

# **MONTREAL PROTOCOL ON SUBSTANCES THAT DEplete THE OZONE LAYER**

## **REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL**

**MAY 2022**

**VOLUME 1: PROGRESS REPORT**



**Montreal Protocol on Substances that Deplete the Ozone Layer**  
**United Nations Environment Programme (UNEP)**  
**Report of the Technology and Economic Assessment Panel**

**May 2022**

**VOLUME 1: PROGRESS REPORT**

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## Foreword

### The 2022 TEAP Report

The 2022 TEAP Report consists of three volumes:

**Volume 1:** *TEAP 2022 Progress Report*

**Volume 2:** *Evaluation of 2022 critical use nominations for methyl bromide and related issues - Interim Report – May 2022*

**Volume 3:** *Decision XXXIII/5 task force report on energy-efficient and low-global-warming-potential technologies*

This is Volume 1

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# 1 Introduction

This is volume 1 of 3 of the 2022 Technology and Economic Assessment Panel (TEAP) Report and contains Progress Reports from the five Technical Options Committees (TOCs) that compose 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).

This report also contains the TEAP and TOC membership lists, as of 30 April 2022, including each member and their term of appointment.

TEAP would like to express its sincere gratitude for the voluntary service and contributions of members of its TOCs and Task Forces. TEAP's tasks have continued to be particularly challenging in view of the COVID-19 pandemic which imposed restrictions to global travel, and changes to scheduled meetings and typical modes of working. To meet these challenges in delivering its reports on time to parties and ensuring the safety of its members, TEAP and its TOCs and Task Forces have held their meetings virtually. However, this year, 3-6 May 2022, TEAP successfully held its first ever hybrid meeting with some members meeting physically in London. We are grateful to the UK for their support with the meeting venue. We want to express our sincere appreciation to the Ozone Secretariat for its support and assistance in providing the TEAP with access to its virtual meeting platform for TEAP meetings.

## 1.1 TEAP Decision XXXIII/5 Energy Efficiency Task Force Update

Decision XXXIII/5 asks TEAP,

*...” to prepare a report on energy efficient and lower- global- warming- potential technologies and on measures to enhance and maintain energy efficiency during hydrofluorocarbon transition in equipment for consideration by the Open-ended- Working Group at its forty-fourth meeting, and in the report to:*

- (a) Update information in the decision XXXI/7 report where relevant, and address additional subsectors not previously covered such as the heat-pump, large commercial refrigeration and larger air-conditioning system sub-sectors;*
- (b) Assess potential cost savings associated with adoption of lower global warming potential energy efficient technologies in each sector, including for manufacturers and consumers;*
- (c) Identify sectors where actions could be taken in the short term to adopt energy efficient technologies while phasing down hydrofluorocarbons;*
- (d) Identify options to enhance and maintain energy efficiency in equipment through deploying best practices during installation, servicing, maintenance, refurbishment or repair;*
- (e) Provide detailed information on how the benefits of integrating energy efficiency enhancements with the hydrofluorocarbon phase-down measures can be assessed. ”*

In order to prepare its report, TEAP established a new 2022 Energy Efficiency Task Force (EETF). Previous Task Forces had mainly restricted their scope to the domestic air conditioning (AC) and self-contained commercial refrigeration equipment (SCCRE) sectors. When establishing the new expertise required to respond to Decision XXXIII/5, TEAP took into account the request to cover additional sectors (heat-pump, large commercial refrigeration, larger air-conditioning systems), installation and servicing, and the assessment of the integration of energy enhancements with HFC phasedown. The EETF Report was assembled in chapters, updating previous information, and addressing the additional subsectors not previously covered. The 2022 Task Force has 24 members (5 female, 19

male) and two consulting experts. There are 13 members from Article 5 (A5) parties and 11 members from non-A5 parties.

## **1.2 TEAP Modelling Update**

TEAP is providing an update on its ongoing work, through a small working group, to build a database model of regional emissions and banks estimates to better respond to parties' requests and to support its work and that of the Assessment Panels. The modelling technique uses a wide range of information including production and consumption data reported to the Ozone Secretariat and the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)<sup>1</sup>, estimates of the lifetime of equipment and foams, emissions rates throughout the product lifecycle, and market and economic influences to estimate banks and expected annual emissions from the historic, current, and projected usage of controlled substances. These expected annual emission estimates for specific ozone-depleting substances (ODS) can then be compared to estimated emissions from available atmospheric chemical concentrations, when available. The same methodology was used by the TEAP Task Force on the Unexpected Emissions of CFC-11 and the latest TEAP Replenishment Task Force Reports.

TEAP is working towards a database that will address all controlled substances, with initial work prioritising a smaller group of substances for the 2022 Assessment Reports. The benefits of developing a TEAP model are the consensus conclusions that can be drawn from the combined knowledge of its experts, e.g., in determining model assumptions, such as lifetime of equipment and foams, emission rates, historic and predicted market and economic impacts. The model can also be refined over time as this knowledge expands or changes. A consistent and transparent, published methodology ensures that the best available assumptions and method are incorporated. The outputs for each chemical can be integrated to allow an evaluation of total ozone depletion potential (ODP) or carbon dioxide equivalent (CO<sub>2</sub>e) units providing a state-of-the-art understanding to support the work of the Montreal Protocol. Any additional product data that parties wish to convey to TEAP could be used to further refine models.

An example of the results of this modelling was the estimated expected emissions and banks of CFC-11 from the work of the TEAP Task Force on Unexpected Emissions of CFC-11. The newest example of modelling results is included in this 2022 TEAP Progress Report, showing the estimated expected emissions and banks of HCFC-141b. More information on TEAP's modelling work will be provided in the 2022 TEAP and TOCs Assessment Reports.

### ***1.2.1 Background for HCFC-141b: A Brief History of Ozone Depleting Substance (ODS) Use in Foams***

Polyurethanes were invented in the 1930s and are used in a wide variety of products. In 1948, closed-cell foams were initially introduced as an insulation in very small quantities and the market slowly increased. Use of steel sandwich building panels and integral skin began in the 1960s. In the late 1970s and 1980s closed-cell polyurethane insulation expanded to include spray foam and sandwich panels. Separately, open cell foams such as flexible and cushioning foams (e.g., shoe soles and cushions) were commercialized in the 1950s.

CFC-11 was initially used as a foam blowing agent in all of these types of foams. The closed-cell foam market developed gradually as confirmed AFEAS CFC-11 sales values showing that CFC-11 sales into closed-cell foams were relatively small until the 1970s with continuous growth throughout the 1980s.

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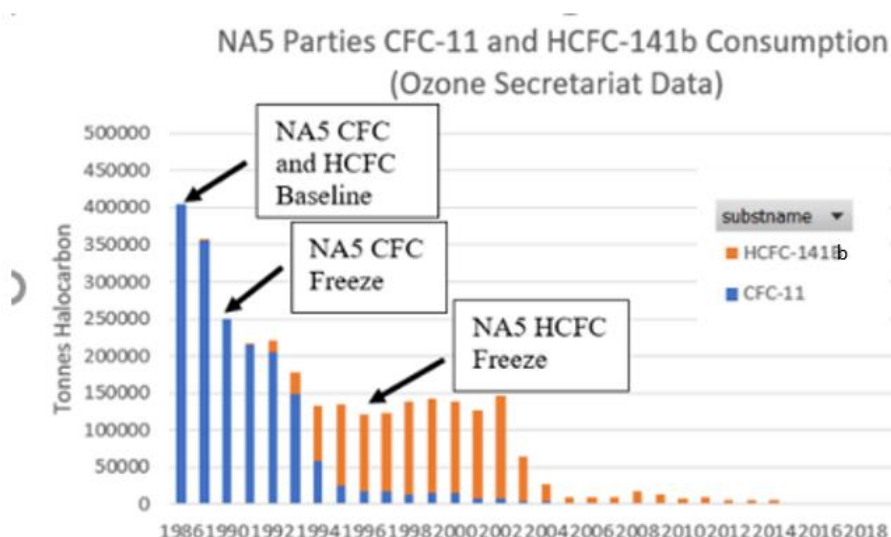
<sup>1</sup>The Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) collected data on a number of CFCs as reported by the producers. Data included market uses as well as estimated emissions. The data could be found here. <https://agage.mit.edu/data/afeas-data>

HCFC-141b was introduced as a replacement for CFC-11 for use as a closed-cell foam blowing agent during the CFC-11 phase-out. HCFC-141b is also undergoing a phase-out as agreed by the parties to the Montreal Protocol. By 2006, non-A5 parties were already transitioning from ozone depleting blowing agents the phase-out of CFC-11 for non-A5 parties completed by 1996. Given its higher ozone depletion potential, many parties regulated HCFC-141b early using a “worst-first” strategy, and so reductions were already well under way for HCFC-141b prior to the phase-out schedule, to be completed by 2020. For example, the United States banned the use of HCFC-141b for use in foam for appliances in 2003, and then in imported products containing HCFC-141b in 2015. Each transition in non-A5 parties resulted in much lower use of halocarbons as foam blowing agents as foam manufacturers shifted to other alternatives including water and hydrocarbons.

### 1.2.2 Estimated regional use of HCFC-141b

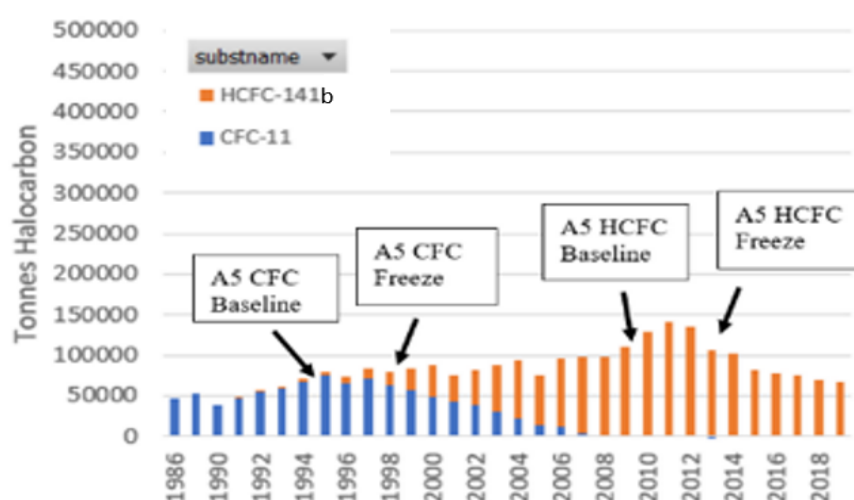
The FTOC completed a detailed analysis of the use of foam blowing agents by foam sector by region in the 2006 FTOC Assessment Report<sup>2</sup>. The FTOC described large, mature foam markets in North America (NA) and Europe (EU) for the types of foams that historically used CFC-11 and HCFC-141b. Other regions all using less than one-third of the quantities used by either North America or Europe. Closed-cell foam markets in Article 5 parties had slowly been growing prior to 2006 as shown in Fig.1.1.

**Fig. 1.1. Non-A5 and A5 parties consumption of CFC-11 and HCFC-141b**



<sup>2</sup> The 2006 FTOC Assessment Report can be found at [https://ozone.unep.org/sites/default/files/2019-05/ftoc\\_assessment\\_report06.pdf](https://ozone.unep.org/sites/default/files/2019-05/ftoc_assessment_report06.pdf).

## A5 Parties CFC-11 and HCFC-141b Consumption (Ozone Secretariat Data)



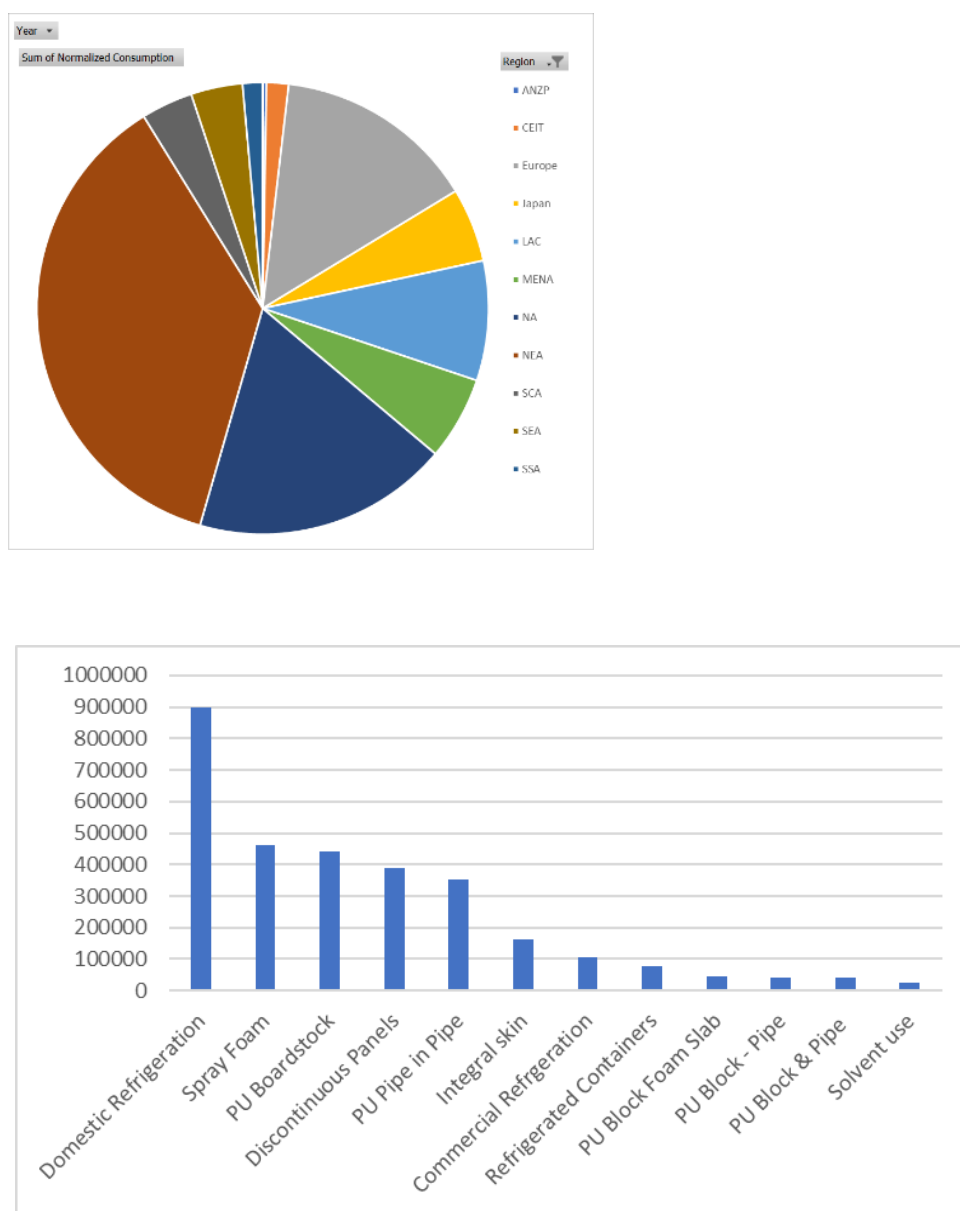
Non-A5 parties completed their phase-out of CFC-11 use as a blowing agent in 1996 and had already completed their phase-outs of HCFC-141b. A5 party baselines were determined in 1995-97 for CFCs and in 2009-10 for HCFCs. A5 party freeze and phaseout started in 1999 for CFCs and in 2013 for HCFCs. Many parties again regulated HCFC-141b using the same “worst-first” approach based on ODP that non-A5 parties used.

### 1.2.3 Estimated global use of HCFC-141b by foam type

The 2006 FTOC Assessment Report sectoral and regional analysis was used to create an estimate of foam use of blowing agents, to estimate banks and emissions based on the estimated losses of blowing agents during different foaming processes and foam lifetimes. In this analysis, HCFC-141b consumption peaked around 2000 in non-A5 parties and in 2011 in A5 parties with the majority used to manufacture foams in North America (NA) and in Northeast Asia (NEA). However, much of the

production of foams in NEA was used in domestic appliances that were exported to other regions of the world.

**Fig. 1.2 HCFC-141b Regional Consumption and Market Use**



#### 1.2.4 Global consumption and estimated emissions of HCFC-141b

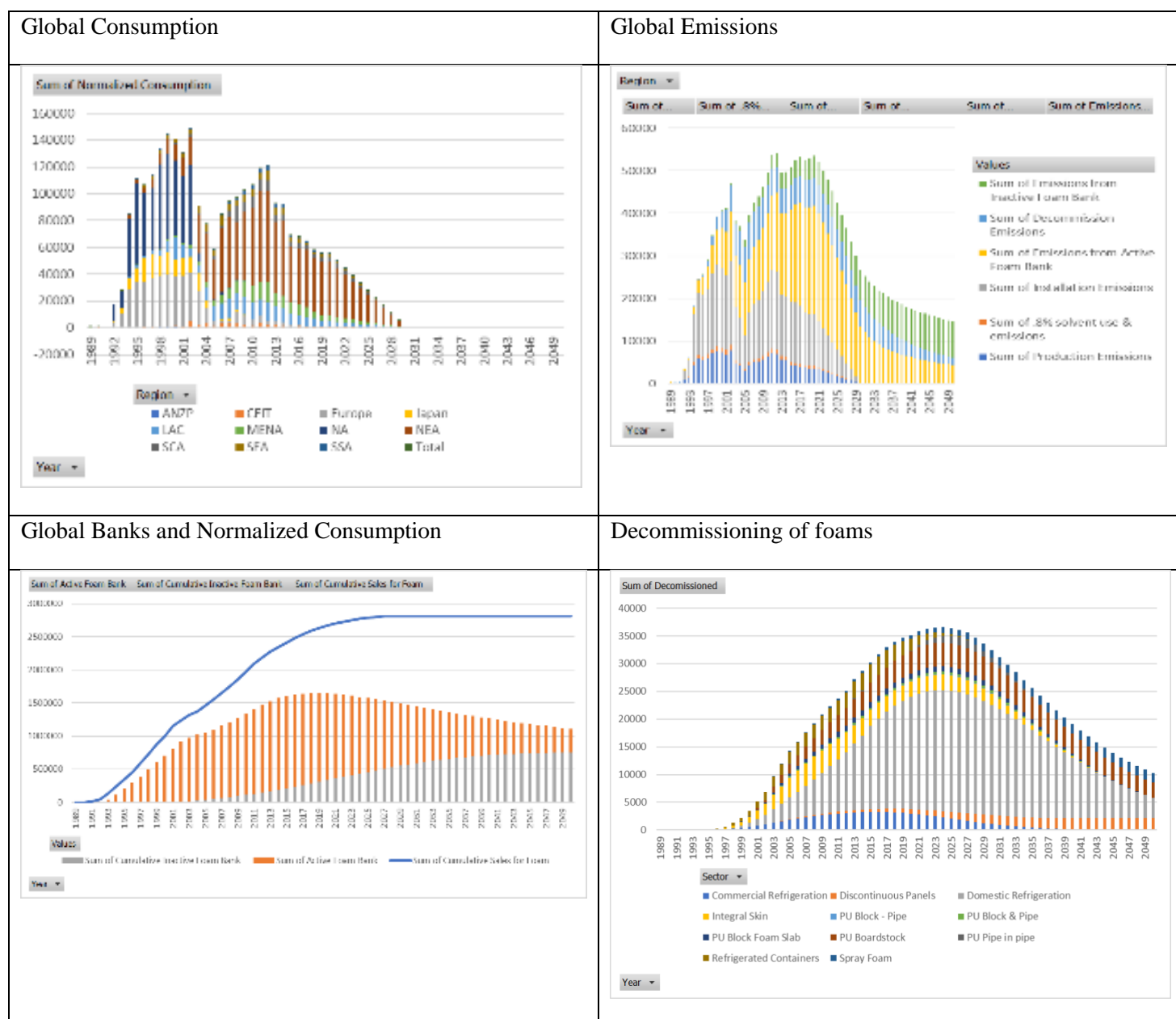
There are two distinct peaks in the production and consumption of HCFC-141b, as policies initially allowed for its use and then mandated its phase-out in non-A5 followed by A5 parties. Policies have also generally mandated bans in the use of HCFC-141b in domestic refrigeration manufacture by 2015 in much of the world.

