO-1224yd(Z)	$CF_3CF=CHCl$	(Z)-1-chloro-2,3,3,3-tetrafluoropropene	148,5	14,5	A1				
HFO-1336mzz(Z)	$CF_3CH=CHCF_3$	cis-1,1,1,4,4,4-hexafluoro-2-butene	164,1	33,4	A1	22,0 days	0,07	2	6

Table B: Data summary for new zeotropic refrigerant blends

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	Safety Class	GWP 100 Year	GWP 20 Year
R-407G	R-32/125/134a (2,5/2,5/95,0)	100,0	–29,2/–27,2	A1	1 400	3 800
R-407H	R-32/125/134a (32,5/15,0/52,5)	79,1	–44,7/–37,6	A1	1 500	3 800
R-407I	R-32/125/134a (19,5/8,5/72,0)	86,9	–39,8/–33,0	A1	1 400	3 800
R-447B	R-32/125/1234ze(E) (68,0/8,0/24,0)	63,1	–50,1/–46,0	A2L	750	2 200
R-449B	R-32/125/1234yf/134a (25,2/24,3/23,2/27,3)	86,4	–46,1/–40,2	A1	1 400	3 200
R-449C	R-32/125/1234yf/134a (20,0/20,0/31,0/29,0)	90,3	–44,6/–38,1	A1	1 200	2 900
R-452B	R-32/125/1234yf (67,0/7,0/26,0)	63,5	–51,0/–50,3	A2L	710	2 100
R-452C	R-32/125/1234yf (12,5/61,0/26,5)	101,9	–47,5/–44,2	A1	2 200	4 100
R-453A	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	A1	1 700	4 100
R-454A	R-32/1234yf (35,0/65,0)	80,5	–48,4/–41,6	A2L	250	890
R-454B	R-32/1234yf (68,9/31,1)	62,6	–50,9/–50,0	A2L	490	1 700
R-454C	R-32/1234yf (21,5/78,5)	90,8	–46,0/–37,8	A2L	150	540
R-455A	R-744/32/1234yf (3,0/21,5/75,5)	87,5	–51,6/–39,1	A2L	150	540
R-456A	R-32/134a/1234ze(E) (6,0/45,0/49,0)	101,4	–30,4/–25,6	A1	650	1 900
R-457A	R-32/1234yf/152a (18,0/70,0/12,0)	87,6	–42,7/–35,5	A2L	150	520
R-458A	R-32/125/134a/227ea/236fa (20,5/4,0/61,4/13,5/0,6)	89,9	–39,8/–32,4	A1	1 600	3 900
R-459A	R-32/1234yf/1234ze(E) (68,0/26,0/6,0)	63,0	–50,3/–48,6	A2L	480	1 700
R-459B	R-32/1234yf/1234ze(E) (21,0/69,0/10,0)	91,2	–44,0/–36,1	A2L	150	530
R-460A	R-32/125/134a/1234ze(E)	100,6	–44,6/–37,2	A1	2 100	4 100

	(12,0/52,0/14,0/22,0)					
R-460B	R-32/125/134a/1234ze(E) (28,0/25,0/20,0/27,0)	84,8	–45,2/–37,1	A1	1 300	3 000
R-460C	R-32/125/134a/1234ze(E) (2,5/2,5/ 46,0/49,0)	105,3	–29,2/–26,0	A1	730	2 000
R-461A	R-125/143a/134a/227ea/600a (55,0/5,0/32,0/5,0/3,0)	109,6	–42,0/–37,0	A1	2 700	5 300
R-462A	R-32/125/143a/134a/600 (9,0/42,0/2,0/44,0/3,0)	97,1	–42,6/–36,6	A2	2 200	4 700
R-464A	R-32/125/1234ze(E)/227ea (27,0/ 27,0/40,0/6,0)	88,5	–46,5/–36,9	A1	1 300	2 700
R-465A	R-32/290/1234yf (21,0/7,9/71,1)	82,9	–51,8/–40,0	A2	150	530

Table C: Data summary for new azeotropic refrigerant blends

Refrigerant Designation	Refrigerant Composition (Mass %)	Molecular Weight	Bubble Point/ Dew Point (°C)	Safety Class	GWP 100 Year	GWP 20 Year
R-513B	R-1234yf/134a (58,5/41,5)	108,7	–29,2/–29,1	A1	560	1 600
R-514A	R-1336mzz(Z)/1130(E) (74,7/25,3)	139,6	29,0/29,0	B1		
R-515A	R-1234ze(E)/227ea (88,0/12,0)	118,7	–18,9/–18,9	A1	380	630
R-516A	R-1234yf/134a/152a (77,5/8,5/14,0)	102,6	–29,4	A2L	140	400

6.3 Domestic appliances

In domestic refrigeration, refrigerant migration from HFC-134a to HC-600a is expected to continue, as per Kigali schedule or earlier, driven by local regulations on HFCs. The product relative costs influence the rate and extent of migration from HFC-134a to HC-600a. This migration began in Japan several years ago and is now occurring in Brazil, Mexico and the United States. This trend will likely proliferate.

Globally, activity with HFC-1234yf in domestic refrigerators remains still limited probably due to cost implications. 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 refrigerant) and the rest will use HFC-134a.

With Kigali Amendment, the announcement of the Association of Home Appliance

Manufacturers (AHAM) of North America on voluntary goal to phase down HFC-134a in household refrigerators and freezers after 2024 becomes significant. It is not yet clear whether the US manufacturers will choose HC-600a or HFC-1234yf as both are flammable and have to adhere to current and emerging safety and energy efficiency standards.

Research continues to evaluate drop-in replacements for HFC-134a refrigerators. The use of HFO-1234yf, HFO-1234ze and blends of HFO-1234yf/HFC-134a and HFO-1234ze/HFC-134a as possible drop-in refrigerants and the energy consumptions may also be comparable with system optimization.

The heat pump clothes (laundry) dryer (HPCD) sales using HFC-134a are rapidly growing in the EU. In addition to R-407C and HC-290 based systems in the market, low GWP HFCs, R-744 and HC-600a are also being explored with significant efficiency gain.

6.4 Commercial refrigeration

While the F-gas regulation 517/2014 is now effective in Europe, in the US, as of the publication of this update, the delisting of the HFCs in EPA's Rules 20 and 21 are no longer in effect. Individual state actions can be expected as evidenced by California's proposed Rulemaking #1, which aims to put all the delisting from SNAP Rule 20 and 21 back in effect in the state. In Canada, the government released in October 2017, a set of restrictions on the use of high GWP HFCs in many different applications including commercial refrigeration.

Several lower GWP refrigerants and HFC/HFO/HCFO blends (both A1 and A2L) are also being approved for use in various equipment types. The recent impact of these developments is summarized below for both synthetic and natural refrigerants as relevant to commercial refrigeration equipment.

In supermarkets, blends such as R-448A, R-449A, R-449B, R-452A, R-407H, R-450A, and R-513A are now beginning to grow in use, starting with Europe and the United States. Component manufacturers (compressors, valves, controls) 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 stand-alone equipment. In the stand-alone equipment category, early trials with HFO-1234yf and HFO-1234ze have started to happen as well.

The use of R-407A and R-407F (at approximately half the GWP of R-404A and with similar performance in systems) continues to grow further in many parts of the world.

Non-halocarbon 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-134, R-450A, R513A or similar and R-717 in limited cases) and in transcritical systems. Transcritical systems continue to be developed extensively to reduce their energy penalty at high ambient conditions through the use of component and system technologies. R-744 is also beginning to see its use in walk-in applications with condensing units.

Stand-alone equipment is increasingly moving from R-404A, HCFC-22 etc., to mostly HC-290. Packaged HC-290 units are growing in acceptance in cold room applications. Charge limits in safety standards continue to restrict the size of the equipment possible with flammable refrigerants, both A3 and A2L.

6.5 Industrial systems

Industrial refrigeration and heat pump systems are an integrated part of the global food chain from harvest to table. Industrial refrigeration is used for cooling all kinds of food from ambient temperature down to just above the freezing point of water or well below. Food and beverage (F&B) are important markets for industrial refrigeration. But industrial refrigeration is also used in a range of other industries such as fishing ships, pharmaceuticals, petro chemicals, airports cooling and heating systems etc.

The majority of large industrial systems in most parts of the world use R-717 as the refrigerant. Where R-717 is not acceptable in direct systems, options include R-744 or glycol and brine 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 always straightforward. In larger systems conversion to R-290 has been performed successfully e.g. petrochemical installations where one more system with flammable gas does not raise any eye brows. It requires acceptance of higher cost fluorochemicals in similar system types or the adoption of more expensive systems with the cheaper refrigerants R-717 and R-744. This transition is slow and is constrained by a lack of trained personnel and lack of experience of the local end-users. It has been facilitated by corporate policy from multinational food and beverage manufacturers. The process of moving from HCFCs to zero ODP, low GWP alternatives would be accelerated by a concerted education and training programme including operational experience and lessons learned from existing systems. This conclusion has been reinforced by several recent fatal accidents in recent years.

Suitable safety standards already exist, for example those published by EN and ASHRAE or the International Organisation for Standardization (ISO) including ISO 5149. ISO 5149 is also available as regional standards e.g. EN-378 and ASHRAE 15. When the upcoming standard of competences of personnel is finished, actually transferred from the EN 13313, the higher standard and competences will help make all types of system safer.

In markets where R-717 is accepted as the preferred refrigerant there is no indication of any likelihood of new refrigerants gaining any significant market share. It is self-evident that if the current range of HFC fluids that could be used in these applications are being avoided due to concerns about refrigerant price and long-term availability in bulk quantities then new fluids, which are expected to be even more expensive than current HFCs will not be any more successful.

There are a few exceptions to this general rule. For example, HFO (R-1234ze (E)) has been demonstrated in large district heating systems as a possible replacement for HFC-134a, however higher swept volumes and higher surface areas on the heat exchangers are required and its performance is not significantly better than HFC-134a. HFO (R-1234ze (E)) has also been demonstrated in centrifugal chillers, which could be used in process cooling or in district cooling installations. This may be a key player in addressing the challenge of rapid market growth in the Gulf Co-operation Countries over the coming years.

The industrial sectors covered by this chapter are too diverse to facilitate the level of development expenditure required to bring a new fluid to market. It therefore follows that if any new development gains market share in industrial systems it will be a fluid developed for some other purpose, either as a refrigerant in smaller mass-market systems or as a foam-blowing agent, solvent or other speciality chemical.

6.6 Transport refrigeration

The transport refrigeration industry continues to phase in lower-GWP refrigerants in new and existing systems instead of R-404A and HFC-134a, respectively.

R-452A has achieved by far the greatest market penetration in newly produced trucks and trailers in Europe. R-513A is still being tested in small tracks and marine containers. Several hundred refrigerated marine containers utilizing R-744 units are in large scale field trial.

The development of ISO 20854 is nearly complete. The standard takes a risk-based approach for the implementation of flammable and semi flammable refrigerants in refrigerated containers.

Recently built reefer ships now all use R-717. Fishing vessels built in Europe use all R-717 or a combination of R-717/R-744.

6.7 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 populous are non-ducted single splits, which are produced in excess of 110 million units per year. All products sold within non-Article 5 countries use non-ODS refrigerants. There is an increasing proportion of production of air conditioners in Article 5 countries that do not use HCFCs. Globally approximately one half of all units produced globally use non-ODP refrigerants.

There has not been a substantial change in activities since the 2017 progress report. Replacement of HCFC-22 production is continuing. In addition to the widespread introduction of HFC-32 in residential split air conditioners in Japan, increased production is continuing in certain countries in South East Asia and sales of products are continuing in Europe.

Enterprises within Article 5 countries, but mainly within non-Article 5 regions, are continuing to evaluate and develop products with various HFC/unsaturated HFC blends, such as those comprising HFC-32, HFC-125, HFC-134a, HFO-1234yf and HFO-1234ze. Further conversion of production lines to HC-290 in China is underway, and (except for small and portable units) there is limited market introduction, which is due to restrictive requirements of safety concerns and standards. In India widespread production of HC-290 split air conditioners continue, with production line conversions underway in several other high ambient countries. Some enterprises within the Middle East still see R-407C and HFC-134a as favourable alternatives to HCFC-22.

Acknowledging that almost all medium and low GWP alternatives are flammable there has been significant progress with the development of new requirements for some safety standards, primarily IEC 6-335-2-40 (particularly for increasing refrigerant charge size), with one working group addressing A2L and another on A2 and A3 refrigerants. The amendment on A2L refrigerants is now published. Due to the complexities of the process it is unclear by when the A2/A3 amendment will be published. Extensive requirements for A2L refrigerants in air conditioners have been available in ISO 5149 for several years. Numerous research activities are investigating a variety of aspects related to the application of flammable refrigerants in air conditioning equipment.

6.8 Water heating heat pumps

The production of heat pumps is increasing due to the positive impact of heat pumps on the reduction of CO_2 emissions, air pollution and use of electricity compared to traditional fossil fuel combustion heating. Consequently, we may expect a larger demand for refrigerants in water heating heat pumps in the future.