Active banks refer to fluorocarbon, such as used as a foam blowing agent in insulating foams, still in active use (in buildings and refrigerators or refrigeration equipment etc.) Inactive banks refer to chemicals no longer in use and are largely represented by fluorocarbons in landfills.

The inactive bank of HCFC-141b is believed to have been largely from foams in refrigerators, while the active bank is now shifting to be largely related to construction foams globally. The global active

bank peak is now estimated to have occurred, with continued decommissioning of appliances and buildings that contain HCFC-141b being greater than new HCFC-141b usage to create new foams. The timing of the global peak for decommissioning of foams containing HCFC-141b is estimated to occur over the next 5 years.

**Fig. 1.3 Global Model Results for HCFC-141b: Total Reported Production and Estimated Banks, Timing of Decommissioning, and Emissions**



### 1.2.5 Consumption, Banks, and Estimated Emissions and Banks of HCFC-141b

Peak reported production and consumption of HCFC-141b in non-A5 parties occurred by 2000 and was largely used in domestic refrigeration foams. The current inactive bank of HCFC-141b is believed to have been used largely from foams in refrigerators. The active bank of foams manufactured in non-A5 parties is also largely in refrigerants.



Peak reported production and consumption of HCFC-141b in A5 parties occurred by 2012 and was largely used in domestic refrigeration foams until 2015, when mandated bans in the use of HCFC-141b in domestic refrigeration occurred in much of the world. The inactive bank of HCFC-141b is believed to have been largely from foams in refrigerators. The active bank of foams manufactured in A5 parties is also largely in refrigerators. The peak of the active bank in A5 parties is estimated to have occurred between 2015 and 2020, with continued decommissioning of appliances and buildings that contain HCFC-141b being greater than new HCFC-141b usage to create new foams.

Regional variations in emissions and decommissioning as well as other details regarding the modelling process will be included in the TEAP 2022 Assessment Report.

### **1.3 Response to Decision XXVIII/2: Decision related to the amendment phasing down HFCs**

At their Twenty-eighth Meeting in October 2016 in Kigali, Rwanda, parties agreed on Decision XXVIII/2 and the Kigali Amendment to phase down HFCs. Paragraph 4 of that decision requested the TEAP “to conduct periodic reviews of alternatives, using the criteria set out in paragraph 1 (a) of decision XXVI/9, in 2022 and every five years thereafter, and to provide technological and economic assessments of the latest available and emerging alternatives to hydrofluorocarbons.”

The criteria referenced in paragraph 1(a) of Decision XXVI/9, “Response to the report of the Technology and Economic Assessment Panel on information on alternatives to ozone-depleting substances,” is as follows (emphasis added):

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

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

- a. ***Update information on alternatives to ozone-depleting substances in various sectors and subsectors and differentiating between parties operating under paragraph 1 of Article 5 and parties not so operating, considering energy efficiency, regional differences and high ambient temperature conditions in particular, and assessing whether they are:***
  - i. ***Commercially available;***
  - ii. ***Technically proven;***
  - iii. ***Environmentally sound;***
  - iv. ***Economically viable and cost effective;***
  - v. ***Safe to use in areas with high urban densities considering flammability and toxicity issues, including, where possible, risk characterization;***
  - vi. ***Easy to service and maintain;***

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

Decision XXVIII/2 requests TEAP to conduct periodic reviews of alternatives to HFCs in 2022 and every five years thereafter. The first requested periodic review in 2022 aligns with the preparation of TEAP's and its TOCs quadrennial assessment reports under Decision XXXI/2, and those reports are planned to be completed at the end of 2022.

Paragraph 6 of Decision XXXI/2 provides the terms of reference for the TEAP quadrennial assessment reports as follows (emphasis added):

*6. That, in its 2022 report, the [TEAP] should include an assessment and evaluation of the following topics:*

- a) Technical progress in the production and consumption sectors in the transition to technically and economically feasible and sustainable alternatives and practices that minimize or eliminate the use of controlled substances in all sectors;*
- b) The status of banks and stocks of controlled substances and the options available for managing them so as to avoid emissions to the atmosphere;*
- c) Challenges facing all parties to the Montreal Protocol in implementing Montreal Protocol obligations and maintaining the phase-outs already achieved, especially those on substitutes and substitution technologies, including challenges for parties related to feedstock uses and by-production to prevent emissions, and potential technically and economically feasible options to face those challenges;*
- d) The impact of the phase-out of controlled ozone-depleting substances and the phase-down of HFCs on sustainable development;*
- e) Technical advancements in developing alternatives to HFCs suitable for usage in countries with high ambient temperatures, particularly with regard to energy efficiency and safety.*

Given that the requests to review alternatives to HFCs overlaps in 2022 with the two decisions, TEAP is planning to convene a TEAP Decision XXVIII/2 Working Group with each TOC represented. The Working Group will prepare a report responding to this decision for submission to the Thirty-fourth Meeting of the Parties, 31 October to 4 November 2022. This report will draw from the information in the TOCs assessment reports which will be submitted by the end of 2022.

TEAP notes that the Decision XXVIII/2 subsequent requests for periodic reviews of HFC alternatives every five years after 2022 no longer coincides with the quadrennial assessments of the TEAP. To manage its workload and minimize duplicative efforts, TEAP requests that parties may wish to consider aligning future periodic reviews as requested in Decision XXVIII/2 with the already planned TEAP and TOCs quadrennial assessment reports.

## **1.4 Key Messages from the Technical Options Committees**

TEAP presents below the main findings of the 2022 Progress Report, as key messages from each of the TOCs.

### **1.4.1 FTOC**

Low-global warming potential (GWP) blowing agent shortages continue in both Article 5 (A5) and non-Article 5 (on-A5) parties which may be due to pandemic-related supply chain issues, raw material and supply chain shortages, manufacturing issues, and severe weather. Undisclosed manufacturing issues from at least one supplier have led to *force majeure* declarations, according to a number of foam manufacturers. As a result, there has been a significant increase in the use of hydrofluorocarbon HFC-365mfc/ HFC-227ea or HFC-365mfc/ HFC-245fa blends in some A5 parties and a reversion to

HFC-365mfc blends and HFC-245fa in some non-A5 parties. Prices of HFCs have also increased during the pandemic. There have also been reported shortages of hydrocarbons, such as cyclopentane.

The transition away from ODS foam blowing agents in some regions and market segments (e.g., spray foam and extruded polystyrene [XPS]) may be delayed because of cost, especially where local codes require higher thermal performance<sup>3</sup>. It should be noted that the price of HFC blowing agents is nearly as high as hydrofluoroolefin/hydrochlorofluoroolefin (HFO/HCFO) prices were prior to the pandemic in some A5 parties.

Hydrocarbon (HC), methylal, methyl formate, and methylene chloride are reportedly being used in blowing agent blends to reduce costs in some parties. FTOC is seeking additional details on the safety measures being taken to address exposure and safety risks.

For example, a number of spray foam (SPF) formulators use 1,2 dichloroethylene as a co-additive for ostensibly improving solubility of HFC and now HFO blowing agents as a means of extending their value. With a boiling range of 48 - 60 °C for both isomers, it can support blowing and may be used further as HFO and HFC supplies are tight<sup>4</sup>. As the transition proceeds and there are continued challenges in supply and costs, foam manufacturers and chemical producers are introducing new options and potential challenges.

#### **1.4.2 HTOC**

In the 2018 Assessment Report, the HTOC anticipated that the initial 10% reduction in HFC production within non-A5 parties would not have a significant impact on the availability of HFCs for fire protection. It was reasoned that the use of HFCs in fire protection is extremely small in comparison to other uses, the emissions are low, and sales of HFCs in most non-A 5 parties were either declining or flat. Instead, the experience in the EU and Japan has shown a movement away from the use of HFCs in new fire protection systems (although use of HFCs in Japan has never been widespread). HFCs have been replaced in large part by low-GWP and no-GWP alternatives such as FK-5-1-12 and inert gases. The US HFC phase-down began on January 1, 2022, and it has already had an impact on the cost and availability of newly produced HFCs for fire protection. The US allocation system is GWP-weighted and the HFCs used for fire protection have very high GWPs, so the impact has been greater than initially expected. It is the HTOC's experience that HFCs contained in fire protection equipment historically have been recycled and reused to a relatively high extent. As the supply of newly produced HFCs for fire protection decreases in response to phase-down regulations, recycling becomes even more important as an alternative source of supply and is likely to increase in the future.

- Parties may wish to consider re-emphasizing the need to foster international trade of recycled/reclaimed high-GWP HFCs, i.e., HFC-227ea, HFC-125 and HFC-236fa used in legacy fire protection applications, which include those in civil aviation lavatory fire protection systems.

The HTOC has identified several issues affecting the availability and quality of recovered halons from all fire protection sectors, but especially from the civil aviation sector. The HTOC also believes that shipbreaking could represent a significant source of halon 1301 which could support on-going

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<sup>3</sup> Although the cost of hydrochlorofluorocarbons (HCFCs) was approximately 20-30% of the cost of high-GWP HFCs, HCFC price is increasing as they are phased out globally. The low price of some high-GWP HFCs, particularly HFC-365mfc which is banned in some non-A5 parties, is leading to an increase in market share, which is slowing the conversion to low-GWP blowing agents

<sup>4</sup> Toxicity of 1,2 dichloroethylene is currently being reviewed by at least one party. Field studies related to Indoor Air Quality in SPF installations often shows some concentration of 1,2-dichloroethane up to months or years after installation due to its higher boiling point and high solubility in foam matrixes.

activities. It is therefore important to conserve this supply to the greatest extent possible. To address these issues parties may wish to consider:

- Requesting the Ozone Secretariat to disseminate the recently developed halon management guidance document available from the HTOC, to all National Ozone Units (NOUs) and sponsoring presentations during all upcoming Ozone Regional Manager Network and other applicable meetings,
- Liaising with their civil aviation authorities to disseminate this halon management guidance document to all applicable entities within their country such as airlines, maintenance, repair, and overhaul (MRO) companies, and associated non-governmental organisations (NGOs),
- Requesting that the International Civil Aviation Organisation (ICAO) formally disseminate through a State letter, the halon management guidance document to all civil aviation authorities requesting that the halon management guidance document receive the widest possible dissemination within their State and/or region,
- Emphasising the importance of effective and complete recovery of halons to minimize halon losses by all parties, particularly those with shipbreaking activities, and
- Re-emphasising the need to allow for appropriate, open trade of recovered, recycled and/or reclaimed halons in bulk containers and in prefilled fire protection components to support enduring halons uses, including civil aviation components that are required to allow aircraft to operate under international airworthiness requirements.

The EU proposal to define perfluoroalkyl and polyfluoroalkyl substances (PFAS) as any substance that contains at least one fully fluorinated carbon  $\text{CF}_2$  or  $\text{CF}_3$  group (without any hydrogen, chlorine, bromine, or iodine (H/Cl/Br/I) atom(s) attached) would include virtually all of the halogenated, clean, agent alternatives to halons, HCFCs and high-GWP HFC fire extinguishing agents except for HFC-23 and  $\text{CF}_3\text{I}$ . Thus, hydrochlorofluorocarbon (HCFC)-124, HCFC Blend A, HCFC Blend B, HFC Blend B, HFC-227ea, HFC-125, HFC-236fa, fluoroketone (FK-5-1-12), 2-bromo-3,3,3-trifluoroprop-1-ene (2-BTP), and Halocarbon Blend 55 could all be included in the proposed regulations. This could leave halons, or in some cases also HFC-23, as the only viable non-PFAS options in some applications.

R&D for civil aviation cargo compartment fire protection systems continues. However, the development and certification timescales remain long and can be uncertain. As such, it will still be at least several more years before any of the fire extinguishing agents being evaluated could be in service on aircraft. If these are not successful, the chances of finding an as-yet undiscovered alternative that is safe and effective are, after so many years of research, are extremely low.

While civil aviation flight hours dropped by 60% during the pandemic, global halon 1301 emissions did not decline. Therefore, emissions do not seem to be dependent on the number or duration of civil aviation flights (i.e., do not occur during flight operation). This does not necessarily mean that civil aviation is not the cause of some of or even a significant amount of the emissions but rather that a different part of the aviation lifecycle such as fire extinguisher maintenance could be responsible for much of these emissions.

- Parties may wish to consider requesting that ICAO continue to sponsor activities related to halon regulation and management, include the HTOC in these activities, and work with the HTOC to provide annual updates on changes to their halon regulations, the status of development and implementation of aviation alternatives, and other halon management issues important for the long-term use and management of halons.

The HTOC is concerned that many personnel who are now responsible for managing fire protection agents controlled by the Montreal Protocol do not have the necessary experience with the issues surrounding the use, recovery, recycling, reclamation, and banking of these agents. To address these issues, parties may wish to consider:

- Supporting programmes to mitigate the loss in institutional memory of fire protection agents controlled by the Montreal Protocol; and
- Supporting awareness programmes to address recovery, recycling, reclamation, and banking of halons as well as HCFC and HFC fire protection agents.

### **1.4.3 MBTOC**

In 2020, reported methyl bromide (MB) consumption for controlled uses was only 69 tonnes, although stocks substantially higher than this may be used in some sectors in various countries. After 20 years of applications for MB critical use during which substantial R&D has taken place on alternatives, some non-A5 parties continue to make critical use nominations without adoption of alternatives.

Quarantine and pre-shipment (QPS) uses of MB (approximately 10,000 tonnes per year), which are exempted from the Montreal Protocol controls, far exceed the use of MB for controlled uses and continue to be the major anthropogenic contributor of MB to the stratosphere. Over the last decade, some parties have succeeded in completely phasing out QPS use of MB, however, the overall global consumption of MB for QPS has not changed markedly since some A5 parties have increased QPS consumption substantially. Despite this, research programs globally are continuing to find successful alternatives to replace MB. The successful application of alternatives to QPS would accelerate the decline in stratospheric MB levels with a near-term impact on ozone.

Since 1999, the reduction in MB production and use from controlled uses has led to a reduction greater than 30% in the concentration of MB in the atmosphere and this has been responsible for more than 35% of the present fall in Effective Equivalent Stratospheric Chlorine and a key driver for the recovery of the ozone layer. Recent data, however, shows that a decline in the atmospheric levels of MB has stalled as emissions of MB from QPS uses and from any unreported uses continue unabated. MBTOC notes that near-term reduction of atmospheric concentrations of MB in the future will overwhelmingly rely on reduction in emissions from QPS or any unknown/unreported uses.

A significant proportion of emissions of MB from QPS can be reduced by recapture, recycling and/or reuse. Recapture of MB from QPS uses have recently been reviewed in New Zealand (NZ), with stepwise increases in use of recapture required by regulations implemented to phase out methyl bromide emissions. In addition, fumigation of the holds of ships with MB will be banned from 2023.

Some specific bilateral agreements are reducing MB use. For instance, India and Canada have agreed to lift the MB fumigation requirement for Canadian pulses exported to India while a systems approach is being established. This measure will potentially reduce QPS MB treatments of pulses on arrival substantially.

It appears that some parties still have difficulties in identifying and reporting MB use for QPS purposes.

MBTOC considers Q and PS to have different priority for use of MB with PS uses having greater potential for adoption of alternatives. PS uses could potentially be phased out because there are technically alternatives which are widely available and suitable worldwide. MBTOC considers that these readily available alternatives for PS could result in replacing 30-40% (i.e., 3000-4000 tonnes) of the total QPS MB use by alternatives. Parties could consider requesting TEAP/MBTOC to update information on QPS uses and their alternatives, specifically allocating the uses under Q versus PS.

Sulfuryl fluoride (SF) is widely registered and adopted around the world as an alternative to MB for disinfestation of dried fruit, tree nuts, grain flour, and timber, and is a key alternative to MB for treatment of empty structures such as flour mills and food and feed processing premises. In recent

years, however, there is growing concern about the high 20-year GWP value of SF currently set at 7510 and MBTOC considers it prudent to ensure that other alternatives are considered.

#### **1.4.4 MCTOC**

Medical and Chemicals Technical Options Committee provides information on the production and use of controlled substances, including for chemical feedstock, HFC-23 by-production and emissions, and new developments for metered dose inhalers (MDIs). It also includes background to, and an update on, TEAP's assessment of destruction technologies under decision XXX/6, to be included in MCTOC's 2022 Assessment Report. The status of aerosols (other than MDIs), laboratory and analytical uses, process agent uses, and n-propyl bromide were reviewed, however, no compelling new information is reported this report.

##### ***Production issues***

As reported by FTOC, there have been reported challenges relating to production and chemical supply in the transition to low-GWP HCFO and HFO foam blowing agents. These challenges relate to several factors, including production constraints, restrictive manufacturing and application patents, high prices of HCFO/HFOs relative to HCFC-141b and HFC blowing agents, and regional shortages of CTC used as starting raw material in the process to manufacture HCFO/HFOs. New production capacity for HCFO/HFOs is expected to become available in 2023.

##### ***Feedstock use of controlled substances***

The proportions of the largest controlled ODS feedstocks in 2020 are HCFC-22 (48% of the total mass quantity), CTC (20%), and HCFC-142b (11%). HCFC-22 is mainly used to produce tetrafluoroethylene, which is then used to make fluoropolymers such as polytetrafluoroethylene. HCFC-142b is used to make polyvinylidene fluoride. The feedstock use of CTC has increased in recent years, due to growing demand for lower GWP HCFO/HFOs and perchloroethylene (PCE).

Accurate and consistent Article 7 reporting of production of controlled substances, including for feedstock uses, contributes to the better understanding and assessment of atmospheric burdens of controlled substances. Reported production can be correlated with related emissions of controlled substances. There are some products that are not reported because they are intermediates not isolated in a chemical manufacturing process. These intermediates may also be emitted in low quantities and detected by atmospheric monitoring. In chemical production, a non-isolated intermediate in a chemical process is not considered as a finished product while it remains within the chemical process. As such, a non-isolated intermediate is not commonly reported. However, a substance that is isolated, most likely purified to a specification, and then used in a distinct, separate process, would be considered as a finished product and subject to reporting as production for feedstock use.

##### ***Destruction technologies***

Decision XXX/6 on destruction technologies for controlled substances requests TEAP to assess destruction technologies listed (in annex II to the MOP-30 report) as not approved or not determined, as well as any other technologies, and to report to the Open-ended Working Group prior to MOP-33. In consultation with the Ozone Secretariat, TEAP and its MCTOC reported in 2021 that an assessment in response to decision XXX/6 will be included in MCTOC's 2022 Assessment Report based on available information.

MCTOC outlined preparations for its assessment of destruction technologies under this decision in the 2020 and 2021 TEAP Progress Reports, including suggested guidance on the type of relevant information needed for assessment, which is included again in this report. The 2020 and 2021 TEAP Progress Reports invited parties to submit this type of information in response to decision XXX/6 paragraph 3. Information from parties was requested to be submitted no later than January 2022 to allow time for assessment. No information has been submitted. The opportunity has now passed for MCTOC to assess new data in time for its 2022 Assessment Report. MCTOC is not currently aware of new information, such as test data, relating to already approved destruction technologies or new

technologies that would allow an assessment. MCTOC is aware of some developments in existing approved destruction technologies and emerging trends that are noteworthy to report in the Assessment Report.

In future, parties may wish to consider providing any new information for TEAP assessment of destruction technologies in January of the same year in which its assessment would be reported either as part of annual TEAP Progress Reports or future quadrennial assessments.

### ***Metered dose inhalers***

MDIs, dry powder inhalers (DPIs), aqueous soft mist inhalers (SMIs), and other delivery systems all play an important role in the treatment of asthma and COPD. New alternative propellant technologies to high-GWP HFC MDIs are under development. DPIs, soft mist inhalers and nebulisers are already available for most molecules and combinations as alternatives to high-GWP MDIs, offering a lower carbon footprint.

### **1.4.5 RTOC**

Since the publication of the RTOC 2018 Assessment Report, one new single component refrigerant and eighteen refrigerant blends have received a designation/classification from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 34 and/or from the International Standards Organisation (ISO) 817. These eighteen refrigerants are listed in tables 6.1, 6.2 and 6.3. Their GWP and ODP values are calculated in the same way as the ones given in the RTOC 2018 Assessment Report.

The importance of reducing direct and indirect CO<sub>2</sub> emissions from the RACHP sector is gaining increasing attention, especially the sustainable design and operation of equipment taking into account the strong growth of the equipment base. Improving the equipment energy efficiency during the HFC phase-down is one major opportunity to reduce energy demand, alongside the phasing down of equipment containing high GWP HFCs. Training in the servicing and maintenance of RACHP equipment to reduce leaks will also reduce emissions of high GWP HFCs.

There has been significant progress with the development of safety standards to support the transition towards lower GWP alternative refrigerants, that are mostly flammable. IEC 60335-2-89 (applicable to commercial refrigeration) was revised to include larger charges of flammable refrigerants (up to 500 g – 1200 g given certain boundary conditions) and is currently being transferred to national standards.

The new edition of the standard IEC 60335-2-405 was approved in April 2022 by the International Electrotechnical Commission. The approved revised version will allow HC-290 (propane), and other flammable refrigerants, to be used in many air conditioning systems and heat pumps that were previously prohibited by the previous version of the standard from using these refrigerants.

The revised safety standard allows for the use of a larger charge of flammable refrigerants (up to 988g of HC-290 in a standard split air conditioning system). This will be possible on new equipment that must have additional safety requirements to ensure the same high level of safety as equipment that does not use flammable refrigerants.

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<sup>5</sup> Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers

The use of flammable refrigerants in air conditioning equipment will lead to a reduction in direct climate emissions compared to systems using R410A.



## 2 Flexible and Rigid Foams TOC (FTOC) Progress Report

### 2.1 Introduction

In non-A5 parties, regulations are driving transitions away from high GWP HFCs, whereas in A5 parties, HPMPs continue to drive transitions. Low- GWP blowing agent shortages continue in both A5 and non-A5 parties which may be due to pandemic-related supply chain issues, raw material and supply chain shortages, manufacturing issues, and severe weather. Undisclosed manufacturing issues from at least one supplier have led to *force majeure* declaration, according to a number of foam manufacturers. As a result, there has been a significant increase in the use of hydrofluorocarbon HFC-365mfc / HFC-227ea or HFC-365mfc/ HFC-245fa blends in some A5 parties and a reversion to HFC-365mfc blends and HFC-245fa in some non-A5 parties. Prices of HFCs have also increased during the pandemic. There have also been reported shortages of hydrocarbons, such as cyclopentane.

The transition away from ODS foam blowing agents in some regions and market segments (e.g., spray foam and extruded polystyrene [XPS]) may be delayed because of cost, especially where local codes require higher thermal performance<sup>6</sup>. It should be noted that the price of HFC blowing agents is nearly as high as HFO/HCFO prices were prior to the pandemic in some A5 parties.

The importation of ozone-depleting foam blowing agents is controlled or under license, and more parties are controlling the import of polyols containing HCFC-141b or other ODS. More action is pending with import restrictions and potential requirements to add a label stating “containing HCFC 141b in formulated polyols”.

It is possible that consolidation among foam manufacturing companies may occur during the phaseout of HCFC blowing agents in A5 parties, as it did in non-A5 parties<sup>7</sup>.

- There is new manufacturing capacity of HCFO-1224yd(Z) in Japan and significant quantities of HCFO-1233zd(E) in China. HFO-1336mzz(E), with a boiling point of approximately 9°C, is also reportedly available in small quantities in some regions
- Non-A5 and A5 parties are facing challenges with the supply of HFO/HCFOs. This has led to market growth of HFC-365mfc in some A5 parties and reversion to HFC-245fa in some non-A5 parties.

### 2.2 Global Foams Market

The annual growth in production of polymer foam was projected to be an estimated 3.8% from 2020 to 2027<sup>8</sup> to 4.8%<sup>9</sup> led by growth in emerging markets. However, the effect of the pandemic and its economic after-effects introduces significant uncertainty to growth projections. It is now assumed that global production may not recover to 2019 levels until 2024 or later.

Overall, the global production of XPS remained stable prior to the pandemic. This material is typically used for its low-moisture permeability and high-compression strength in applications including refrigerated transport, perimeter insulation and cold stores. Polyurethane, polyisocyanurate, and phenolic rigid foam are not used as widely as other thermal insulation materials in building

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<sup>6</sup> Although the cost of hydrochlorofluorocarbons (HCFCs) was approximately 20-30% of the cost of high-GWP HFCs, HCFC price is increasing as they are phased out globally. The low price of some high-GWP HFCs, particularly HFC-365mfc which is banned in some non-A5 parties, is leading to an increase in market share, which is slowing the conversion to low-GWP blowing agents

<sup>7</sup> There may be some extra capacity that will be resolved at this time especially where local demand has changed due to building codes or other changes in construction design and overall demand.

<sup>8</sup> [Polymer Foam Market Size, Share & Trends Analysis Report, 2020 - 2027](#) - Grand View Research as viewed 4/3/22

<sup>9</sup> [The Future of High Performance Foams](#) to 2021 – Smithers as viewed 4/3/22

insulation due to relatively high cost. However, the low thermal conductivity of all three types of foam at wide operating temperatures dominates the insulation demand from the cold chain and district cooling and heating systems, including internal building services usage.

Polymer foams encasing vacuum-insulated panels in appliances and aerogels in industrial pipe insulation offer ultra-high insulation performance and are used in specialized applications in refrigeration and construction.

### **2.2.1 Major Issues Influencing the Global Foams Market**

Continued focus on reducing heating and cooling load in buildings and appliances will likely include the increased use of polymeric foams as thermal insulation.

Global growth in population influences the demand for polymeric foams used in the main end-use industries, including building & construction, the cold chain, furniture & bedding, packaging and transportation industries (e.g., automotive industries (cars, buses, motorcycles), trains, ships etc.). Polyurethane, polyisocyanurates, polystyrene and phenolic foams contribute to the energy efficiency of heating and cooling systems in buildings, while flexible polyurethane foams provide acoustic insulation, energy absorption for packaging, and comfort in applications such as mattresses and furniture.

The main factors influencing thermal insulation requirements are legislative, regulatory, and building standard mandates to reduce heating and cooling loads in commercial and residential buildings. The EU and NA are currently the leading proponents of building codes to improve energy efficiency in the construction industry, while the global appliance industry continues to develop new more energy-efficient models.

Investment in infrastructure in China includes several end-uses for polymeric foams. The investment programme includes a range of opportunities for polymeric foams in the cold chain, district cooling and heating, high speed rail and the construction of temperature-controlled data server centres. Simplification of building codes may also allow greater use of polymeric foams for insulation materials in residential and commercial buildings.

According to Markets and Markets<sup>10</sup>, the global cold chain market size is estimated to be valued at USD 233.8 billion in 2020 and is projected to reach USD 340.3 billion by 2025, recording a compound annual growth rate (CAGR) of 7.8%. There is significant increasing demand from the retail sector and to mitigate food waste and degradation. The Asia Pacific region is expected to grow the fastest due to the presence of major food and healthcare providers.

In Europe, the volume of XPS foam insulation is increasing in line with gross domestic product (GDP) growth with variation in individual countries. There is some increased demand for thick (>200mm) XPS panels to meet certain construction requirements<sup>11</sup>.

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<sup>10</sup> [Cold Chain Market by Application \(Fruits & Vegetables, Dairy & Frozen Desserts, Fish, Meat & Seafood, Bakery & Confectionery\), Temperature Type \(Frozen, Chilled\), Type \(Refrigerated Transport, Refrigerated Warehousing\), Region - Global Forecast to 2025](#) – Markets and Markets as viewed 4/3/22

<sup>11</sup> Thicker XPS is used decoratively and for roofs where they can be cut around protruding features. Thicker foams also do not allow for moisture intrusion between layers which reduces thermal performance and provide more weight for ballast to prevent wind uplift and may have implications for building structure. Multiple layer XPS foam manufacturing techniques usually require the use of bonding chemicals which may increase thermal conductivity or water transfer. Additionally, those chemicals are likely to make the recycling process of XPS either much more complicated or impossible which is economically undesirable. There are very few manufacturers that can produce this as a monolithic board, leading to the use of multiple layers, which has some disadvantages, or the need by producers to invest in new thermal bonding technology.

In NA, use of all insulation continues to recover from the pandemic, however the use of XPS appears to be growing at a lower rate especially where other products (e.g., EPS for construction below ground) may be replacing XPS as building insulation requirements change and builders seek the most cost-effective insulation.

There is likely to be some recovery of all markets negatively impacted by the pandemic, including construction projects halted due to lack of funds, quarantine mandates, and resulting labour shortages

In Japan, “The Act on Rational Use and Proper Management of Fluorocarbon”, was amended effective April 1, 2020, to require companies to submit a voluntary action plan for the HFC phase down /phase out. In 2020, the average GWP of blowing agents used by the residential spray foam industry was limited to less than 100, with a target HFC consumption of less than 620MT in 2020 and 450MT by 2024.

The average GWP of the system houses that met the goal by 2020 was 17.3 with the remainder achieving the goal by September 2021. There were challenges with the cold chain transition and the total HFC consumption was 821MT over the action plan.

### **2.3 Factors Impacting Blowing Agent Choice**

It has been estimated that 80-84% of HCFC-141b in A5 parties will be replaced with non-fluorocarbon alternatives including water-blown foams. Evolving HCFC and HFC phase-out plans will have a large impact on the choices of non- ODP options.

In **A5 parties**, a growing number of foam producers are required by regulation to transition to zero ODP blowing agents. In some parties, use of HCFCs is now limited to applications where HCs are nearly universally considered to be unsuitable, such as PU spray foam. Many parties are limiting the import of CFC-11 and HCFC-141b pre-blended polyols to prevent manufacture of foam using ODS. There is a growing trend for small- and medium-sized enterprises (SMEs) consuming 1000 tonnes or more to self-formulate blends for their own systems especially in Asia.

As designed, as the phasedown progresses, the limited availability and increasing price of HCFCs will drive the selection of foam blowing agents. The availability of high-GWP HFCs, particularly HFC-365mfc/HFC-227ea (which is banned in many non-A5 parties), is preventing the transition to low GWP substances. However, due to the pandemic, its price has reportedly risen to the pre-pandemic price of HFC-245fa.

China’s Ministry of Housing, Urban, and Rural Development is streamlining the existing 3,000 standards into 300. It is likely to modify GB50016 “Code of Design on Building Fire Protection and Prevention” allowing for additional use of spray foam, which presents a significant challenge to small and medium-sized enterprises (SMEs) on choice of blowing agents.

In Latin America, some parties may ban imports of HCFC-141b and HCFC-141b containing polyols in the largest PU foam markets in the near term. Some parties are also considering labelling requirements stating “containing HCFC 141b” on drums and containers of formulated polyol using HCFC-141b and its blends. These measures could improve control on HCFC-141b commercialised in the region. During the last decade, major enterprises, mainly in the domestic/commercial refrigeration and continuous panel sectors have been successfully converted to HCs. HCFC Phaseout Management Plan (HPMP) projects continue to focus on implementation at SMEs, examining a wide range of non-HC pure and blended blowing agents (e.g. low volumes of HFOs, CO<sub>2</sub> (water), methyl formate, methylal (dimethoxymethane), and blends). The use of hydrocarbons pre-blended in foams continues to be of concern, as their use requires safety measures and plant modifications for blending facilities and for SMEs.

In India, approximately 70% of companies are using non-ODS/low-GWP technologies. The remainder are using HFCs. No companies are using HCFCs.

In some A5 parties, there has been an increase in the use of methylal, methylene chloride<sup>12</sup> and hydrocarbons, specifically pentanes, with HFCs to reduce cost. There are some limits to availability and allowance of use because of safety (flammability) and health (human exposure) concerns.

In **non-A5 parties**, in the EU, high-GWP fluorinated gases are being phased down under F-Gas Regulations. In 2015 in the EU, all HFCs with GWP greater than 150 were banned for foam manufacturing for use in domestic appliances. By January 2023, all HFCs with GWP greater than 150 will cease being used in all foam manufacturing. Foams and polyol-blends containing HFC must be labelled, and the presence of any HFC has to be mentioned in the technical documentation and marketing brochures. The F-Gas Regulation operates on the supply-side through a quota system, which means that supply of HFC blowing agents to the foam sector is being constrained well before the phase-out dates and sees a major shift from HFC systems towards HFO. Product standards are being reviewed to incorporate the new blowing agents to support CE marking and the Declaration of Performance required when placing construction products on the EU market.

The regulation of HFOs and HCFOs are different between parties. In some EU countries, unsaturated HCFCs and HFCs are defined as volatile organic compounds (VOC) and require environmental permits for use. Other EU countries exempt them from VOC regulations based on their Maximum Incremental Reactivity (MIR) in comparison to ethane. Denmark, which previously regulated unsaturated HCFCs and HFCs by the same laws as high-GWP HFCs, has lifted the restriction when the GWP value is below 5 through a dedicated ordinance. In Switzerland, under the Swiss ODS Ordinance, HCFO-1233zd which has an ODP of 0.00034 is considered an ODS. However, the law provides a mechanism for obtaining exemption based on the low-GWP value and its energy efficiency.

Some governments are developing regulations related to per- and poly-fluoroalkyl substances (PFAS), the definition of which may or may not include Montreal Protocol controlled substances and their substitutes. This is creating uncertainty for industry regarding long-term availability of some alternatives. Some companies and other stakeholders have reported that they are delaying decisions regarding selection of alternatives with concerns about how those fluorinated alternatives might be limited as a result of regulations.

### **2.3.1 Low-Pressure Spray Foam**

Two-component polyurethane spray foam products processed by low-pressure mixing is often used to seal gaps in the building envelope and insulate cavities in the building. Polyol blends are stored in pre-pressurized tanks at low pressure and often contain a liquid and a gaseous blowing agent (to propel the blend into the cavity). The pressurized foam system can create challenges in maintaining stability of low-GWP blowing agents and catalysts.<sup>13</sup> However, recent research shows improved stability of polyol blends<sup>14</sup>

## **2.4 HFOs and HCFOs in Current Use**

**HFOs/HCFOs** provide an alternative to HCs that can eliminate or reduce the flammability or use of flame retardant for polyurethane, polyisocyanurate, and extruded thermoplastic foam production,

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<sup>12</sup> Methylene chloride is a controlled substance in some parties due to its use in processing cocaine.

<sup>13</sup> Recent papers focus on catalysts for the trimerization reaction.