In most non-article 5 countries the transfer to non-ODS refrigerants was completed several years ago. But, based on its favourable thermodynamic properties and high efficiency in heat pump applications, HCFC-22 is still in use for high and moderate temperature water and space heating heat pumps in the A5 countries.

In Europe, the legislation on fluorinated greenhouse gases has shown its first impact on the refrigerant choice including refrigerants for water heating heat pumps. Due to the higher prices for higher GWP refrigerants there is a growing interest in lower GWP refrigerants. Some options that were reported in the 2014 RTOC report are now commercialised. These refrigerants are HC-290, HFC-32 and R-744. Blends with HFO refrigerants are under investigation now.

For some products, there is no suitable solution due to the limited availability of components for the products, mainly compressors. Some other regions outside the EU tend to follow the change where it is economical and technical feasible. Also, in Japan, there is an uptake in the use of R-744 and HFC-32 for the use in water heating heat pumps.

In Europe, Japan and the US, legislation is now in place on minimum energy efficiency for space heating and water heating heat pumps. This has limited the refrigerant options for air to water heat pumps (as some fall below the required minimum efficiency).

6.9 Chillers

Chillers using low GWP refrigerants have been commercialized and are emerging in the market. See Table D. This comes after years of research and screening of alternative refrigerant candidates. It is expected that the transition to low GWP refrigerants will take some years owing to the high investment and the large product development effort to convert the huge array of product types and sizes. It is also noted that non-fluorinated refrigerants are available in some chiller types, albeit in select sizes, rather than broad, complete product lines.

Table D: Emerging refrigerants used in chillers

Product	Dominant Refrigerants Presently Used	Emerging Refrigerants
Large chillers with centrifugal compressors using low pressure refrigerants	HCFC-123 [1] HFC- 245fa (less common) R-718 (less common)	HCFO-1233zd(E) R-514A R-718
Large chillers with centrifugal compressors using medium pressure refrigerants	HFC-134a	R-513A HFO-1234yf HFO-1234ze(E)
Mid-size chillers with positive displacement (screw) compressors	HFC-134a HC-290[3] R-717[2]	R-513A HFO-1234yf[2] HFO-1234ze(E) [2] HC-290[3] R-717[2]
Small chillers with positive displacement (scroll or reciprocating) compressors	R-407C R-410A	HFC-32[2] R-452B[2] R-290[3] R-744

[1] *Phase out in new equipment in 2020 for Article 2 Countries, 2030 for Article 5 Countries*

[2] *Classified as safety group A2L or B2L refrigerant (flammable), means there are special considerations contained in product or safety code and standards for safe application.*

[3] *Classified as safety group A3 refrigerant (highly flammable) currently available in air cooled chillers installed outdoors*

The refrigerants that are being commercialized may not be the final choices. Chemical producers and chiller manufacturers will continue to focus their efforts on refrigerant candidates that provide energy efficiencies that are equal to or better than the refrigerants being replaced and reduce product development cost and time.

Customers and regulators alike are interested in less energy consumption and lower energy cost. There continues to be consumer and regulatory pressure to improve full and part load or seasonal energy consumption which will have a positive climate impact.

Global warming effects from chillers are dominated by their energy use during their operating life, not direct emissions. The direct global warming effect from refrigerant emissions are minimal because emissions have been significantly reduced in recent years through lower charge systems, low-leak designs, manufacturing and testing improvements, and improved service practices.

6.10 Motor vehicle air conditioning (MAC)

In response to the Montreal Protocol, new motor vehicles with air conditioning (MAC) have been equipped with systems using HFC-134a with some R-407C use in buses. By the year 2000, the transition to HFC-134a was complete in all developed countries and in 2007 in developing countries.

In 2013, as a consequence of the European MAC Directive and U.S. EPA regulations the transition to lower GWP refrigerants started. Now almost all new light vehicles in Europe and many in the United States and other countries are equipped with HFO-1234yf mobile air conditioners. A slower transition to HFO-1234yf for heavy vehicles and delivery vans is also occurring.

R-744 is also an alternative, which some premium models have started using in 2017. R-744 is also under evaluation for use in heat pumps on electrified vehicles.

The current systems are of direct expansion type. Indirect expansion (secondary loop) systems are starting to appear on electrified vehicles that require thermal management system for the cooling of batteries and electric motors.

Counterfeit refrigerants are becoming a major issue, even where HFC-134a is relatively inexpensive (~ US $5/lb or US $11/kg). Counterfeit HFC-134a contains multiple CFC, toxic, or corrosive components and can destroy equipment and injure end-users. The counterfeit risk will likely become even more significant as more expensive refrigerants (e.g. R-1234yf) become available. The price of HFC-1234yf (~ US$ 40-45/kg) is currently a barrier for its uptake in developing countries.

The diffusion of electrified vehicles in the main markets (Europe, North America and China) have generated significant development activity among car manufacturers to design proper thermal management systems. The thermal management system integrates the air conditioning (cooling and heating) with the use of secondary fluids for the cooling of batteries, electric motors and other components.

6.11 Energy efficiency and sustainability applied to refrigeration systems

The term sustainable refrigeration is linked to understanding and assessing the efficient use of resources of all kinds, but especially energy for operating refrigeration systems.

Beside others, energy efficiency considerations were the basis for the introduction of the chapter on sustainable refrigeration in the UNEP TEAP 2010 Assssment Report. In the period 2014-2018, the importance of energy efficiency for the selection of refrigerants has increased significantly.

Therefore, there is an increasing use of tools and mechanisms for sustainable product development, considering the entire life cycle of the product and factors for the selection of refrigerants. Selection criteria are mainly energy efficiency, climate impact, adaptability for thermal energy storage, costs, technological level, safety and flammability. There is an emphasis in LCCP and TEWI as selection tools.

The effects of policy and regulatory measures, industry commitments, labelling of energy efficient products and other factors are growing in many regions and countries.

Refrigeration and air conditioning sustainability is being considered beyond what has been dedicated only to refrigerants, going a more holistic look at the lifecycle of an air conditioning and refrigeration system. Opportunities are being identified to achieve sustainability improvements along the lifecycle of a refrigeration system through the reduction of use of raw materials and the establishment of codes of ethical conduct for suppliers along the value chain.

6.12 Not-in-Kind(NIK) technologies

The present classification of NIK technologies has been expanded into:

- Commercially available (at least one manufacturer),
- Widely commercially available (more than one manufacturer),
- Emerging (last step before commercialization),
- Research and Development (first development stage for a promising technology).

Some technologies in the last period changed status from R &D to Emerging and more technologies are commercially available.

6.13 High ambient temperature (HAT) considerations

There is a continuing movement and discussion on the recognition and perception of the HAT issue, related to the importance of designing equipment and systems especially for HAT conditions when in reality market forces and the volume of equipment installed each year in HAT countries do not always allow for a commercially viable special design.

Safety is of special consideration when risk assessment models are being drawn for the use of flammable refrigerants in the different regions. The elevated refrigerant charge amounts needed to meet HAT conditions and the capability of technicians in the service sector of HAT countries requires a focus on providing a risk assessment model for HAT conditions in HAT countries.

The adoption by the Kigali Amendment of a special phase-down regime for certain HAT countries has facilitated the discussion which is now concentrated on the technical aspects of HAT rather than the policy or political issues.

6.14 Modelling of RACHP systems

There are a number of models used to calculate data for refrigeration and air conditioning applications: (1) Combined thermodynamic, flow and heat transfer models used in R&D to investigate the impact of refrigerant heat transfer, refrigerant properties, flow patterns (either steady state or dynamic simulation) to investigate component, cycle and equipment design; (2) Thermodynamics based models that calculate energy efficiency and energy consumption for an R/AC application under certain well determined ambient conditions, (3) Models that focus on total (climate relevant) emission reductions. They depart from assumptions or data on the number of pieces of equipment of certain types in the AC subsector and from test data regarding energy efficiency improvements possible by changing refrigerants, and can therefore calculate climate benefits expressed in CO_2-eq.; these models often combine the climate benefit with impacts of energy efficiency increase and heat-cooling load reduction, which makes the whole not very transparent; this also because the fuel mix in power generation plays an important role here, (4) Inventory models that calculate the amounts of refrigerant charged into refrigeration and air conditioning equipment, based on sales data of various types of equipment for a country or region, which can then also be defined as the (total, regional) bank of refrigerants. Together with assumptions regarding leakage and recovery during operation and end of life, and most importantly, during servicing and maintenance, the refrigerant demand and the refrigerant emissions can be determined for a given year, as well the bank fluctuations over a certain period.

For the RTOC 2018 assessment report, the focus for modelling will be on “bottom-up” models used to predict the regional or global refrigerant demand for R/AC equipment. It requires the determination of the number of pieces of equipment charged with refrigerants (which then forms the total inventory or “bank”), and knowledge related to the average lifetime and the emission rates of equipment, plus assumptions on recycling, disposal, and other parameters. Important parameters are the number of pieces of equipment (per sub-sector) manufactured in certain countries or certain regions per year, this also dependent on economic growth (GDP) parameters, the types of refrigerants used, the ongoing development in equipment design, and, last but not least, the required refrigerant demand for servicing. A very sensitive issue here is the growth in sales of equipment, which are currently often completely disconnected from overall economic growth parameters. It is therefore quite challenging to find good data on the production of various types of equipment and the related sales for domestic use and export. Needless to say, that these are extremely important data (or parameters) for any “bottom-up” method. It can be stated that good progress has so far been made during the year 2018 in determining these parameters, albeit with considerable uncertainty ranges, based on the publication of sales data and on manufacturing information for the period 2014-2017. It is expected that the availability of all the data and parameters will enable to develop “bottom-up” scenarios for the refrigerant demand (and related banks and emissions) for the next 5-year period, i.e., towards the freeze year for HFCs for Group I Article 5 countries under the Kigali Amendment.

One other important aspect needs to be mentioned here, which is the check of the “bottom-up” demand data for the R/AC sector with reliable chemical manufacturing data for both HCFCs and HFCs worldwide, as well on a regional basis. It is an advantage that the R/AC market for HFC chemicals can be determined reasonably well since the use of HFCs for other sectors is quite moderate and can be estimated pretty well. Where HCFC production data can be taken from Article 7 reporting to UNEP, the HFC production data have to be derived from extrapolations from manufacturers ‘data, from consultancy market data reports etc., as well as from specific country information. An advantage is that production in non-Article 5 parties of some of the most used HFCs in R/AC is reported to the UNFCCC. Further analysis then has to dive into further checks of HFC chemical production data from a very small number of chemical manufacturers in Article 5 parties, where both domestic production and production for export of equipment are parameters that need to be looked into. There is some similarity of the HCFC R/AC market in the past with the current HFC market, although growth parameters of the latter make comparisons often challenging. This “chemical check” is currently one of the most important ongoing efforts. It is expected that for the 2018 RTOC assessment report (later this year), an adequate set of data will be available to enable a good cross-check of the global (and some regional) “bottom-up” derived data for demand, which would then automatically include a check of R/AC banks and emissions data.

7 Decision XXIX/9 - TEAP Working Group report on HCFCs - Update

Additional information became available to TEAP after publication in March 2018 of the Decision XXIX/9 TEAP Working Group report on HCFCs. The information below updates that report with the new information.

7.1 Solvents and other niche uses

In relation to the topical medical aerosol application in the Russian Federation, which uses HCFC-22 and -141b as propellant and solvent, the TEAP is now aware of an aerosol foam product used to provide local anti-inflammatory and antiseptic action, and to stimulate healing. Other analogues exist that perform a similar function, and potential alternative propellants include LPG, HFCs, isobutane/HFC-152a blends, HFOs, compressed gas such as nitrogen, air, or carbon dioxide. Patients and doctors in the Russian Federation are claimed to prefer this particular HCFC aerosol foam product, and Russian pharmacies cannot sell flammable aerosol products. Also, when used for radiation skin burns, LPG propellant acts as a skin irritant. In other non-Article 5 parties, similar products do not use HCFCs for this purpose. In the United States, for example, an isobutane/HFC-152a blend is used that has low flammability in foams. HFO-1234ze is also under investigation and testing for these types of aerosol applications.

Regarding the solvent use of HCFC-225 for syringe/needle coating in Japan, alternative non-ODS solvents are used in Europe and the United States (e.g. HFEs). Topical creams are also available as pain relief for injections. HCFC-141b is used for this purpose in Article 5 parties.

7.2 Fire Protection[32]

Two fire protection equipment manufacturers in the United States have expressed a desire to continue to use HCFC-123 as a streaming agent for portable and wheeled unit applications in the 2020-2030 timeframe. They point out that in the applications where clean agents are required, HCFC-123 is superior to the other alternative agent, fluoroketone, FK-5.1.12. They also state that once a new commercially-available USEPA SNAP-approved clean agent is available, it will take approximately 10 years to develop and commercialize based on previous history of developing new clean agent extinguishers. This timescale is consistent with that stated by the HTOC in this 2018 TEAP Progress Report (Chapter 3). Currently the only potential alternative is 2-BTP; according to these two U.S. manufacturers, this firefighting agent has promising performance characteristics, but its current workplace exposure limits in the U.S. prevent any realistic mass production of an extinguisher utilizing 2-BTP.