<sup>14</sup> Koh et al, Novel Concept to Improve Shelf Life of LP 2K SPF with HFO 1234ze 2021 Center for Polyurethane Institute Conference; Thomas et al<sup>7</sup> Low GWP Two-Component Low Pressure Spray Foam Using CO<sub>2</sub> as a Blowing Agent; 2021 Center for Polyurethane Institute Conference

eliminating the capital investment required to address safety when using HCs as a blowing agent. In addition, HFOs/HCFOs can 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 by SMEs to HFOs/HCFOs is currently slowed by both their greater expense, and limited but improving, supply in A5 parties. HFO/HCFOs are sometimes blended with other blowing agents to reduce costs in both A5 and non-A5 parties.

Manufacturers of HFO/HCFOs have increased capacity of some of the HFOs/HCFOs to meet the demand for low GWP blowing agents that is expected to result from the implementation of low GWP regulations. Continued coordination could be helpful to ensure that there is adequate supply as regulations are implemented.

In Japan, shortages of HFOs/HCFOs slowed HFC conversions in rigid polyurethane foams in 2021 and volumes of HFOs/HCFOs reaching 3700MT in 2021. Markets also contracted in 2021, particularly in spray foam. In 2020 HCFO-1224yd(Z) was commercialized in Japan<sup>15</sup>. The boiling point of HCFO-1224yd(Z) is the same as that of HFC-245fa. HCFO-1224yd(Z) is also used as a refrigerant and solvent in addition to blowing agent.

The Multilateral Fund published outcomes from a demonstration project at foam system houses<sup>16</sup> to formulate pre-blended polyols for spray polyurethane foam applications using new catalyst packages that resulted in foam properties comparable to those blown with HCFC-141b. The cost of the foam was 22-46% greater than the cost prior to the pandemic.

Methyl formate used as a sole blowing agent continues to increase around the world in rigid foam applications and integral skin foam applications. It is also being used in A5 parties as a co-blowing agent with HFCs for various rigid foam applications. Methyl formate blends with HFCs are also being used in the United States for manufacturing XPS boards and in some cases blends with HFCs and HCFOs for rigid polyurethane foams.

#### **2.4.1 Extruded Polystyrene (XPS) Foam Blowing Agents**

Some XPS manufacturers note that there continue to be challenges for the conversion of XPS foam blowing agents for some foams and regions depending on specific product needs noting that new foam blowing agents cannot directly replace current products and that the need to maintain density does not necessarily allow for reduced loading of higher cost blowing agents. They further note that preparation for conversion to flammable<sup>17</sup> blowing agents requires approximately 18 to 36 months for capital investment and product qualification based on the specific end use (e.g., walls, roofs, structural support, transportation, cold storage). It was also noted that at least one non-flammable, mid-range (750 GWP) blend, containing HFC-134a, is currently under consideration for use.

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<sup>15</sup> Its boiling point is 15°C and its molecular weight is 149

<sup>16</sup> [http://www.multilateralfund.org/Our%20Work/DemonProject/Document%20Library/8311ax5\\_Thailand.pdf](http://www.multilateralfund.org/Our%20Work/DemonProject/Document%20Library/8311ax5_Thailand.pdf)

<sup>17</sup> A new paper on flammability hazards of HFO-1234ze during processing. *Comprehensive Evaluation of the Flammability and Ignitability of HFO-1234ze*; R.J. Bellair, L.S. Hood, Process Safety and Environmental Protection, In Press (2019).

<https://www.sciencedirect.com/user/error/ATP-2?pii=S0957582019313734>

In China there are Chinese equipment vendors offering both CO<sub>2</sub> based and HFC solutions for medium to large enterprises. It is expected that CO<sub>2</sub> based systems will predominate for the phase out of HCFCs.

Other blowing agents and co-blowing agents continue to be used in small quantities. Isopropyl chloride (2-Chloropropane) is blended with isopentane generally for phenolic foam. Foam additives FA188 and PF-5056 are highly fluorinated, C5 or greater olefins whose GWPs are close to 100 and have been viewed technically as nucleating agents. However, based on the European Norm standard (EN13165), this material can be found in the cell gas after 6 months at 70°C in polyisocyanurate (PIR) foam, so then it is also classified as a blowing agent.

A patented chemical blowing agent (trade named CFA8<sup>18</sup>) is being promoted, as a foam blowing agent, to the polyurethane market by China's Butian New Materials and Technology Company. It is expected that other innovative chemical and physical blowing. The technology involves carbonic acid salts of polymeric amines which liberate CO<sub>2</sub> upon heating above a certain temperature, typical of polyurethane processing conditions. Hence, it is a latent source of CO<sub>2</sub> blowing gas but has limitations due to relatively high residual water content and low molar mass of bound CO<sub>2</sub>.

It is expected that other innovative chemical and physical blowing agent technologies may be introduced over the coming years.

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<sup>18</sup> PCT/CN2017/083948 (WO2017206692 A1) 201610393108.0 (CN107089927A)

### **3. Halons TOC (HTOC) Progress Report**

#### **3.1 Introduction**

Owing to the COVID-19 travel restrictions, the HTOC has been holding monthly virtual meetings and plans to continue to do so. As such, the HTOC did not meet in person in Q1 of 2022. Instead, a series of virtual meetings was held during the week of 21 March 2022, each one focused on a specific chapter of the 2022 Assessment Report. In addition, with travel restrictions now easing, the HTOC is planning an in-person meeting in June 2022 to finalise the Peer-Review Draft of the 2022 Assessment Report.

#### **3.2 Effect of the HFC Production Phase-down**

In the 2018 Assessment Report, the HTOC anticipated that the initial 10% reduction in HFC production within non-Article 5 parties would not have a significant impact on the availability of HFCs for fire protection. It was reasoned that the use of HFCs in fire protection is extremely small in comparison to other uses, the emissions are low, and sales of HFCs in most non-Article 5 parties were either declining or flat. Instead, the experience in the EU and Japan has shown a movement away from the use of HFCs in new fire protection systems (although use of HFCs in Japan has never been widespread). HFCs have been replaced in large part by low-GWP and no-GWP alternatives such as FK-5-1-12 and inert gases. The US HFC phase-down began on January 1, 2022, and it has already had an impact on the cost and availability of newly produced HFCs for fire protection. The US allocation system is GWP-weighted and the HFCs used for fire protection have very high GWPs, so the impact has been greater than initially expected. It is the HTOC's experience that HFCs contained in fire protection equipment historically have been recycled and reused to a relatively high extent. As the supply of newly produced HFCs for fire protection decreases in response to phase-down regulations, recycling becomes even more important as an alternative source of supply and is likely to increase in the future.

- Parties may wish to consider re-emphasizing the need to foster international trade of recycled/reclaimed high-GWP HFCs, i.e., HFC-227ea, HFC-125 and HFC-236fa used in legacy fire protection applications, which include those in civil aviation lavatory fire protection systems.

#### **3.3 Availability and Quality of Recycled Halon 1301**

The HTOC has identified several issues affecting the availability and quality of recovered halon 1301 from the civil aviation sector.

The issues concerning contaminated halon recovered from the aviation sector are at best continuing but possibly getting worse based on input provided to the HTOC by recycling companies. The Halon Recycling Corporation (HRC), as part of their outreach program on proper halon management, has recently developed a guidance document for airlines and maintenance, repair, and overhaul (MRO) companies that outlines best practices for eliminating contamination during servicing. This free guidance document is available via the HTOC for wide-spread dissemination.

Likewise, the previously reported issue with some countries placing regulatory barriers that restrict the import of fire extinguishing components containing halons that are required for emergency replenishment after a halon discharge is continuing.

The previously reported difficulties in shipping bulk recovered halon 1301 across national boundaries as some authorities appear to be classifying recovered halon as hazardous waste under the Basel Convention, thus preventing shipment also continues.

The world's first pilot halon destruction and carbon offset project occurred in February 2021 in the US, where approximately 1.22 tonnes of halon 1301 were destroyed under the American Carbon Registry, a private voluntary US greenhouse gas registry. This methodology incentivizes destruction of Halon 1211 and Halon 1301 from fire equipment or systems. The HTOC does not know whether the Halon 1301 used in the pilot destruction project was not reclaimable (due to contamination), and therefore destruction was the best option, or whether regardless of the halon quality, the project proceeded purely on the basis of wanting to dispose of the halon to meet "sustainability" commitments of the entities involved to create carbon offset credits for transactional / commercial purposes.

Owing to the continued global halon demand in enduring fire protection applications such as aviation, the HTOC has previously recommended that destruction as a final disposition option should be considered only if the halons are contaminated and cannot be reclaimed to an acceptable purity. The HTOC continues to maintain this position. Furthermore, the HTOC recommends extending this position to all halogenated gaseous fire extinguishants and recommends destruction only as a final resort when any fire extinguishant cannot be reclaimed to industry specifications.

The HTOC believes that shipbreaking could represent a significant source of halon 1301 which could support on-going activities. Bearing that in mind the entire fleet of ships with halon on-board are reaching their end of life and this supply of halon will then be exhausted, it is imperative that recovery of halons from this source be prioritized and conserved to the greatest extent possible.

Parties may wish to consider:

- Requesting the Ozone Secretariat to disseminate the halon management guidance document recently developed by HRC available from the HTOC, to all National Ozone Units (NOUs) and sponsoring presentations during all upcoming Ozone Regional Manager Network and other applicable meetings,
- Liaising with their civil aviation authorities to disseminate the halon management guidance document to all applicable entities within their country such as airlines, maintenance, repair, and overhaul (MRO) companies, and associated non-governmental organisations (NGOs),
- Requesting that the International Civil Aviation Organisation (ICAO) formally disseminate through a State letter, this halon management guidance document to all civil aviation authorities requesting that the halon management guidance document receive the widest possible dissemination within their State and/or region,
- Emphasising the importance of effective and complete recovery of halons to minimize halon losses by all parties, particularly those with shipbreaking activities, and
- Re-emphasising the need to allow for appropriate, open trade of recovered, recycled and/or reclaimed halons in bulk containers and in prefilled fire protection components to support enduring halons uses, including civil aviation components that are required to allow aircraft to operate under international airworthiness requirements.

### **3.4 Proposed EU Perfluoroalkyl and polyfluoroalkyl substances (PFAS) Regulations**

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) refers to a class of chemicals that contains fluorine atoms bonded to carbon atoms. Historically, PFAS was used to describe longer chain compounds that were used in products such as paper, textiles, leather, carpets, and firefighting foam. The regulation of PFAS chemicals initially focused on perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) both used in firefighting foams. In June 2020, five European countries - Germany, the Netherlands, Norway, Sweden, Denmark - officially declared their intention to submit to the European Chemicals Agency (ECHA) a proposal for a Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) restriction covering all PFAS chemicals. This proposed, expanded definition in the EU would define PFAS as any substance that contains at least one fully



fluorinated carbon CF<sub>2</sub> or CF<sub>3</sub> group (without any H/Cl/Br/I atom attached). This definition of PFAS would encompass virtually all of the halogenated, clean agent alternatives to halons, HCFCs and high-GWP HFC fire extinguishing agents (HFC-23 and CF<sub>3</sub>I being the only exceptions). Thus, hydrochlorofluorocarbon (HCFC)-124, HCFC Blend A, HCFC Blend B, HFC Blend B, HFC-227ea, HFC-125, HFC-236fa, fluoroketone (FK-5-1-12), 2-bromo-3,3,3-trifluoroprop-1-ene (2-BTP), and Halocarbon Blend 55 could all be included in the proposed regulations. The proposed restriction would prohibit the manufacture, import, sale and use of PFAS and products containing PFAS at some future date. The expected date of submission of the PFAS restriction proposal to ECHA is January 2023. Based on the current schedule if a PFAS REACH restriction is adopted it would likely be completed in 2025 and become effective sometime after that. REACH restrictions usually include exemptions (derogations) for uses that have no alternatives that are considered essential.

Regardless of whether derogations are granted or not, these uses represent only a very small market. This, in turn, would have a direct bearing on commercial viability of these agents, potentially influencing decisions to continue use of non-PFAS agents (i.e., halons or HFC-23). Restricting or prohibiting the sale or use of these gaseous agents would have significant impacts on the ability of users to effectively protect a range of special hazards from fire and explosion (as described in existing HTOC Assessment Reports and Technical Notes available on the Ozone Secretariat website).

Further, derogations are typically limited to only allow sufficient time for industry to develop alternatives. Fire protection timescales for development and deployment are long, with timescales for some applications such as civil aviation being extremely long and often uncertain. As an example, 2-BTP is the result of a 20-year search for an alternative to Halon 1211 in aviation hand-held extinguishers. It is currently replacing Halon 1211 on most new production aircraft, and all existing aircraft in the EU are expected to be retrofit under existing regulation to 2-BTP by 2026. It took 15 years once identified as a potential candidate to replace Halon 1211 to develop and gain approval. There are now no other candidate agents for this use that do not fall under this broad PFAS definition. CF<sub>3</sub>I is removed from consideration owing to toxicity, and all of the not-in-kind alternatives that have been tested for this use failed the minimum performance standards. In other words, the only alternative to 2-BTP would be to revert back to (or keep using) Halon 1211. This is similar to many uses of halon 1301 where the only agents that will work are the original halon or high-GWP HFCs, e.g., extremely low temperature applications, aviation lavatories, and some military applications.

### **3.5 New Developments in Aviation Fire Protection**

Handheld fire extinguishers containing halon 1211 on aircraft registered in the EU will be banned after 2025 according to EU legislation. They will most likely be replaced on civil passenger aircraft with 2-BTP extinguishers although pending regulation of 2-BTP as a PFAS is a concern. Additionally, the announced withdrawal of the Underwriters Laboratories (UL) standard for halon extinguishers should lead to cessation of UL-marked extinguisher production after January 2025, regardless of whether the aircraft is registered in the EU or not. This may drive replacement of halon 1211 extinguishers outside of the EU for logistics/standardization reasons, thus increasing the amount of halon 1211 extinguishers being removed from service. As civil aviation represents a significant fraction of the halon 1211 market, as it transitions to alternatives there may be implications on the overall market for recycled halon 1211, which could affect availability for other users.

Alternatives to halon 1211 have yet to be developed for the different sizes of handheld extinguishers that are installed onboard military aircraft and helicopters, and on smaller civil aircraft. The process of replacing an extinguisher is costly and is delaying the development of the smaller unit used in cockpits and the larger one used in baggage compartments in these aircraft. The HTOC anticipates difficulties in replacing these other extinguishers as there are currently no standardized test methods, classifications, or certification procedures for these other-sized extinguishers. Pending regulation on 2-BTP as a PFAS in the EU also adds uncertainty to resolving this issue.

R&D for cargo compartment fire protection systems continues. However, the development and certification timescales remain long and can be uncertain. As such, it will still be at least several more years before any of the fire extinguishing agents being evaluated could be in service on aircraft. If these are not successful, the chances of finding an as-yet undiscovered alternative that is safe and effective are, after so many years of research, extremely low.

Parties may wish to consider requesting that ICAO continue to sponsor activities related to halon regulation and management, include the HTOC in these activities, and work with the HTOC to provide annual updates on changes to their halon regulations, the status of development and implementation of aviation alternatives and other halon management issues important for the long-term use and management of halons.

### **3.6 New Fire Extinguishing Agents**

#### **3.6.1 *HCFO/Fluoroketone blend***

A new total flooding agent to potentially replace halon 1301, HCFC blends, and high GWP HFC-227ea and HFC-125, has been introduced to the US National Fire Protection Association and International Organisation for Standardisation (ISO) fire protection committees. It is a 50-50% blend by mass of the hydrochlorofluoroolefin HCFO-1233zd(E) and the fluoroketone FK 5-1-12. Both components have low GWPs and negligible or zero ODPs. However, both of the components fall under the proposed definition of PFAS by the EU. It is too early to determine whether this blend will be a viable alternative to halons, HCFCs and high-GWP HFCs. The HTOC will continue to monitor and report progress on this agent.

#### **3.6.2 *Update from India***

Owing to the COVID-19 pandemic, little progress has been made recently on development of new extinguishing agents. Toxicity studies are planned, but the timescale for completing these is not known at this time. Some intermediate-scale fire tests are planned for the near future.

#### **3.6.3 *Market Considerations***

Halons have been replaced with a range of firefighting alternatives meaning that any one agent has less of a market share than the agent it is replacing. Additionally, the experience with recycling of halons has shown that proper agent management will greatly reduce the need for newly produced agent. Therefore, the potential market for any new, single fire suppressant diminishes thereby making the business decision to develop new alternatives less attractive than in the past. Thus, fewer companies are willing to invest the significant resources necessary to develop chemicals that do not have wider application than fire suppression. For example, one major chemical manufacturer with a long history of providing firefighting agents has indicated to at least one potentially interested party that they do not plan to further the commercialization of a promising candidate solely as a potential total flooding alternative for halon 1301, HFC-227ea or HFC-125 due to its relatively small projected market (already competing with other existing alternatives such as FK-5-1-12, inert gases, water, etc.) unless and until it were to find broader use in non-fire application(s). The HTOC is concerned that after many years of ongoing research, the chances of finding an as-yet undiscovered alternative that is safe and effective are now extremely low.

Although initially reported as an issue for portable extinguishers in civil aviation, the loss of UL listing for fire extinguishing parts for halon 1301 systems is being reported to affect enduring users of halons outside of civil aviation as well. This can affect the ability to continue to use halon in these fire protection systems thereby changing market demand. It is not clear at this point how much of an effect this will have on the availability or price of recycled halons. The HTOC will continue to monitor this issue.

## **3.7 Other Updates**

### **3.7.1 *Effects of Alternative Refrigerants Selection***

The HTOC continues to express concern, as raised in the 2021 HTOC Progress Report, with expanded use of alternative refrigerants due to their potential flammability and yet to be determined effects on firefighting systems (e.g., agent effectiveness, by-products generated, etc.). In addition to industry standard tests for measuring flame propagation (ASHRAE-34/ISO-817), new methods are being developed, but not yet available, to address these concerns. Additional information will be included in the HTOC 2022 Assessment Report

### **3.7.2 *Knowledge and training***

The HTOC has a continuing concern regarding the historical knowledge that has been lost due to the length of time over which the Montreal Protocol activities have been conducted. Many personnel who are currently responsible for managing fire protection agents covered by the Montreal Protocol are not experienced with the issues surrounding the use, recovery, recycling, reclamation, and banking of these agents. The HTOC is finding that this is becoming an increasing challenge as it works with various parties and organisations on issues related to acquiring halons or identifying alternatives to meet their continuing needs. For example, many NOU staff members indicated to the HTOC that they are looking for information that is already available from HTOC reports, but they seem unaware that the information is available and/or where to find it on the Ozone Secretariat website.