7.3 Use of Recycled HCFCs

A recent report by the USEPA[33] has modelled the projected servicing demand for HCFCs in air-conditioning, refrigeration, and fire suppression sectors in the US for the period 2020-

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[32] HTOC uses the terms ‘fire protection”, “fire suppression” ‘fire extinguishing” interchangeably.

[33] Draft Report: The U.S. phaseout of HCFCs: Projected Servicing Demand in The U.S. Air-Conditioning, Refrigeration, and Fire Suppression Sectors for 2020-2030. https://www.epa.gov/sites/production/files/2018-04/documents/draft_report_the_us_phaseout_of_hcfcs_projected_servicing_demands_in_the_u.s._air_conditioning_refrigeration_and_fire_suppression_sector_2020-2030_0.pdf

2030. Over this period, the overall installed base of HCFC-123 in the US is projected to decrease from 29,300 to 17,400 tonnes, thus potentially yielding approximately 1100 – 1300 tonnes per year of recycled material. The USEPA Vintaging Model (described in the report) estimates that 90% of this amount will be available. However, historical reclamation data is significantly below this (approx. 200 tonnes over the last 5 years). The overall annual demand for HCFC-123 in the US is estimated to be 820 tonnes in 2020, falling to 580 tonnes in 2030 of which fire protection is estimated to be 260 tonnes per annum throughout this period. This indicates that for this region there does not appear to be sufficient recycled HCFC-123 to meet projected demand. The also implies that the overall demand for HCFC-123 for fire protection globally estimated in previous report was too high. Based on these new data, the TEAP estimates that the global demand for HCFC-123 in fire protection is likely to be half of the original estimate, i.e. a total of 450 tonnes annually. This demand is anticipated to also account for other existing fire protection uses of HCFC-123 as discussed in the Decision XXIX/9 Working Group report.

8 Decision XXVI/5- Laboratory and analytical uses of ODS

Decision XXVI/5(2) requests TEAP "...to report no later than 2018 on the development and availability of laboratory and analytical procedures that can be performed without using controlled substances under the Montreal Protocol". MCTOC is preparing a response to this decision, with plans to report in time for the 30th MOP.

Information is currently being collected about ODS uses of laboratory and analytical uses (LAUs), and possible alternatives to those uses. Article 7 data related to LAUs has been analysed to determine reported ODS and quantities of their production and consumption. Small quantities of a wide range of about 40 different ODS are used in this application, with an overall trend of decreasing global production over time. MCTOC will focus on the major ODS by quantity, which are carbon tetrachloride and CFC-113. It will also consider more minor uses of HCFCs and methyl bromide. It will consider available information from non-Article and Article 5 parties.

For laboratory uses, initial investigations indicate that there are now a variety of alternatives to replace the use of carbon tetrachloride as a solvent in bromination reactions involving *N*-bromosuccinimide.

For analytical procedures, investigations are being undertaken into procedures that have required the use of ODS and any available alternatives. These investigations are proving to be challenging for the following reasons.

- Documented international and national standards are multitudinous, and these standards vary from country to country and cover a wide range of different applications.
- It is difficult to identify and access a complete range of relevant published standards set by organisations such as the International Organization for Standardization (ISO), ASTM International (ASTM), and the European Committee for Standardization (CEN).
- Redundant standards are still available from standard-setting organisations after being replaced by newer methods. It is sometimes difficult to characterise and identify whether a standard is new or replaced, and how it might relate to possible alternative procedures. This can hinder the identification of available alternative procedures.

MCTOC would welcome available information from parties on this topic. MCTOC continues to seek new members who are experts in laboratory and analytical uses. Parties may wish to consider nominating experts.

9 Other TEAP matters

9.1 TEAP and TOCs organisation

As indicated in Annex 1, TEAP currently includes 20 members including 6 Senior Experts. In addition, almost 150 experts serve on its five TOCs. TEAP recognises and is grateful for the voluntary service of the TEAP and TOCs members, past and present, and their substantial contributions. to the successful protection of the ozone layer.

In TEAP's Decision XXIV/8 Task Force Report (May 2013), individual TOCs membership numbers in the 2014-2018 period were anticipated to remain the same or decrease from the 2013-2014 period due to anticipated attrition during the 2014 reappointment process; the exception to this was RTOC, which was predicted to retain or increase its previous membership numbers based on anticipated workload. Annex 1 of this report provides updated TOC membership lists, which include the start dates and current terms of appointment for all members. As a result of Decision XXIV/8, a majority of TOC members will reach the end of their appointment at the end of 2018. There is a risk of loss of expertise. However, this is also an opportunity to re-assess the skill mix required, and re-focus the TOCs on the continuing phaseout of ODS under the Montreal Protocol and the phasedown of HFCs under the Kigali Amendment going forward.

TEAP is taking a broad view of its work for parties going forward under these mandates, its current pool of experts, the potential loss of expertise through attrition or lack of support for some experts, the need for specific and cross-cutting expertise within TOCs and the TEAP itself. TEAP is working to identify appropriate expertise and find qualified candidates interested and available to serve in these positions. TEAP will communicate these needs through its matrix of needed expertise and communication with interested parties in order to manage an orderly transition, avoiding significant disruption to its work. TEAP seeks to discuss with Parties how to engage experts in these areas, mindful of the need for geographical and gender balance.

In addition to the above update, TEAP takes the opportunity in this report to bring to the attention of the Parties specific issues relevant to particular TOCs:

9.1.1 FTOC

TEAP co-chair Ashley Woodcock stepped down as interim co-chair with the Decision XXIX/20 appointment by parties of Helen Walter-Terrinoni (USA) as co-chair. She joins current co-chair Paulo Altoe (Brazil) who was appointed in 2016.

FTOC had a successful meeting in London in April 2018. FTOC has 22 members (9 from A5 parties and 13 from non-A5 parties). Five new members have been appointed in the last 12 months, and two members have retired. FTOC members have participated in the responses and Decision XXVIII/8 on phaseout of HCFCs, and Decision XXVI/4 on Destruction. FTOC assessment report is being drafted.

9.1.2 HTOC

One new member was added to the HTOC in 2018; Mr Khaled Effat (Egypt) to provide expertise particularly in the North Africa and Middle East regions. The HTOC is still seeking additional expertise as detailed in Annex 1 Matrix of Needed Expertise.