Parties may wish to consider:

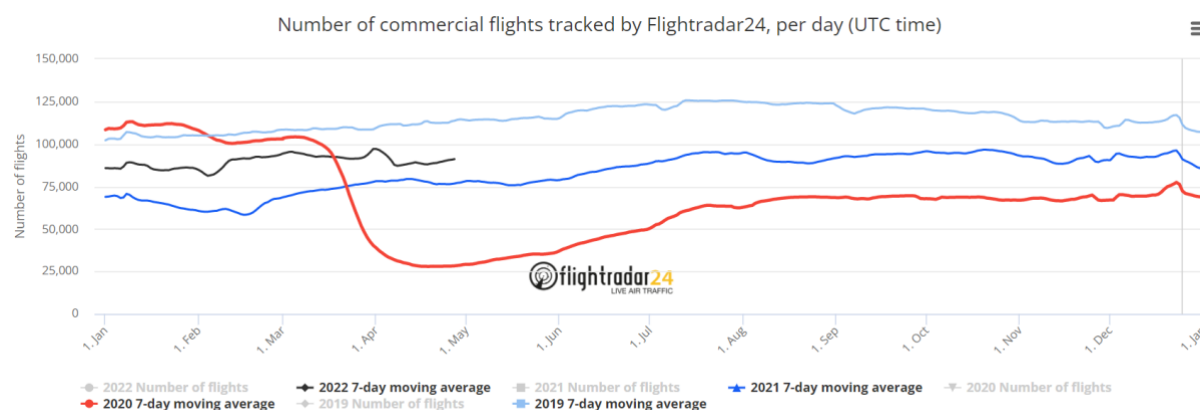
- Supporting programmes to mitigate the loss in institutional memory of fire protection issues under the Montreal Protocol; for example, including HTOC reports and technical notes, presentations, etc. in Ozone Regional Manager Network or other applicable meetings, and
- Supporting training and awareness programmes to address recovery, recycling, reclamation, and banking of HCFC and HFC fire protection agents.



## 4 Updated response to Decision XXX/7: Future availability of halons and their alternatives

In the early stages of the COVID-19 pandemic in 2020, the HTOC raised concern that the economic downturn caused by the global response to the pandemic would have a lasting impact on the Halon 1301 sector. This remains the case. Airframe manufacturers have lowered their production rates and lowered their forecasts for aircraft sales for the next several years. Their internal predictions are that growth rates will not return to pre-COVID-19 levels for at least five years. Additionally, airlines have accelerated decommissioning their older, less efficient aircraft and are replacing them with new, smaller aircraft that use less halon (i.e., wide body, twin aisle aircraft are being replaced by narrow body, single aisle aircraft).

Figure 4.1 below shows the large decline in the number of commercial aviation flights in March-April 2020, and the gradual recovery in 2020 and 2021. In April 2022 flights were approximately 20% below the corresponding period in 2019.



**Fig. 4.1. Effect of the COVID-19 Pandemic on Global Aviation. Source: Flightradar24<sup>19</sup>**

A major question that was raised by the HTOC was if the economic impacts caused by the COVID-19 pandemic would present a new opportunity to understand the installed amounts and emissions (i.e., needs) of halon 1301 from the enduring uses that was never possible before. For example, did emissions change by region or did emissions change in relation to civil aviation flights or flight hours that could be directly attributed to changes in operations owing to the pandemic? The data for the latest estimates of global emissions based on atmospheric abundances though 2020 do not show any significant decrease in halon 1301 emissions during 2020. Since we know that civil aviation flight hours dropped by 60% during the pandemic, this suggested that global emissions for at least 2020 did not correlate well with civil aviation flight operations. In other words, total global emissions do not seem to be dependent on the number or duration of civil aviation flights. This does not necessarily mean that civil aviation is not the cause of some of or even a significant amount of the emissions but rather that a different part of the aviation lifecycle such as fire extinguisher maintenance could be responsible for much of these emissions. The HTOC is awaiting the 2021 data on the estimates of global emissions based on atmospheric abundances and is also working with ICAO, relevant

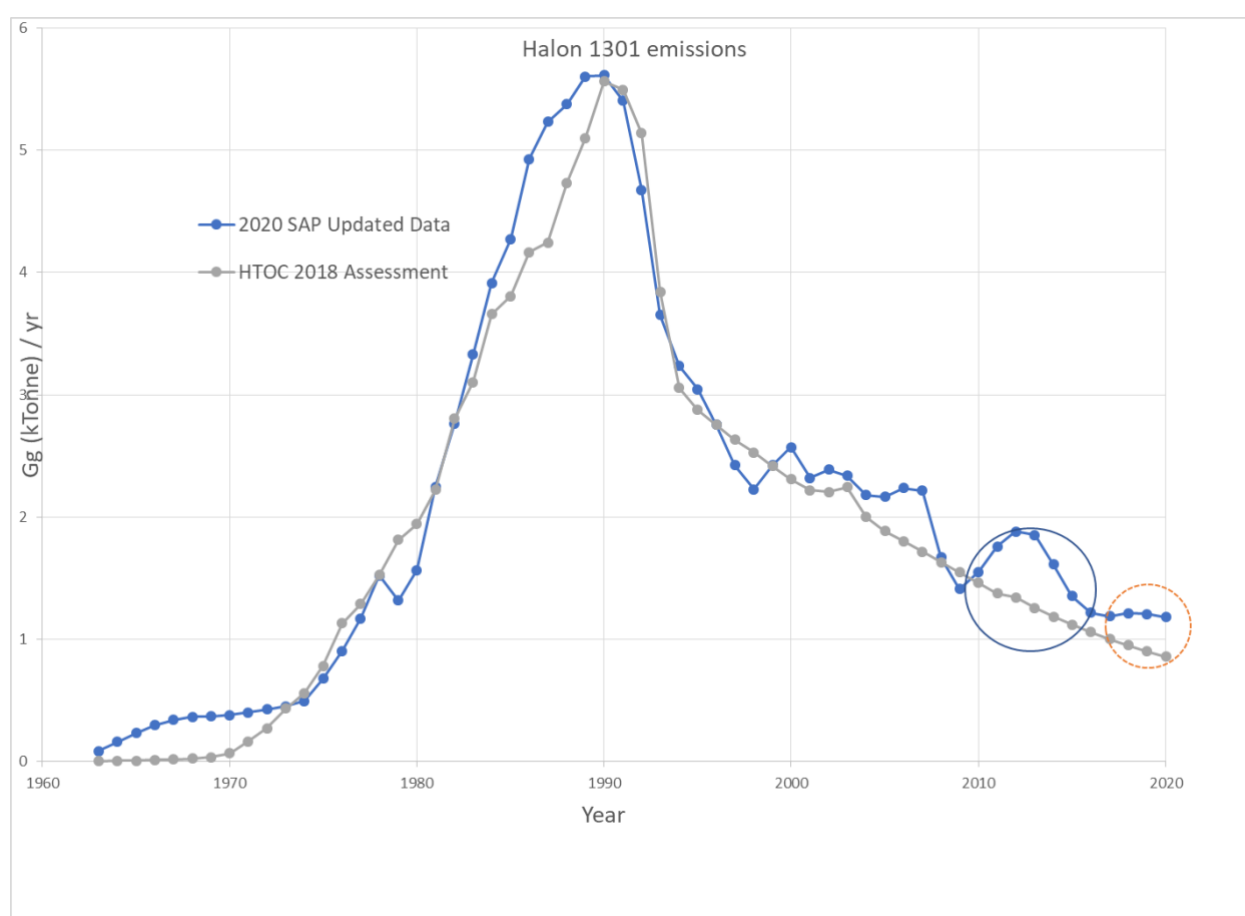
<sup>19</sup> “Flightradar24 website ; <https://www.flightradar24.com/data/statistics> Retrieved 28th April, 2022

companies, and civil aviation NGOs and working groups to better understand not only the magnitude of the emissions but also potentially where in the life cycle these emissions are occurring.

Additionally, the HTOC continues to work cooperatively with the International Maritime Organization (IMO), maritime / merchant shipping NGOs, and other halon 1301 sector experts to understand the implications of these data to update the modelling and estimates for current and projected halon 1301 market in terms of uses, installed base and annual emissions. This remains a significant task for the HTOC and will be reported to the parties as part of its upcoming 2022 Quadrennial Assessment.

## 4.1 Global Halon 1301 Emissions

There are two approaches that are provided in the HTOC Assessment reports on estimating halon 1301 emissions: (1) the HTOC model (in grey in Figure 4.2), and (2) estimates derived from measured atmospheric abundances combined with its atmospheric lifetime (the blue data in Figure 4.2).



**Fig. 4.2. Comparison of halon 1301 emissions from the HTOC model versus the latest estimates derived from atmospheric abundances**

In general, the agreement between the two approaches is remarkably good. However, there have been two recent periods where the emissions estimated from atmospheric measurements are higher than the HTOC modelled emissions, indicated by the blue and orange circles. The first is from about 2010 to 2016, and the second from about 2018 to 2020. The HTOC is concerned about these discrepancies because any “additional” halon 1301 emissions over those estimated by the HTOC model would decrease the size of the global halon bank estimated by the HTOC and therefore would reduce the estimated amount of halon that will be available to support enduring uses. The HTOC is continuing to

work with atmospheric scientists from the Advanced Global Atmospheric Gases Experiment (AGAGE) network to determine if additional data analysis can provide any insight into these “additional” emissions.





## 5 Methyl Bromide TOC (MBTOC) Progress Report

The May 2022 MBTOC Progress Report provides an overview on the production and consumption of MB for both controlled and exempted (QPS) uses and a summary of MB alternatives developed for sectors for which critical uses have been nominated this year for use in 2023 or 2024.

Recent research on alternatives to QPS uses of MB and the trend in atmospheric emissions of MB is also presented. MBTOC considers that accurate reporting and determination of the correct categories of uses of MB for Q and PS are critically important to assist the parties understanding of these uses and for the future development and adoption of alternatives around the world for these uses.

A brief overview of the situation with the use and adoption of re-capture/recycling of MB for QPS uses in different sectors and regions is also presented. In the absence of phase out of MB, this technology is considered essential to adopt in order to reduce emissions from MB use without damaging the ozone layer.

An update on the collaboration between the International Plant Protection Convention (IPPC) and MBTOC, plus some remaining challenges associated with MB use and phase-out are discussed.

### 5.1 Global MB production and consumption

#### 5.1.1 *Controlled uses*

##### ***Production***

In the past decade, four parties have reported production of MB for controlled uses: China, Israel, Japan, and the United States. Japan has not reported production since 2014 and China has not reported since 2018. In 2020, Israel reported a negative amount of -68.8 tonnes (i.e., zero production; exports taken from stockpiles) and the US reported production of MB for controlled uses of 6.83 tonnes that same year (2020).

##### ***Consumption***

In 2020, reported MB consumption for controlled uses was 69 tonnes. This matches with amounts granted under the Critical Use Exemption (CUE) by the MOP (A5 parties 35.7 tonnes; non-A5 parties 33.3 tonnes) and is a significant reduction from the 116 tonnes consumed in 2019. In addition, MB amounts drawn from stockpiles and exported to A5 parties in 2020 were reported by EU of - 6.2 tonnes, by Israel - 68.8 tonnes and the United States - 19.2 tonnes. (Negative values result from such amounts being exported, i.e., not consumed domestically)

Phase-out of the remaining controlled uses of MB has continued under the CUE process; in 2022 only three parties requested CUNs. This reflects successful adoption of alternatives in the vast majority of sectors where MB was once used, both as a soil fumigant and as a postharvest or structural treatment (or re-categorisation to QPS by one party).

In some A5 parties, it is possible that continuing controlled critical uses may be being supplied from an estimated 1,200 tonnes of stocks (presumably pre-2015 stocks), instead of making a CUE application.

#### 5.1.2 *Methyl bromide production and consumption for QPS (exempted uses)*

##### ***Production of MB for QPS***

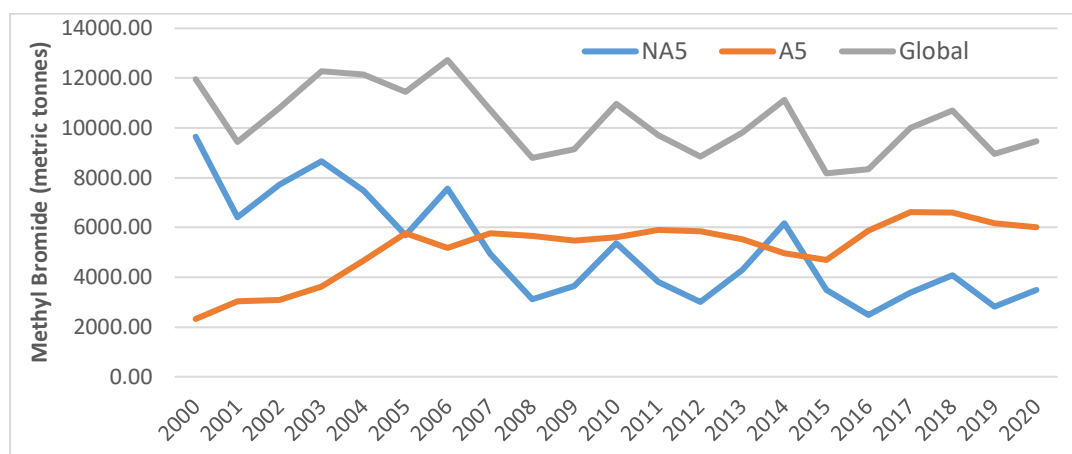
Reported world production of MB for QPS amounted to 10,143 metric tonnes in 2020. Five parties, two A5s (China and India) and three non-A5 parties (United States, Israel, and Japan) currently produce MB for QPS.

### Consumption of MB for QPS

QPS uses continue to far exceed the use of MB for controlled uses and are now the major anthropogenic contributor of MB to the stratosphere. QPS treatments are highly emissive of MB, although some countries are implementing emission reduction technologies. In particular, recapture of MB to reduce emissions associated with QPS use is increasing in some countries where regulations are driving its adoption (e.g., New Zealand).

Over the last decade, the average global consumption of MB for QPS has remained stable at around 10,000 tonnes/year in spite of some parties completely phasing out QPS use of MB (e.g., EU). Consumption varies, sometimes widely, from year to year: e.g., between 2017 and 2018, there was an increase in global consumption for QPS (10,700 tonnes), followed by a decline in 2019 (8,970 tonnes) and once again an increase in 2020 to about 9,500 tonnes (Fig 5.1).

**Fig. 5.1 Consumption of MB for QPS (exempted) uses from 2000 to 2020**

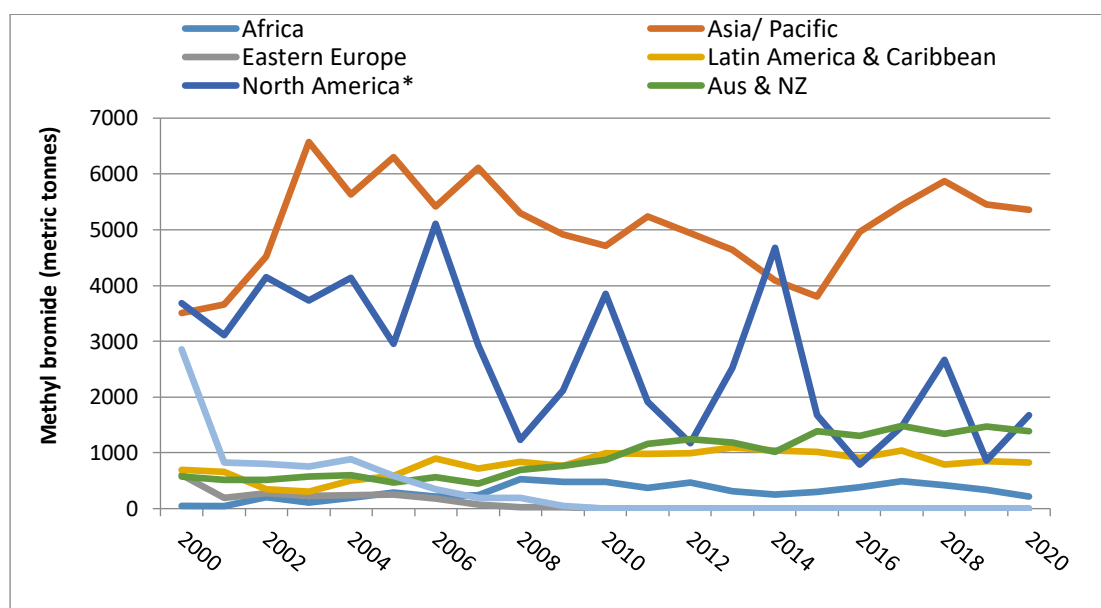


Source:

Ozone Secretariat Data Access Centre, accessed April 2022. NA5: Non-Article 5 parties. A5: Article 5 parties.

Non-A5 parties have shown a downward trend in consumption since 1999, whilst consumption has been increasing in A5 parties since 2015. Increased use in some regions (Figure 5.2) is offsetting the benefits gained by phasing out MB for controlled uses globally.

**Fig. 5.2. Consumption of MB for QPS (exempted) uses from 2000 to 2020**



Source: Ozone Secretariat Data Access Centre, accessed April 2022 \* Includes USA and Canada only

Even though MB used for QPS is exempted from phase-out under the Montreal Protocol, parties are encouraged to minimize and replace these uses whenever possible. However, there is no real incentive to do so, and various factors take priority: economic constraints, market access restrictions due to lack of internationally accepted alternatives or the very slow and tedious process to obtain regulated alternatives for quarantine use bilaterally and within the IPPC. Nevertheless, initiatives are being proposed to use alternatives and include QPS uses being considered under the CUE process (Nothomb, 2021). Increasing registration of ethanedinitrile for wood products, which are a major user of MB, may reduce MB use substantially in the near future.

MBTOC suggests that parties may wish to revisit the current QPS definition for pre-shipment applications with a view of establishing whether it is possible to remove the “preshipment” option or control the use of methyl bromide for that purpose, given that alternatives are readily available and an estimated 30-40% of the QPS consumption falls into this category.

This would require parties to make a clear distinction between “Q” and “PS” categories of use and report them separately. MBTOC stands ready to assist parties in achieving this. As a first step, parties may wish to ask MBTOC to update information collected for its 2010 and 2011 reports in response to Decision XX/6 and other relevant decisions of the Protocol.

Pre-shipment treatments are generally aimed at a lower standard of pest control than quarantine uses and are normally targeted against pests that are not quarantine pests. Whilst quarantine treatments should lead to a commodity that is at least 99.9% free of regulated quarantine pests, pre-shipment only requires the consignment to be “*practically free*” of pests. This lower level of security gives greater opportunity to use a wider choice of alternatives, which in a large number of cases are well-proven and immediately available in both A5 and non-A5 parties. In general, these alternatives also have, a reduced requirement for efficacy testing.

## **5.2 Update on alternatives for remaining critical uses**

Technically and economically feasible chemical and non-chemical alternatives to MB have been found for virtually all soils, structure and commodity applications for which MB was used in the past including nearly all critical uses applied for since 2005. Comprehensive information is available on the adoption of key alternatives in the MBTOC 2018 Assessment Report (MBTOC, 2019) past MBTOC CUN reports (MBTOC, 2003 - 2021) and the MBTOC Progress Report (TEAP, 2003-2021).

This May 2022 progress report provides updated information on recent research related to alternatives for controlled uses of MB for which critical uses are still being requested, namely strawberry runners (soil-borne pathogens and weeds) and houses (wood pests).

### **5.2.1 Strawberry runner production – Australia**

Australia continues to prioritize the registration of Methyl Iodide (MI) as the most efficient alternative to MB for treating soil grown with strawberry nurseries in the State of Victoria. Extensive R&D in the runner industry at Toolangi, Victoria, proved that soil disinfestation with MI/Pic controls soil-borne pathogens and weeds as effectively as MB/Pic, and produces equivalent runner yields to MB/Pic in commercial trials. Although in 2012 Arysta Life Sciences withdrew its application to register MI in Australia and other countries around the world, *Saluterra Pty Ltd* has applied for registration of *MI/PIC 980 Soil Fumigant* in strawberry runner production. The product has been shown to control *Fusarium*, *Pythium*, *Phytophthora*, *Rhizoctonia*, *Sclerotium rolfsii*, *Macrophomina phaseolina*, plant parasitic nematodes and seeds of some weed species.

The Australian research program continues to look at other alternatives with encouraging results: ethane dinitrile (EDN), TF-80®, microwave treatments, and different rates and formulations of MI/Pic. DMDS and DMDS/Pic are being trialed in Australia since 2014 and Arkema is proceeding with registration.

## 5.2.2 *Strawberry runner production – Canada*

Many countries producing strawberry runners find soilless culture systems technically and economically feasible, at least for a portion of certified nursery production operations, as well as for stock plants. Such systems allow for producing pest and disease-free nursery material that meets the required plant health standards (López-Galarza *et al.*, 2010; Rodríguez-Delfín, 2012; Xu, 2019 Wei *et al.* 2020;).

Canada continues to conduct research aimed at perfecting a soilless production system that will avert the need for soil fumigants, as no chemical alternatives to MB are allowed on Prince Edward Island, where the need for a CUE arises. Other Canadian Maritime provinces do not need MB to produce healthy strawberry runners in similar circumstances.

## 5.2.3 *Structures – disinfestation of houses in South Africa*

The Republic of South Africa (RSA) has continually reduced their nomination for treating structures (houses) with MB but still finds challenges. Disinfestation of wooden structures in dwellings is achieved with either heat (Hofmeier, 1996; Reichmuth *et al.*, 2002; 2007) or SF (Reichmuth *et al.*, 2003, Ducom *et al.*, 2003) in many countries around the world. Williams and Sprengel (1990) have demonstrated the efficacy of these treatments against eggs of key pests of wood like anobiid and lyctid beetles.

La Fage *et al.* (1982) showed that SF was effective against the Formosan termite *Cryptotermes formosanus* (Isoptera: Rhinotermitidae). There are significant differences in tolerance between adult insects and especially eggs to SF (eggs versus adults; see also MBTOC's review on SF-use in previous reports). Both the literature and trained fumigators do not recommend using SF at temperatures below 20°C, due to pronounced increase of tolerance of the eggs of target pests.

Other alternatives include ethane-dinitrile (EDN), with good penetration characteristics, high efficacy and short application time (Ryan *et al.*, 2006). EDN<sup>®</sup> applications limit the risks of pests and diseases spreading within the agricultural and timber industry. BLUEFUME<sup>™</sup> (HCN) is also a promising treatment for controlling wood infesting pests in packages and structures and was registered in the EU in 2017. Pest resistance is currently not an issue with EDN or HCN and their wide range of action for controlling timber pests (insects, mites, rodents, nematodes, fungi, etc.) makes them good potential alternatives to MB for treating wooden structures (Hnatek *et al.*, 2018).

## 5.3 **QPS uses of methyl bromide**

MBTOC keeps track of research on alternatives to MB for QPS purposes, as well as on the status of registration and availability of alternatives to MB around the world.

### 5.3.1 *Chemical alternatives*

#### 5.3.1.1 Hydrogen cyanide (HCN)

HCN continues to show promise as an alternative to MB South Korea for treatment of stem and bulb nematodes infesting garlic cloves (Zouhar *et al.*, 2016) and New Zealand for some fruit. Malaysia also reported registration of HCN in 2019/2020 as an alternative to MB for postharvest treatments (Glassey, pers comm., 2021).

#### 5.3.1.2 Ethyl formate (EF)

Efficacy of EF and MB were compared for disinfestation of the citrus mealybug *Planococcus citri* (Hemiptera: Pseudococcidae) on bananas imported into South Korea (Park *et al.*, 2020). Results showed that EF fumigation

sorption to bananas and packaging materials lowered the realized EF concentrations around banana and reduced the mortality of *P. citri* eggs despite similar efficacy of MB and EF for controlling *P. citri*.

Cho *et al.*, (2020) evaluated the combined effect of EF (20 g/m<sup>3</sup>) plus PH<sub>3</sub> (1 g/m<sup>3</sup>) on mealy bugs nursery plants and despite good control there was some phytotoxicity of the treatments.

EF was evaluated as a potential MB alternative for controlling exotic ants and termites from stone and lumber imported into Korea with encouraging results. Commercial scale trials suggest that EF fumigation may be applicable for disinfestation of invasive worker ants and female alates of *Soleopsis invicta* on imported lumber (Kim, D. *et al.*, 2021). New Zealand has adopted EF (with CO<sub>2</sub>) to control both ants and the brown marmorated stick bug ([Approved biosecurity treatments](#)).

Spotted wing drosophila, *Drosophila suzukii* (Diptera: Drosophilidae) in the U.S. and Europe has become a major phytosanitary trade barrier. Kwon *et al.* (2021a) explored the potential of using stand-alone EF treatment and a combined treatment of EF and cold temperature for *D. suzukii* in imported blueberries. In small scale pilot studies, 9-day stand-alone cold treatment at 5°C was sufficient for complete control of *D. suzukii* eggs and larvae tested, but not pupae. The efficacy of this cold treatment appeared to improve when *D. suzukii* eggs were first treated with low-dose EF (LCt50% level) prior to the cold treatment.

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Hemiptera: Pentatomidae) is a sap sucking insect native to China, Japan and Korea that has become invasive in North America, Europe and Chile. It causes significant damage to a wide array of economically important crop species. Ethyl formate (with CO<sub>2</sub>) has been successfully tested against overwintering BMSB by Kawagoe *et al.*, (2022) with a 4-hour treatment schedule using 15 g/m<sup>3</sup> EF and 3% CO<sub>2</sub>.

Kim, *et al.* (2021) attempted to shorten phosphine treatment time and avoid resistance to this fumigant with a combined treatment with EF for control of *Planococcus citri*. The efficacy of PH<sub>3</sub> decreased after reducing the treatment time, but synergistic effects were observed at all stages of development of *P. citri* when both fumigants were used simultaneously for 4 h.

Kwon *et al.* (2021b) evaluated the efficacy of EF, Phosphine (PH<sub>3</sub>) and EF + PH<sub>3</sub> on the mushroom fly, *Lycoriella mali* (Diptera: Sciaridae), the primary pest in imported mushrooms in South Korea. The combination treatment had a synergistic effect, with no phytotoxic damage.

### 5.3.1.3 Phosphine (PH<sub>3</sub>)

Recent research continues to support use of phosphine as an alternative to MB fumigation of stored grain. One small scale project (Arora *et al.*, 2021) showed effectiveness of phosphine in well-sealed systems under Indian conditions against three common beetle pests of wheat with 7 and 10-day exposures.

Sri Lanka and Pakistan are increasing the acceptance of PH<sub>3</sub> to replace MB for imported grains (Mirage News, 2022).

In Japan, a newly developed method for applying aluminum phosphide that prevents residual powder remaining on treated grain layer, substantially saving labor is now registered. Sachets of dose formulation are hung above the grain layer; phosphine gas is generated from the formulation and evenly distributed throughout the grain layer with air circulation. Once the fumigation is finished sachets are removed from the silo and disposed safely (Soma *et al.*, 2018).

Bean thrips (BT), *Caliothrips fasciatus* (Thysanoptera: Thripidae), are a pest of concern to certain countries that import fresh citrus fruit from California, USA. Walse and Jimenez (2021) conducted a series of laboratory-scale exploratory fumigations with different phosphine formulations to evaluate the postharvest control of adults. Results provided evidence to support the control of BT following fumigation with an applied dose of ≤ 1.5 g m<sup>-3</sup> phosphine, showing good potential for this treatment.

The khapra beetle, *Trogoderma granarium* (Coleoptera: Dermestidae) is one of the most important quarantine pests of stored grains. Most studies with phosphine gas highlight eggs as the most tolerant stage. Lampiri and Athanassiou (2021) recently suggest delayed effects of phosphine fumigation on larval growth and faster hatching in eggs exposed to phosphine for 2 days.

Gourgouta *et al.* (2021) conducted mortality tests on different life stages of the khapra beetle (including diapause larva), with phosphine at dosages of 50, 100, 200, 300, 500 and 1,000 ppm for 3 days and found that although eggs are the most tolerant to phosphine, 100% were killed with 1,000 ppm of phosphine after a 3-day exposure.

Lampiri (2021) found that 2-day-old eggs of *T. granarium* are more susceptible than 1-day-old eggs. Faster hatching was observed in eggs exposed to phosphine for 2 days compared to controls and the result was more pronounced for 1-day-old than 2-days-old eggs. In contrast to the 2-d exposure, hatching rates of eggs exposed to 4 and 6 days were notably reduced, while there was a delay in egg hatching compared to controls. These dissimilar patterns in larval growth may suggest certain delayed effects of phosphine fumigation. The results of the work can be further utilized for the development of phosphine-based quarantine and pre-shipment treatments for the control of *T. granarium*.

Lampiri *et al.* (2021) also tested four stored product species: *Oryzaephilus surinamensis* (L.), *Tribolium castaneum* (Herbst), *Sitophilus oryzae* (L.) and *Rhyzopertha dominica* (F.) with populations that had different levels of phosphine resistance. The majority of susceptible populations of all species were instantly immobilized even in the shortest exposure period (15 min), in contrast with resistant populations that were active even after 300 min. After exposure to phosphine, populations and exposure time affected mortality of susceptible populations, whereas resistant populations recovered regardless of species and exposure time. Additional bioassays showed the presence of the "sweet spot", i.e., decrease of mortality with the increase of concentration. For most of the tested species, the "sweet spot" appeared in 1000 and 2000 ppm at a 5-h exposure time, regardless of the level of resistance to phosphine. Temperature was also observed as being important. The results are particularly relevant in terms of the assessment of resistance and in the context of non-linear recovery at elevated concentrations, indicating the occurrence of strong hormetic reversals in phosphine efficacy.

Resistant and tolerant red flour beetles *Tribolium castaneum* (Coleoptera: Tenebrionidae) and the lesser grain borer *Rhyzopertha dominica* (Coleoptera: Bostrichidae) were exposed to 0 (control), 1000, and 3000 ppm of phosphine for 15 or 90 minutes to estimate behavioral and mobility responses (Agrafioti, *et al.*, 2020). For both species, the highest percentage of dead adults was noted at 3000 ppm for both exposure times. Changes in movement parameters can be further exploited in assessing the efficacy of different management tactics, such as trapping and sampling.

#### Co-fumigation of reduced rates of phosphine and sulfuryl fluoride

control highly resistant rusty grain beetles, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae) (Jagadeesena *et al.*, 2021).

MBTOC notes as in previous reports that resistance to phosphine (PH<sub>3</sub>) has been recorded in storage pests around the world (Opit *et al.*, 2012; Jagadeesan *et al.*, 2012). Recent surveys in major grain-growing countries confirms this ongoing concern for PH<sub>3</sub> resistance, as grain is stored every where and resistant insects survive poor fumigations (Collins *et al.*, 2017; Nayak *et al.*, 2020).

#### 5.3.1.4 Nitric oxide (NO)

NO is considered as an alternative to MB for postharvest pest control on lettuce, particularly the currant-lettuce aphid *Nasonovia ribisnigri* (Hemiptera: Aphididae) and western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae) (Yang and Liu, 2019).

Liu and Simmons (2021) demonstrated that NO fumigation was effective against all life stages of the light brown apple moth, *Epiphyas postvittana* (Lepidoptera: Tortricidae). NO was further shown to be effective against navel orangeworm, *Amyelois transitella* (Lepidoptera:Pyralidae) although timing and application rates were variable depending upon the life stage to be treated (Yang et al., 2021). Eggs were more tolerant to NO than larvae and pupae.

#### 5.3.1.5 Ethanedinitrile (EDN)

Research on EDN as an alternative to MB for QPS uses, particularly for timber and logs is very active for example in New Zealand, the Czech Republic and Korea with encouraging results (Armstrong and Najar-Rodriguez, 2019; Najar-Rodriguez *et al.*, 2020; Stejskal *et al.*, 2017; Uzunovic *et al.*, 2019).

Phosphine, SF and ED were tested against the pinewood nematode, in a range of artificially infested wood samples with high moisture content and, in some cases, the bark layer intact on the surface exposed to the fumigant. Phosphine and SF successfully eliminated pinewood nematodes on pine wood chips but neither was completely effective on pine blocks with intact bark. EDN was effective on pine chips, blocks and logs at all the doses tested: 40-100 mgL<sup>-1</sup> for 24 h at 20C. Ethanedinitrile appears to be a promising alternative to MB for the fumigation of pine logs. Further testing at lower temperatures and doses, and with commercial-scale log loads is recommended (Seabright *et al.*, 2020).

The New Zealand EPA has recently approved EDN for use on export logs and timber but not imported logs and timber. This has the potential of reducing about 600 tonnes of MB however some requirements still need to be met particularly in relation to safe application methods and acceptance by trade partners.

Malaysia, which reported usage of 170 tonnes of MB for QPS in 2019, has registered EDN in 2019/2020 as an alternative to MB for postharvest treatments (Glassey, pers comm, 2021). Consumption in 2020 was reported at 136 tonnes. South Korea has also registered EDN for logs and timber (Draslovka MBAO 2020).

#### 5.3.1.6 Sulfuryl fluoride (SF)

SF has long been shown to penetrate wood as effectively as MB and is also known to have a great potential for controlling forest pest insects; it is considered suitable for fumigation of exported logs. As such it has been implemented into the recommendations for a range of phytosanitary treatments in quarantine (ISPM 15, 2018; ISPM 28, 2017).

Cottrell *et al.*, (2020) recently published research on the control of the pecan weevil, *Curculio caryae*, (Coleoptera: Curculionidae), which is native to North America and is a quarantine pest, with SF.

SF is also being used in the USA and Europe as a quarantine treatment on cargo at risk of carrying the Brown Marmorated Stink bug *Halyomorpha halys* to Australia and New Zealand. It is approved for export logs to China from Australia and being used on European logs to China (Reichmuth pers comm, 2022).

Myers *et al* (2021) have evaluated a treatment for khapra beetle *Trogoderma granarium* using a combination SF and propylene oxide (PPO).

### **5.3.2 Non-chemical alternatives**

#### 5.3.2.1 Irradiation

Use of irradiation for postharvest treatment of fresh commodities to free them from insect pests of quarantine concern continues to increase. However, many commodities are stored in controlled or

modified atmospheres to preserve commodity quality and extend shelf life and low-oxygen environments have been shown to affect radiotolerance in some insects, e.g. the cabbage looper, *Trichoplus iani* (Hübner) (Lepidoptera: Noctuidae) (Lopez-Martinez *et al.*, 2016).

This is not the case of *Drosophila suzukii* Matsumura (Diptera: Drosophilidae) where low oxygen modified atmospheres did not enhance survival of *D. suzukii* pupae irradiated at 60 Gy in sweet cherry (Follett *et al.*, 2018).

In South Korea, Cho *et al.* (2019) examined the effects of gamma-ray irradiation on the development and reproductive sterility of whiteflies, *Bemisia tabaci* and *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) on exported strawberry fruit. They found that 100 Gy suppressed the development and reproduction of eggs and adults in both species.

Zhao *et al.*, (2021) reported that the combination of modified atmosphere (MA) and ionizing radiation led to synergistic effects successfully controlling oriental fruit flies in irradiated fruit held in a 1% O<sub>2</sub> atmosphere for 14- or 15-days. This resulted in the required efficacy of 99.9968% mortality at 95% confidence level.

#### 5.3.2.2 Radio frequency

New methods to utilize radiofrequency (RF) power have been investigated by Lagunas-Solar *et. al.*, (2006) as a physical thermal method for disinfecting and disinfesting various foods and non-food materials, including agricultural soils. Control of fungi and nematodes was effectively achieved.