9.1.3 MBTOC

MBTOC met in Melbourne, Australia in March 2018. Membership continues to be at a historical low with 16 members (including one economist). The required expertise in soils, structures and commodities and QPS is adequate to complete the current tasks. One new member from Turkey was appointed in 2018. MBTOC is still seeking to recruit experts for the nursery industries, particularly an expert having a clear understanding of issues affecting the strawberry runner industries globally.

9.1.4 MCTOC

MCTOC combines a range of very different sectoral topics, including aerosols, sterilants, MDIs, chemicals (solvents, process agents, chemicals issues such as feedstock and production, laboratory and analytical uses), and destruction technologies. MCTOC has 3 co-chairs and 34 members, with 12 from A5, and 25 from non-A5 parties, and 3 consulting experts. In 2017, Helen Tope (Australia) was appointed as MCTOC co-chair for a term of up to four-years concluding in 2021. The terms of appointment of 21 members will conclude in 2018, and MCTOC is in the process of reviewing membership and considering nominations for reappointment.

In readiness for its assignments, MCTOC co-chairs recruited new members in areas of aerosols, MDIs, and destruction technologies in 2018, and continues to seek new members in destruction technologies and laboratory and analytical uses. Identifying relevant experts related to laboratory and analytical uses is challenging because there are few people who are professional specialists on this topic. Steven Bernhardt (US) and Tunde Otulana (US) retired as members in early 2018, and MCTOC is grateful to them for their contributions over many years. Chemicals, destruction technologies, aerosols, and MDI members met together face to face for MCTOC’s meeting in Bruges in March 2018 to consider progress and assessment reports. Finding the value in meeting face to face, MDI members agreed they would meet in future years if and when there was a specific need to do so, in preference to teleconferencing. Sterilants members, who participate via correspondence, met via a teleconference in March.

9.1.5 RTOC

RTOC met in Bruges in October 2017 and Delhi in 2018. The RTOC has 3**7** experts nominated from 20 parties (13 members from A5 parties, 24 from non-A5 parties). A number of RTOC members including co-chairs are on the Decision XXIX/10 Task Force on Energy Efficiency.

RTOC will appoint 3 new members (US, Brazil, Indonesia) with immediate effect to broaden expertise. Many RTOC members reach the end of their appointments at the end of 2018. This will enable RTOC to consider its organization and structure, and to re-focus its efforts related to its anticipated work for parties going forward.

9.2 Continuing challenges

The role of TEAP and its TOCs continues to evolve to meet the current and future needs of parties. The TEAP, its TOCs and other Temporary Subsidiary Bodies, has had to change its focus, as the Montreal Protocol has moved from introducing and strengthening control schedules (based upon assessment reports), to managing the use of controlled chemicals and to compliance with the Protocol. The TEAP role will again evolve with the adoption of Kigali Amendment and the phasedown of HFCs. TEAP continues to work so that its TOCs are structured in size and expertise to support future efforts of the Parties but takes the opportunity in this report to address ongoing challenges and bring them to the attention of the Parties.

The challenge to TEAP and TOC leadership remains to identify candidates with adequate history and experience as well as technical expertise and time, in order for TEAP to continue to meet the significant demands of delivering outputs to support the deliberations of Parties, without loss of continuity. The main approach taken by TEAP and its TOCs is to appoint experts in new technical areas (e.g. Safety, Energy Efficiency) to contribute into TEAP Task Forces, and/or TOCs, where new appointees can share their experience, knowledge, ability to communicate, and capacity to provide relevant data in a timely manner. Some of these experts could become TOC or TEAP members should the parties request further studies on such new technical areas.

The workload related to the tasks assigned to TEAP and its TOCs has grown substantially in recent years with the responses to various requests of the Parties; if unaddressed this situation will increasingly affect the delivery and timeline of TEAP's outputs. Members of TEAP and TOCs often concurrently serve on TEAP Task Forces adding to the workload and making it difficult to meet deadlines.

TOCs have been challenged with attrition through retirement of members and loss of expertise. This is of growing concern to the consensus process of the committees where a range of independent expert opinions is necessary. Absence of funding is of growing concern for TOC and TSB co-chairs, with the substantial administrative responsibility to bring their respective groups to consensus, generate draft reports, and then deliver final products within strict deadlines.-The members of TEAP and its TOCs provide their expertise and work on a voluntary basis and many are finding the increasing time commitment and overall workload required difficult/impossible to manage in the context of a full-time occupation.

TEAP is determined to re-invigorate its membership and leadership, but at the same time maintain involvement of TOC and senior expert members with substantial experience to ensure the continuity of its work for Parties. In view of the Kigali Amendment, TEAP is also considering recruiting contributing members with the expertise needed to address any knowledge gaps at least for a period of time. TEAP points out that 7 of its 20 members will reach the end of current appointments in 2018. This provides risk of loss of expertise and continuity, but it is also an opportunity for re-invigorating and refocussing TEAP.

To ensure that the functioning of the TEAP and its TOCs continue providing timely assessments to support the discussions of parties, both TEAP and the parties may need to consider the overall annual workload, the deadlines for delivery and the support provided to TEAP, at the time of making decisions requesting this work.

TEAP welcomes the opportunity to further engage with Parties to address these challenges to the functioning of the TEAP and its TOCs going forward and remains committed to providing Parties with the best possible, independent, technical consensus reports to support their work.

Annex 1: TEAP and TOC membership and administration

The disclosure of interest (DOI) of each member can be found on the Ozone Secretariat website at: http://ozone.unep.org/en/assessment-panels/technology-and-economic-assessment-panel. The disclosures are normally updated at the time of the publication of the progress report. TEAP's Terms of Reference (TOR) (2.3) as approved by the Parties in Decision XXIV/8 specify that
"… the Meeting of the Parties shall appoint the members of TEAP for a period of no more than four years…and may re-appoint Members of the Panel upon nomination by the relevant party for additional periods of up to four years each.". TEAP member appointments end as of 31 December of the final year of appointment, as indicated in the last column of the following tables.