RF applications are currently limited to frozen foods, fruit juices, post-baking drying, and some pasteurization processes due to high costs and uncertainty regarding the RF properties of foods and other materials. At University of California at Davis, new bands of the RF spectrum (few kHz to < 10 MHz) have been studied and tested successfully allowing significant cost reductions and capable of operating high energy efficiency.

A project developing radio frequency (RF) technology has generated the data required to have this treatment method approved by the IPPC in compliance with ISPM-15 for wood packaging, but cost effectiveness needed to be improved for adoption to occur. In 2016, it was found that by adding pressure to the RF chamber during treatment dramatically reduced the time required to treat, improved heating uniformity, and reduced energy and labor costs significantly. A commercial application is close to realization.

#### 5.3.2.3 Controlled atmospheres (CA) and temperature treatments

Controlled atmospheres (with low content of oxygen and increased CO<sub>2</sub> and/or nitrogen content) combined with low temperature are increasingly used and accepted as quarantine treatments, often with good potential to replace MB.

The use of low oxygen by increasing nitrogen is an effective management strategy for the control of *T. granarium* on different commodities (figs, plums and sultanas) following a certain action plan based on specific combinations of temperature and exposure (28°C for 9 days or 40°C for 2.5 days of exposure) (Sakka *et al.*, 2022). When comparing a high carbon dioxide concentration modified atmosphere of 70% or a low oxygen concentration of 0.1%, the latter was more effective in controlling this pest. An exposure period of 4 days at 28°C was effective, as no progeny production was recorded (Vassilakos *et al.*, 2019). The schedule for import treatment (e.g. rice) from khapra countries to Australia using CA is now published and can be downloaded at <https://www.awe.gov.au/biosecurity-trade/import/arrival/treatments/treatments-fumigants#controlled-atmosphere-treatment>.



In Vietnam, a continuous in-line CA treatment process, which takes only 40 minutes kills insects attacking dry commodities in all stages of development. The treatment is conducted within a compartment at 55-70 C (depending on the product) and a very low oxygen environment, where the product is dropped in and any insects present are eliminated within 30 min. A conveyor belt then takes the product to a second compartment at 15 - 25 C where it is cooled down to ambient temperatures by mechanical means. The cooling process also enables moisture control of the product. The system works with a heat pump and cooling system, with high energy efficiency and is currently commercially operated for treating nuts and trialed for dried fruit products and fresh fruit (Bergwerff, pers comm).

Patil *et al.* (2019) reported a novel cold-quarantine treatment for mango quarantine pests combining cold storage at 2°C with artificial ripening with 150 ppm ethylene and modified atmosphere (fruit enclosed in perforated bags), resulting in significantly reduced chilling injury and ensuring consumer acceptance (taste, aroma and texture).

The tomato leafminer *Tuta absoluta*, (Lepidoptera, Gelechiidae), an invasive and increasingly troublesome pest species affecting tomatoes, other solanaceous species and many other crops including cut flowers, can limit exports in various countries, is effectively controlled with modified atmospheres and cold treatments (Tarusikirwa *et. al.*, 2021; Riudavets *et. al.*, 2016).

Hot water treatment combined with high-pressure controls taro mite, *Rhixoglyphus sp.*, and root knot nematodes, *Meloidogyne spp.*) (Jamieson, 2018).

## **5.4. Methyl bromide emissions and recapture**

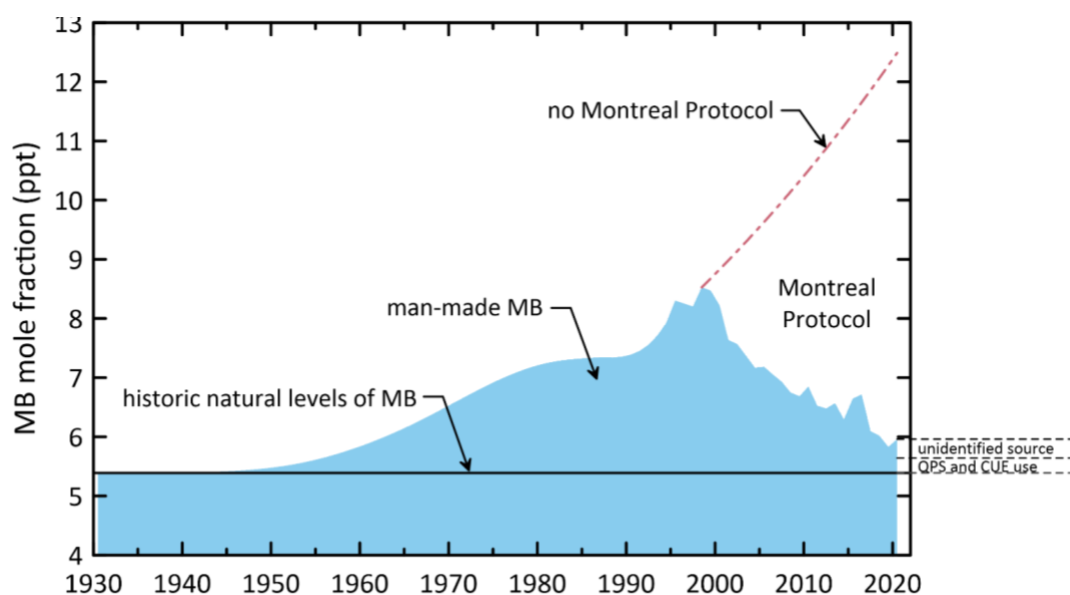
### **5.4.1 Emissions of MB**

Since 1999, the reduction in MB production and use has led to a more than 30% reduction in the concentration of MB in the atmosphere and this has been responsible for more than 35% of the present fall in Effective Equivalent Stratospheric Chlorine and a key driver for the recovery of the ozone layer (Porter and Fraser, 2020). Figure 3 provides an update of the atmospheric concentration of MB up until 2021 and shows that after a period of increase in MB concentration in the atmosphere from 2015-2017, the MB concentration appeared to continue to decline until the last few years (Figure 5.3.)

The slight rise in 2020/2021 suggests that there is still a measurable level of unidentified source of MB within the fluctuations of change of atmospheric concentrations, which could be due to natural fluctuations or from changes in consumption, presumably for QPS or possibly from unknown uses (Choi *et al.*, 2022).

As indicated earlier in this report, future gains in reduction of atmospheric concentrations will rely on reduction in emissions from QPS use of MB, by either reducing use of MB for QPS or by reducing emissions of MB from QPS applications by recapture, recycling and/or reuse.

**Fig. 5.3. Trend in Atmospheric concentration of methyl bromide (ppt) from 1930 - 2020.**



Source: Fraser, Porter, Derek (Australia, pers. comm. 2022)

#### 5.4.2 Copper based chemicals contribute to unaccounted atmospheric MB levels

A current study by Jiao *et al.*, (2022) indicates that application of copper (II)-based chemicals may increase atmospheric concentrations of methyl halides, especially for  $\text{CH}_3\text{Br}$  (~10% of the missing sources), contribute to stratospheric halogen load, and thereby affect ozone levels. A simplified estimation suggests this process may be responsible for  $4,100 \pm 1,900 \text{ t CH}_3\text{Br yr}^{-1}$  and  $2,500 \pm 700 \text{ t CH}_3\text{Cl yr}^{-1}$ , respectively.

Of note is that copper production has gone up 65% in the last 10 years.

Nicewonger *et al.*, (2022) found that interannual variations in the atmospheric MB are related to El Niño Southern Oscillation (ENSO) events, and the increased burning during the warm phase of ENSO is determined to be the most likely cause of these interannual changes.

#### 5.4.3 Recapture of MB

As noted in previous MBTOC reports, in 2010 the New Zealand Environmental Protection Agency (NZ EPA) ruled that all QPS MB emissions were to be recaptured as of October 2020, although this had been extended through to February 2022. In response, a range of new technologies for recycling and recapture systems have been developed that are able to recapture up to 90% of MB in the headspace within hours, in commercial conditions (MPI, 2021). However, due to the lack of available technology to achieve the required targets the NZ EPA reassessed this ruling. The majority of current emissions from container and undercover log QPS fumigations at four major ports are being controlled with available recapture equipment, but emissions arising from fumigation of ship holds remained a challenge.

The NZ EPA in 2021 completed a reassessment of MB. The reassessment focused on recapture requirements, and a comprehensive suite of controls to mitigate the risks of MB use including banning the fumigation of ships holds from 1 January 2023.

In general terms, recapture of MB refers to the use of technology to remove methyl bromide from the fumigated enclosure, so that it cannot be released into the air. From 1 January 2023, 80% of the MB

used will need to be recaptured from every container fumigation, increasing to 99% recapture from 1 January 2031. From 1 January 2022, recapture technology must be used on half of all undercover fumigations, and all must use recapture technology from 1 January 2025. New carbon-based equipment has been developed to recapture MB from large log stacks and is proving to be around 90% effective. [Assessment of Methyl Bromide Fumigation Recapture Regimes \(mpi.govt.nz\)](https://www.mpi.govt.nz/assessments/1222/mb-fumigation-recapture-regimes/)

A requirement to use “dosing to concentration” technology will be required from 1 January 2024; at least 50% of all fumigations must be dosed to concentration, increasing to 100% of all fumigations from 1 January 2027. This is intended to reduce the amount of MB being used while maintaining efficacy with monitoring of concentration during the fumigation.

The reassessment decision encourages parties to continue negotiations with international trade partners to reduce and, where possible, eliminate the use of MB, and to explore alternative processes.

In Australia, a specific regulation on damage of emissions of MB to the ozone layer in addition to concerns on MB emissions on public health have led to adoption of recapture systems into several major fresh vegetable and fruit markets. Regulations also exist in other sectors of the world (e.g., US timber exports) to implement systems to reduce emissions. Limitations to date have been the added cost for the user of equipment required to recapture and destroy or landfill compared to venting directly to the atmosphere. In addition, in most areas local policies are generally not in place to encourage or mandate their use or are difficult to implement.

## 5.5 International Plant Protection Convention (IPPC)

As per the Memorandum of Understanding signed between the Montreal Protocol and the IPPC, MBTOC continues to collaborate with the IPPC. A short contribution featuring MBTOC’s recent activities which are of relevance to IPPC was submitted to the IPPC for inclusion under the agenda item “Written reports from international organizations” of the IPPC’s 16<sup>th</sup> meeting of the Commission on Phytosanitary Measures (CPM). This virtual meeting took place in April 2022, and MBTOC co-chairs and some members attended some sessions.

MBTOC also monitored developments arising from the work conducted by the convention with potential to impact MB use and replacement. There are now 32 approved treatments available shown in the [IPPC Phytosanitary Treatments search tool](https://www.ippc.int/en/core-activities/standards-setting/technical-panels/technical-panel-phytosanitary-treatments/phytosanitary-treatments-tool/) (<https://www.ippc.int/en/core-activities/standards-setting/technical-panels/technical-panel-phytosanitary-treatments/phytosanitary-treatments-tool/>)

One ISPM and four draft phytosanitary treatments, some with potential to replace MB were presented for consultation (IPPC, 2021a) and adopted during CPM-16 (IPPC, 2022) as follows

- Cold treatment of ‘Red Globe’ grape for *Drosophila suzukii* (Diptera:Drosophilidae)
- Vapor heat treatment of dragon fruit (*Selenicereus undatus* (Haworth) D.R. Hunt) for *Planococcus lilacinus* (Cockerell)
- Cold treatment for *Thaumatotibia leucotreta* on *Citrus sinensis* (2017- 2029)
- Revision of ISPM 18 (Guidelines for the use of irradiation as a phytosanitary measure)
- Irradiation treatment for *Pseudococcus jackbeardsleyi*

Additionally, the following International Standards for Phytosanitary Measures (ISPM) that will contribute to reducing the need to treat with MB were approved in 2021 (IPPC, 2021b):

- ISPM 28 Phytosanitary treatments for regulated pests
- ISPM 44 Requirements for the use of modified atmosphere treatments as phytosanitary measures (adopted in 2021)

In addition, MBTOC continues to support IPPC’s “Recommendation on replacement or reduction of the use of methyl bromide as a phytosanitary measure” (IPPC 2008, published 2017).

## 5.6 Other issues

### 5.6.1 International trade treated with MB

MBTOC is aware that the Ministry of Food Security and Research of Pakistan is initiating an inquiry on the single importer of MB which is also the sole distributor and fumigator. The ministry has constituted a committee, which was mandated to investigate the controversy over MB imports and the monopoly existing in this sector and fix responsibility for any wrongdoing that may have occurred in the past. MBTOC hopes that this enquiry results in better awareness and reporting of MB use (Pakistan Today, 2022).

India and Canada have agreed to lift the MB fumigation requirement for the Canadian pulse export to India while a systems approach is being worked out. This measure will potentially reduce MB treatments of pulses on arrival substantially.

MBTOC further notes that some parties do not report MB consumption and yet have certified MB fumigators to enable the import of grain exports. For example, Lao PDR exporting to Australia: [lao-pdr\\_1.pdf \(awe.gov.au\)](#). Tonga on its part, fumigates watermelons destined for New Zealand with MB, but does not report any consumption.

### 5.6.2 Post-harvest use for cured hams

Methyl bromide is still used on stored ham in the United States, although no CUE has been applied for or granted since 2016; the use is small (less than 2 tonnes) and drawn from limited stock. An alternative method is to use protective netting treated with polypropylene glycol (Zettler *et al.*, 2001), which is awaiting approval from the U.S. Department of Agriculture (USDA). The industry cannot use SF because control of mite eggs is only achieved by increasing the exposure amount to levels which affect ham quality and which leave unsafe residues (Zhang *et al.*, 2017).

Research on alternatives for this use continues and includes phosphine (with resistance management), establishing efficacy and experimental criteria for quarantine applications, and the development of models to quantitatively understand the underpinnings of fumigations and related phytosanitary treatments (Walse *et al.*, 2018). Very recent studies (Yang *et al.* 2022), show that nitric oxide is effective against all mite stages and 100% control was achieved on ham.

### 5.6.3 Sulfuryl fluoride and its GWP

SF is widely adopted around the world as an alternative to MB for disinfestation of structures. Its registration and commercial adoption occurred in the 1990s and continued for many years until it was made available in many countries. SF is a key alternative to MB for treatment of empty structures such as flour mills and food and feed processing premises, particularly buildings larger than 40,000 m<sup>3</sup>, where heat treatment is not an option due to logistic reasons. Its use around the world is extensive. For example, Germany alone uses about 200 t of SF which replaces controlled as well as QPS uses of MB.

There is growing concern about SF use due to its high global warming potential (GWP), which puts the continuity of its registration at risk (Gressent *et al.*, 2021; Miller *et al.*, 2017; Reimann *et al.*, 2015; Dillon *et al.*, 2008). The 20year GWP value of SF is reported at 7510 (IPCC, 2021). The IPCC states that, although the contribution of SF to ERF (Effective Radiative Forcing) is small, the atmospheric abundance of SF reached 2.5 ppt in 2019, which is a 46% increase from the value recorded in 2011.

Gressent *et al* (2021) have used atmospheric observations from the Advanced Global Atmospheric Gases Experiment (AGAGE) to show that global emissions of SF increased from close to zero in the early 1980s to ~2.4 Gg yr<sup>-1</sup> in 2019. They report that the primary source of these global emissions in 2019 was structural fumigation in North America, but that the increase over the last two decades has also been driven by the growing use of SF in postharvest treatment of crops in many countries around the world.

In the EU, there are preliminary indications SF registration and use may become complicated due to GWP issues. Due to its wide adoption as an alternative to MB for disinfestation of structures, deregistration of SF would create significant disruption in pest control strategies. Recapture and other technologies to reduce emissions could be considered to reduce its negative effects as correlated to its high GWP. The Department of Civil and Environmental Engineering at Stanford University, USA is working on capturing SF on activated carbon and destruction by electrochemical treatment (Mitch, 2020).

#### 5.6.4 Reporting of methyl bromide stocks and their uses

MBTOC is concerned that confusion can exist over how stocks of methyl bromide are reported by countries for production and consumption for controlled non-QPS uses and exempted QPS uses. Although only three countries report MB production, recent reporting information received under Article 7 data has been difficult to interpret against known uses. Information reported under Article 7 for MB consumption is even more confusing for sorting out how stockpiles are being used.

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## 6 Medical and Chemicals TOC (MCTOC) Progress Report

This report of the Medical and Chemicals Technical Options Committee provides information on the production and use of controlled substances, including for chemical feedstock, HFC-23 by-production and emissions, and new developments for metered dose inhalers (MDIs). It also includes background to, and an update on, TEAP's assessment of destruction technologies under decision XXX/6, to be included in MCTOC's 2022 Assessment Report. The status of aerosols (other than MDIs), laboratory and analytical uses, process agent uses, and n-propyl bromide were reviewed, however, no compelling new information is reported this report.

### 6.1 Production issues and use of controlled substances for chemical feedstock

#### 6.1.1 *Production and chemical supply issues in the transition to low-GWP HCFOs and HFOs*

As reported by FTOC, there have been reported challenges relating to production and chemical supply in the transition to low-GWP HCFO and HFO foam blowing agents, namely HCFO-1233zd, HFO-1234ze, and HFO-1336mzz. Similar challenges have not been reported for the production of alternatives for other sectors. The challenges relating to foam blowing agents are related to several factors.

Firstly, there are currently production constraints for these HCFO/HFOs worldwide, partly resulting from the global economic environment, making it difficult to meet demand. Global development and manufacturing of HCFO/HFO blowing agents is also limited due to the restriction of patents, especially application patents; at present, only a few companies have established production capacity. New production capacity for HCFO/HFOs foam blowing agents is being built in China and the United States, which is expected to become available in 2023.

Secondly, the high price of HCFO/HFOs has had a major impact on global use. For instance, the price of HCFOs/HFOs is currently much higher than HCFC-141b and even higher than HFC-245fa and HFC-365mfc. This is another reason why markets are continuing to use HCFC-141b, HFC-245fa and HFC-365mfc. HCFO/HFOs production is still in the early stages of commercialisation and high prices are to be expected, just as they were for HFCs in their early commercialisation. The complexity of manufacturing processes for some HCFO/HFOs may also be contributing to their higher price because the production processes are relatively more complicated than for HFCs.