1. Technology and Economic Assessment Panel (TEAP) 2018

Co-chairs	**Affiliation**	**Country**	**Appointed through**
Bella Maranion	U.S. EPA	US	2020
Marta Pizano	Consultant	Colombia	2018*
Ashley Woodcock	University of Manchester	UK	2018*
Senior Experts	**Affiliation**	**Country**	**Appointed through**
Mohamed Besri	Inst. Agronomique et Vétérinaire Hassan II	Morocco	2018*
Suely Machado Carvalho	Consultant	Brazil	2019
Marco Gonzalez	Consultant	Costa Rica	2018*
Rajendra Shende	Terre Policy Centre	India	2020
Sidi Menad Si-Ahmed		Algeria	2018*
Shiqiu Zhang	Peking University	China	2018*
TOC Chairs	**Affiliation**	**Country**	**Appointed through**
Paulo Altoé		Brazil	2020
Adam Chattaway	UTC Aerospace Systems	UK	2020
Sergey Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2021
Kei-ichi Ohnishi	Asahi Glass	Japan	2019
Roberto. Peixoto	Maua Institute (IMT), Sao Paulo	Brazil	2021
Fabio Polonara	Universitá Politecnica delle Marche	Italy	2018*
Ian Porter	La Trobe University	Australia	2021
Helen Tope	Energy International Australia	Australia	2021
Daniel P. Verdonik	Jensen Hughes	US	2020
Helen Walter-Terrinoni	Chemours	US	2021
Jianjun Zhang	Zhejiang Chemical Industry Research Institute	PRC	2019

** Indicates members whose terms expire at the end of the current year*

TEAP's TOR (2.5) specifies that *"TOC members are appointed by the TOC co-chairs, in consultation with TEAP, for a period of no more than four years…[and] may be re-appointed following the procedure for nominations for additional periods of up to four years each."* New appointments to a TOC start from the date of appointment by TOC co-chairs and end as of 31st December of the final year of appointment, up to four years.

2. TEAP Flexible and Rigid Foams Technical Options Committee (FTOC)

Co-chair	Affiliation	Country	Appointed through
Helen Walter-Terrinoni	Chemours	US	2021
Paulo Altoé	Dow	Brazil	2020
Members	**Affiliation**	**Country**	**Appointed through**
Samir Arora	Industrial Foams	India	2020
Paul Ashford	Anthesis	UK	2019
Angela Austin	Consultant	UK	2019
Kultida Charoensawad	Covestro	Thailand	2019
Roy Chowdhury	Foam Supplies	Australia	2018*
Joseph Costa	Arkema	US	2020
Rick Duncan	Spray Polyurethane Association	US	2018*
Koichi Wada	Bayer Material Science/JUFA	Japan	2018*
Ilhan Karaağaç	Izocam	Turkey	2020
Shpresa Kotaji	Huntsman	Belgium	2018*
Simon Lee	Dow	US	2018*
Yehia Lotfi	Technocom	Egypt	2018*
Lisa Norton	Solvay	US	2019
Miguel Quintero	Consultant	Colombia	2019
Sascha Rulhoff	Haltermann	Germany	2018*
Enshan Sheng	Huntsman	China	2018*
Dave Williams	Honeywell	US	2018*
Guolian Wu	Samsung	US	2020
Consulting Expert			**Yearly**
Sally Rand	Consultant	US	2018

** Indicates members whose terms expire at the end of the current year*

3. TEAP Halons Technical Options Committee (HTOC)

Co-chair	Affiliation	Country	Appointed through
Adam Chattaway	UTC Aerospace Systems	UK	2020
Sergey N. Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2021
Daniel P. Verdonik	JENSEN HUGHES, Inc.	USA	2020
Members	**Affiliation**	**Country**	**Appointed through**
Jamal Alfuzaie	Consultant – Retired	Kuwait	2018*
Johan Åqvist	FMV	Sweden	2019
Youri Auroque	European Aviation Safety Agency	France	2019
Seunghwan (Charles) Choi	Hanchang Corp	South Korea	2018*
Michelle M. Collins	Consultant- EECO International	USA	2018*
Khaled Effat	Modern Systems Engineering	Egypt	2021
Carlos Grandi	Embraer	Brasil	2020
Laura Green	Hilcorp Alaska, LLC	USA	2020
Elvira Nigido	A-Gas Australia	Australia	2020
Emma Palumbo	Safety Hi-tech srl	Italy	2018*
Erik Pedersen	Consultant – World Bank	Denmark	2020
R.P. Singh	CFEES, DRDO	India	2020
Donald Thomson	MOPIA	Canada	2020
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan	2020

Consulting Experts	Affiliation	Country	Appointed through
Pat Burns	A-Gas Americas	USA	All one year renewable terms
Thomas Cortina	Halon Alternatives Research Corporation	USA	
Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan	
Nikolai Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	
Steve McCormick	United States Army	USA	
John G. Owens	3M Company	USA	
John J. O'Sullivan	Bureau Veriitas	UK	
Mark L. Robin	Chemours	USA	
Joseph A. Senecal	Kidde-Fenwal Inc.	USA	
Ronald S. Sheinson	Consultant – Retired	USA	
Robert T. Wickham	Consultant-Wickham Associates	USA	

** Indicates members whose terms expire at the end of the current year*

4. TEAP Medical and Chemicals Technical Options Committee (MCTOC)

Co-chairs	Affiliation	Country	Appointed through
Kei-ichi Ohnishi	Asahi Glass	Japan	2019
Helen Tope	Energy International Australia	Australia	2021
Jianjun Zhang	Zhejiang Chemical Industry Research Institute	China	2019
Members	**Affiliation**	**Country**	**Appointed through**
Emmanuel Addo-Yobo	Kwame Nkrumah University of Science and Technology	Ghana	2018*
Fatima Al-Shatti	Kuwait Petroleum Corporation	Kuwait	2018*
Paul Atkins	Oriel Therapeutics Inc. (A Novartis Company)	USA	2018*
Bill Auriemma	Diversified CPC International	USA	2021
Olga Blinova	Russian Scientific Center "Applied Chemistry"	Russia	2018*
Steve Burns	AstraZeneca	UK	2021
Nick Campbell	Arkema	France	2018*
Jorge Caneva	Favaloro Foundation	Argentina	2018*
Nee Sun (Robert) Choong Kwet Yive	University of Mauritius	Mauritius	2018*
Rick Cooke	Man-West Environmental Group Ltd.	Canada	2021
Davide Dalle Fusine	Chiesi Farmaceutici (seconded at Chiesi China)	Italy	2018*
Maureen George	Columbia University School of Nursing	USA	2021
Kathleen Hoffmann	Sterigenics International Inc.	USA	2020
Eamonn Hoxey	E V Hoxey Ltd	UK	2018*
Jianxin Hu	College of Environmental Sciences & Engineering, Peking University	China	2018*
Ryan Hulse	Honeywell	USA	2020
Biao Jiang	Shanghai Institute of Organic chemistry, Chinese Academy of Sciences	China	2018*
Javaid Khan	The Aga Khan University	Pakistan	2018*
Andrew Lindley	Independent consultant to Mexichem UK Ltd. and to the European Fluorocarbon Technical Committee	UK	2020
Gerald McDonnell	DePuy Synthes, Johnson & Johnson	USA	2018*
Robert Meyer	Independent Consultant to Greenleaf Health	USA	2018*
John G. Owens	3M	USA	2020
Jose Pons Pons	Spray Quimica	Venezuela	2019
Hans Porre	Teijin Aramid	Netherlands	2018*
John Pritchard	Philips	UK	2018*
Rabbur Reza	Beximco Pharmaceuticals	Bangladesh	2018*
Paula Rytilä	Orion Corporation Orion Pharma	Finland	2019
Surinder Singh Sambi	Indian Institute of Chemical Engineers (Northern Region)	India	2018*
Rajiev Sharma	GSK	UK	2021
Roland Stechert	Boehringer Ingelheim	Germany	2018*
Jørgen Vestbo	University of Manchester	Denmark	2021
Kristine Whorlow	Non-Executive Director	Australia	2018*
Ashley Woodcock	University Hospital of South Manchester	UK	2019
Yizhong You	Journal of Aerosol Communication	China	2018*
Consulting Experts	**Affiliation**	**Country**	**One-year renewable terms**
Archie McCulloch	Independent Consultant to European Fluorocarbon Technical Committee (EFCTC)	UK	
Hideo Mori	Tokushima Regional Energy	Japan	
Lifei Zhang	National Research Center for Environmental Analysis and Measurement	China	

** Indicates members whose terms expire at the end of the current year*

5. TEAP Methyl Bromide Technical Options Committee (MBTOC)

Current appointment terms for the three MBTOC co-chairs finalise at the end of the current year.

Co-chairs	Affiliation	Country	Appointed through
Marta Pizano	Consultant - Hortitecnia Ltda	Colombia	2021
Ian Porter	La Trobe University	Australia	2021
Members	**Affiliation**	**Country**	**Appointed through**
Jonathan Banks	Consultant	Australia	2018*
Mohamed Besri	Emeritus Professor, Institut Agronomique et Vétérinaire Hassan II	Morocco	2021
Fred Bergwerff	Oxylow BV	Netherlands	2018*
Aocheng Cao	Chinese Academy of Agricultural Sciences	China	2018*
Sait Erturk	Plant Protection Central Research Institute	Turkey	2018*
Ken Glassey	MAFF – NZ	New Zealand	2018*
Eduardo Gonzalez	Fumigator	Philippines	2018*
Rosalind James	USDA	US	2020
Takashi Misumi	MAFF – Japan	Japan	2018*
Christoph Reichmuth	Honorary Professor	Germany	2018*
Jordi Riudavets	IRTA – Department of Plant Protection	Spain	2019
Akio Tateya	Technical Adviser, Syngenta	Japan	2018*
Alejandro Valeiro	Nat. Institute for Ag. Technology	Argentina	2018*
Nick Vink	University of Stellenbosch	South Africa	2018*

** Indicates members whose terms expire at the end of the current year*

6. TEAP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC)

Co-chairs	Affiliation	Country	Appointed through
Roberto de A. Peixoto	Maua Institute of Technology, IMT, Sao Paulo	Brazil	2021
Fabio Polonara	Universita' Politecnica delle Marche	Italy	2018*
Members	**Affiliation**	**Country**	**Appointed through**
James M. Calm	Engineering Consultant	USA	2018*
Radim Cermak	Ingersoll Rand	Czech Rep	2018*
Guangming Chen	Zhejiang University, Hangzhou	China	2018*
Jiangpin Chen	Shanghai University	China	2018*
Daniel Colbourne	Re-phridge Consultancy	UK	2018*
Richard DeVos	General Electric	USA	2018*
Sukumar Devotta	Consultant	India	2018*
Martin Dieryckx	Daikin Europe	Belgium	2018*
Dennis Dorman	Trane	USA	2018*
Bassam Elassaad	Consultant	Lebanon	2018*
Ray Gluckman	Gluckman Consulting	UK	2020
Dave Godwin	U.S. EPA	USA	2018*
Marino Grozdek	University of Zagreb	Croatia	2018*
Samir Hamed	Petra Industries	Jordan	2018*
Martien Janssen	Re/genT	Netherlands	2018*
Michael Kauffeld	Fachhochschule Karlsruhe	Germany	2018*
Jürgen Köhler	University of Braunschweig	Germany	2018*
Holger König	ref-tech Consultancy	Germany	2018*
Lambert Kuijpers	A/genT Consultancy	Netherlands	2020
Richard Lawton	CRT Cambridge	UK	2018*
Tingxun Li	Guangzhou University	China	2018*
Dhasan Mohan Lal	Anna University	India	2019
Maher Mousa	MHMENG Consultancy	Saudi Arabia	2019
Petter Nekså	SINTEF Energy Research	Norway	2018*
Horace Nelson	Consultant	Jamaica	2018*
Carloandrea Malvicino	Fiat Ricerche	Italy	2018*
Tetsuji Okada	JRAIA	Japan	2018*
Alaa A. Olama	Consultant	Egypt	2018*
Alexander C. Pachai	Johnson Controls	Denmark	2018*
Per Henrik Pedersen	Danish Technological Institute	Denmark	2018*
Rajan Rajendran	Emerson Climate Technologies	USA	2018*
Giorgio Rusignuolo	Carrier Transicold	USA	2018*
Asbjorn Vonsild	Danfoss	Denmark	2018*
Sauel Yana Motta	Honeywell	Peru	2019
Hiroichi Yamaguchi	Toshiba Carrier Corp.	Japan	2020

** Indicates members whose terms expire at the end of the current year*

Annex 2: Matrix of needed expertise

As required by the TEAP TOR an update of the matrix of needed expertise on the TEAP and its TOCs is provided below valid as of May 2018.

Body	Required Expertise	A5/ Non-A5
Foams TOC	XPS technical knowledge in Asia, especially India and China	A5
Halons TOC	Fire suppression applications in civil aviation Knowledge of halon alternatives and their market penetration Knowledge of banking and supplies of halon and alternatives Knowledge of ship breaking activities	A5, South East Asia A5, Africa, South America, South Asia A5 Africa, South America A5 or non-A5
Methyl Bromide TOC	Issues related to the validation of alternatives to MB for certification of nursery plant materials related to movement across state and international boundaries and related risk assessment Expert in economic assessment of alternatives to MB Expert in QPS uses of MB and alternatives	A5 or non-A5 Non-A5 A5
Medical and Chemical TOC	Destruction technologies (experts with knowledge on the range of different technologies) Laboratory and analytical uses (experts with knowledge of analytical procedures)	A5 or non-A5
Refrigeration TOC	To be further considered	
Senior Experts	To be further considered	