Another challenge is regional shortages of CTC for feedstock use in HCFO/HFO production.<sup>20</sup> CTC is the main starting raw material in the process to manufacture HFC-245fa, HFC-365mfc, HFO-1234ze, HFO-1234yf, and HCFO-1233zd. While it is likely there is adequate global production capacity of chloromethanes-CTC and perchloroethylene (PCE)/CTC to meet global CTC demand, CTC production, supply, use, and export are subject to factors that could inadvertently impact global supply and availability. These factors include national licensing controls; rights to place on market; and regional imbalances in supply and demand. With the increasing demand for CTC as a raw material for a range of chemicals, regional shortages of CTC for feedstock use have become a challenge for both producers and users.

#### 6.1.2 *Use of controlled substances for chemical feedstock*

Feedstocks are chemical building blocks that allow the cost-effective commercial synthesis of other chemicals. Controlled substances (ODS and HFCs) can be produced and/or imported or exported for

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<sup>20</sup> HFO-1336mzz production does not use CTC.

use as feedstocks. As raw materials, feedstocks are converted to other products, except for *de minimis* residues and emissions of unconverted raw material. Emissions from the use of feedstock consist of residual levels in the ultimate products, and fugitive leaks in the production, storage and/or transport processes. Significant investments and effort are spent to handle ODS and HFC feedstocks in a responsible, environmentally sensitive manner and, in most countries, are regulated through national pollution control measures.

The definition of production under the Montreal Protocol excludes the amounts of controlled substances entirely used as feedstock in the manufacture of other chemicals. Notwithstanding, parties are required to report the production of controlled substances for feedstock uses annually.<sup>21</sup> Similarly, the definition of consumption excludes controlled substances entirely used as feedstock, nevertheless, imports and exports of controlled substances to be used entirely as feedstock must be reported by parties.

### **6.1.3 How Article 7 reporting of production for feedstock uses contributes to understanding atmospheric burdens**

Article 7 of the Montreal Protocol prescribes requirements for each party for the annual reporting of statistical data on production, imports, and exports of each of the controlled substances. Reporting is further described in various decisions of the meetings of parties. Some decisions introduce additional data requests that parties may report voluntarily.

Article 7, paragraph 3, *Each Party shall provide to the Secretariat statistical data on its annual production (as defined in paragraph 5 of Article 1) of each of the controlled substances listed in Annexes A, B, C, E and F and, separately, for each substance,*

*– Amounts used for feedstocks, ...*

The Montreal Protocol defines that some quantities of controlled substances are not considered controlled substances under the Protocol owing to the insignificant emissions from their uses. Decision IV/12, clarifies the definition of controlled substances, *“That insignificant quantities of controlled substances originating from inadvertent or coincidental production during a manufacturing process, from unreacted feedstock, or from their use as process agents which are present in chemical substances as trace impurities, or that are emitted during product manufacture or handling, shall be considered not to be covered by the definition of a controlled substance contained in paragraph 4 of Article 1 of the Montreal Protocol”*. Decision IV/12 further urges *“...parties to take steps to minimize emissions of such substances, including such steps as avoidance of the creation of such emissions, reduction of emissions using practicable control technologies or process changes, containment or destruction”*.

As noted, parties are required to report the production, import and export of controlled substances for feedstock uses annually. Reported feedstock is a valuable data set that can be correlated with related emissions of controlled substances, either from their production, use or with the expected impact of emission abatement measures. Two recent examples are (i) the trend in HFC-23 by-product emissions<sup>22</sup> from the feedstock and non-feedstock production of HCFC-22<sup>23</sup>, and (ii) the correlation<sup>24</sup> of emissions of octafluorocyclobutane (PFC-318), a by-product from tetrafluoroethylene (TFE) and

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<sup>21</sup> Montreal Protocol Article 7 para 3.

<sup>22</sup> K. M. Stanley, D. Say, J. Mühle, C. M. Harth, P. B. Krummel, D. Young, S. J. O’Doherty, P. K. Salameh, P. G. Simmonds, R. F. Weiss, R. G. Prinn, P. J. Fraser, M. Rigby, Increase in global emissions of HFC-23 despite near-total expected reductions, *Nature Communications*, **11**, Article number: 397 (2020), <https://doi.org/10.1038/s41467-019-13899-4>.

<sup>23</sup> See 2021 TEAP Progress Report – Volume 1, section 5.4.

<sup>24</sup> A correlation is a derived mathematical association between emissions of octafluorocyclobutane (PFC-318), the high-GWP by-product in the manufacture of TFE and HFP, and HCFC-22 production, used as the feedstock in TFE and HFP

hexafluoropropene (HFP) production, with the production and use of HCFC-22 as feedstock in TFE and HFP production.<sup>25,26</sup> Production for non-feedstock uses also results in emissions from use and from banks for a wide range of applications. Expected emissions can be calculated based on reported production data and can be compared to atmospheric burden and emission trends of controlled substances. A recent important example is the unexpected CFC-11 emissions.<sup>27</sup> However, there are some products that are not reported because they are intermediates not isolated in a chemical manufacturing process.<sup>28</sup> These intermediates may also be emitted in low quantities and detected by atmospheric monitoring.<sup>29</sup>

#### **6.1.4 Reporting of controlled substances for feedstock uses**

As revised in decision XXX/10 and Annex III to MOP-30, Article 7 data reporting instructions and guidelines require the reporting of feedstock uses for all controlled substances and, when calculating production, the Montreal Protocol allows countries to deduct amounts of controlled substances used for feedstock and amounts destroyed. When reporting production data, parties are not expected to deduct these figures from their data. The Secretariat makes the necessary deductions. All feedstock produced during a calendar year is reportable for that year, even if it has not been used.

The 1999 Handbook on Data Reporting under the Montreal Protocol provides guidance on data collection for production for use as feedstock.

*“For collecting data on production (including data on production for use as feedstock and process agents, for essential uses, QPS and increased production), you can rely on the sources mentioned in Section 2.4.*

*Section 2.4 extract: The relevant data on all categories of production are to be provided by the manufacturers based on voluntary or mandatory reporting. The manufacturers of ODS are usually large chemical companies and are, therefore, in most cases identified relatively easily. Note, however, that halons and carbon tetrachloride may also be manufactured on a smaller scale. For these, you might need to spend some effort to identify relevant companies. To ensure high data quality, the information provided by industry can be audited by an independent consultant and verified with the help of on-site inspections and inspection of the company’s documentation.”*

The Montreal Protocol includes the term “used as feedstock”, e.g., Article 1, paragraph 5, ““Production” means the amount of controlled substances produced, minus the amount destroyed by

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production. TFE and HFP are used in fluoropolymer production. Almost all HCFC-22 that is produced and used as feedstock is pyrolysed to produce TFE and HFP, a process in which PFC-318 is a known by-product. This process, using HCFC-22 as feedstock, results in a significant proportion of the global PFC-318 emissions.

<sup>25</sup> Global emissions of perfluorocyclobutane (PFC-318, c-C<sub>4</sub>F<sub>8</sub>) resulting from the use of hydrochlorofluorocarbon-22 (HCFC-22) feedstock to produce polytetrafluoroethylene (PTFE) and related fluorochemicals, J. Mühle et al, Atmos. Chem. Phys., 22, 3371–3378, <https://doi.org/10.5194/acp-22-3371-2022>, 2022.

<sup>26</sup> MCTOC will report further on this in its 2022 Assessment Report.

<sup>27</sup> Decision XXXI/3 TEAP Task Force Report on Unexpected Emissions of Trichlorofluoromethane (CFC-11)

<sup>28</sup> See 2021 TEAP Progress Report – Volume 1, section 5.3.5.

<sup>29</sup> Martin K. Vollmer, Jens Mühle, Stephan Henne, Dickon Young, Matthew Rigby, Blagoj Mitrevski, Sunyoung Park, Chris R. Lunder, Tae Siek Rhee, Christina M. Harth, Matthias Hill, Ray L. Langenfelds, Myriam Guillevic, Paul M. Schläuri, Ove Hermansen, Jgor Arduini, Ray H. J. Wang, Peter K. Salameh, Michela Maione, Paul B. Krummel, Stefan Reimann, Simon O’Doherty, Peter G. Simmonds, Paul J. Fraser, Ronald G. Prinn, Ray F. Weiss, and L. Paul Steel, Unexpected nascent atmospheric emissions of three ozone-depleting hydrochlorofluorocarbons, PNAS February 2, 2021 118 (5) e2010914118; <https://doi.org/10.1073/pnas.2010914118>

*technologies to be approved by the Parties and minus the amount entirely used as feedstock in the manufacture of other chemicals.”*

There is no definition for production for use as feedstock or associated guidance. However, there is the definition of “controlled substances produced” in Article 1, paragraph 5, *“Controlled substances produced” as used in Article 1, paragraph 5 is the calculated level of controlled substances manufactured by a party. This excludes the calculated level of controlled substances entirely used as a feedstock in the manufacture of other chemicals...*” The term “manufactured” is not defined; although a common-sense definition is “to make or process (a raw material) into a finished product”.

In chemical production, a non-isolated intermediate in a chemical process is not considered as a finished product while it remains within the chemical process. As such, a non-isolated intermediate is not commonly reported. For example, the formation of the intermediate HCFC-21 is not commonly reported as a feedstock in the process of manufacturing HCFC-22. However, a substance that is isolated, most likely purified to a specification, and then used in a distinct, separate process, would be considered as a finished product and subject to reporting as production for feedstock use. For example, when HCFC-21 is isolated and then used in the production of HCFC-225, its production is reported as feedstock.

Examples of the use of controlled substances as intermediates and feedstocks and associated reporting, based on the available reported data:

- A controlled substance that is generated and used on the same integrated chemical plant complex, as part of a multistep process, is not a finished product and has not been reported as feedstock production.
  - E.g., HCFC-132b and HCFC-133a as non-isolated intermediates for HFC-134a production.
- A controlled substance that is used by the same or a different company on the same or nearby chemical site in a distinct separate chemical process, which may transport the substance by pipeline, rail, or road transfer. The substance is a finished product and has been reported as feedstock production.
  - HCFC-22 used to produce TFE/HFP
  - Quantities of HCFC-133a that are isolated and then used in a separate process have been reported as feedstock.

Further examples of high-volume chemical products that may be produced via non-isolated intermediates that are controlled substances are presented in Table 5.1.

**Table 6.1 High-volume chemical products that may be produced by non-isolated controlled substance intermediates (non-exhaustive list)**

Product	Feedstock	Non-isolated controlled substance intermediates
CFC-11	CTC	
CFC-12	CTC	CFC-11
CFC-113	Perchloroethylene	CFC-112
CFC-114	Perchloroethylene	CFC-112, CFC-113
CFC-115	Perchloroethylene	CFC-112, CFC-113, CFC-114
HCFC-22	Chloroform	HCFC-21
HFC-32	Methylene chloride (CH <sub>2</sub> Cl <sub>2</sub> )	HCFC-31
HFC-125	Perchloroethylene	HCFC-121, HCFC-122, HCFC-123, HCFC-124
HFC-134a	Trichloroethylene; or CFC-113	HCFC-132b, HCFC-133a, HCFC-131a; or CFC-113a, CFC-114a, HCFC-124a
HFC 143a	1,1-dichloroethylene or 1,1,1-trichloroethane	HCFC-141b, HCFC-142b
HFC-152a	Vinyl Chloride	HCFC-151a
HFC-245fa	HCC-240fa	HCFC-243fa, HCFC-244fa
HFO-1234yf	Hexafluoropropene	HFC-236ea, HFC-245eb
HFO-1234yf	HCC-1230xa or HCC-240db	HCFC-244bb
Trifluoropropylene	Tetrachloropropane	HCFC-253ea

*Explanatory note: CFC-11, CFC-12 and CFC-115 are not, or not typically, used as feedstock. Small quantities of CFC-12 may be reported in some years. Previously they were high volume chemicals. As the production of CFC-113 for emissive uses is no longer permitted, the conversion of CFC-113 to CFC-113a is assumed to be a feedstock use (as noted in UNEP/OzL.Pro/ExCom, 88/78 Annex) and in the 2021 TEAP Progress Report).*

The reporting of production for feedstock use has recently been discussed at the Multilateral Fund Executive Committee (ExCom) meetings and by the Production Sector Sub-group.<sup>30</sup>

<sup>30</sup> UNEP/OzL.Pro/ExCom/87/58, UNEP/OzL.Pro/ExCom/88/IAP/3, UNEP/OzL.Pro/ExCom/87/57, UNEP/OzL.Pro/ExCom/88/78.

### **6.1.5 Common feedstock applications of controlled substances**

Table 6.2 shows common feedstock applications for controlled substances, although the list is not exhaustive. Parties report amounts of controlled substances used as feedstock to the Ozone Secretariat, but they do not report 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 6.2: Common feedstock applications of controlled substances (this list is not exhaustive)**

Feedstock	Products	Further conversion products	Comments
CFC-113	Chlorotrifluoroethylene	Chlorotrifluoroethylene based polymers	Polymers include poly-chlorotrifluoroethylene (PCTFE), and poly-fluoroethylenevinyl ether (PFEVE).
CFC-113	CFC-113a		CFC-113a may be an intermediate and may be transported off-site for use as a feedstock.
CFC-113a	Trifluoroacetic acid (TFA) and pesticides (including cyhalothrin)		Starting with CFC-113, CFC-113a is as an intermediate for TFA. Alternatively, CFC-113a may be directly produced as the starting feedstock. TFA is a pesticide and medical intermediate.
CFC-113, CFC-113a, CFC-114a, HCFC-124	HFC-134a		One sequence for production of HFC-134a begins with CFC-113, which is converted to CFC-113a, then to CFC-114a and HCFC-124 as intermediates.
CFC-113a	HFO-1336mzz isomers		Low GWP alternatives for HFC-245fa and HCFC-123.
CTC	CFC-11 and CFC-12		Production and consumption of these CFCs has fallen to zero based on reported data. However, a small quantity of CFC-12 (<100 tonnes) is intermittently reported for feedstock use. It is not known for what the CFC-12 was used.
CTC	With water to make CO <sub>2</sub> and HCl: the HCl is subsequently reacted with methanol to make methyl chloride and water	Methyl chloride in chloromethanes (CMs) plant converted to dichloromethane (DCM) and chloroform (CFM)	A method of recycling CTC into useful products rather than destruction operated in CMs plant complex.
CTC	Perchloroethylene		High volume use.
CTC	With hydrogen to make chloroform with methane and HCl as by-products	Chloroform is used to make HCFC-22	A method of recycling CTC into useful products rather than destruction operated in CMs plant complex
CTC	Chlorocarbons including vinyl chloride, chloropropanes and chloropropenes	Feedstocks for production of HFC-245fa and some HFOs and HCFOs: HFO-1234yf, HCFO-1233zd, and HFO-1234ze.	HFOs and HCFOs are ultra-low GWP fluorocarbons used in refrigeration, air conditioning and insulation and production is increasing.
CTC	With acrylonitrile, intermediates	Pyrethroid pesticides.	CCl <sub>3</sub> groups in molecules of intermediates become =CCl <sub>2</sub> groups in pyrethroids.
CTC	With 2-chloropropene - Intermediates	Production of HFC-365mfc	
CTC	With vinylidene chloride - Intermediates	Production of HFC-236fa	

Feedstock	Products	Further conversion products	Comments
CTC	With benzene to make triphenylchloromethane (trityl chloride)	Intermediate for dyes and pharmaceuticals such as antiviral drugs	Trityl chloride is an efficient tritylation agent.
CTC	With 1,3-dichloro-4-fluorobenzene to make 2,4-dichloro-5-fluorobenzoyl chloride (DCFBC)	Intermediate for example in the synthesis of highly active antibacterial agent ciprofloxacin	
CTC	With methyl 3,3-dimethyl-4-pentenoate to produce methyl 4,6,6,6-tetrachloro-3,3-dimethylhexanoate		
1,1,1-trichloroethane	HCFC-141b, -142b, and HFC-143a		Note that an alternative process uses 1,1-dichloroethylene (vinylidene chloride, VDC) as feedstock; VDC is not an ODS.
HCFC-21	HCFC-225 isomers		Reaction of TFE with HCFC-21 to give HCFC-225 isomers. Product used as a solvent or intermediate
HCFC-225ca	HFO-1234yf and HCFO-1224yd		HCFC-225 (produced from TFE and HCFC-21) can be further reacted to produce HFO-1234yf and HCFO-1224yd
HCFC-22	Tetrafluoroethylene (TFE, HFO-1114)	Polymerized to homopolymer (PTFE) and also co-polymers. Route to HFC-125	Very high-volume use. Work has been done for decades to find an alternative commercial route to TFE, without success.
HCFC-22	Hexafluoropropylene (HFP, HFO-1216)	Co-produced with TFE and used as monomer or copolymer, e.g., FEP. Route to HFO-1234yf. Route to HFC-227ea.	Fluorinated ethylene-propylene polymers (FEP)
HCFC-22	With 2,2,2-trifluoroethanol, then chlorination to anaesthetic isoflurane $\text{CF}_3\text{CHClOCHF}_2$	Isoflurane by reaction with HF is converted to anaesthetic desflurane $\text{CF}_3\text{CHFOCHF}_2$	
HCFC-22	Sulfentrazone		Sulfentrazone ( <i>N</i> -(2,4-Dichloro-5-[4-(difluoromethyl)-3-methyl-5-oxo-4,5-dihydro-1 <i>H</i> -1,2,4-triazol-1-yl] phenyl) methanesulfonamide) is a broad-spectrum herbicide.
HCFC-123	HCFC-124, HFC-125		
HCFC-124	HFC-125		
HCFC-123	Production of TFA		
HCFC-133a	HCFC-123, CFC-113a		HCFC-133a can be transformed to HCFC-123 by chlorination and further to CFC-113a

Feedstock	Products	Further conversion products	Comments
HCFC-133a	Production of trifluoroethanol		
Bromotrifluoromethane	Production of the pesticide fipronil and other chemicals		Bromotrifluoromethane may also be an intermediate when HFC-23 is used as a starting material in the production of fipronil and other chemicals. Bromotrifluoromethane is used as feedstock in the preparation of chemicals including fipronil (insecticide), mefloquine (antimalarial), and DPP-IV inhibitor (antidiabetic). CF <sub>3</sub> generated from bromotrifluoromethane can be introduced into a wide range of organic molecules by nucleophilic substitution.
HCFC-141b	HCFC-142b, HFC-143a		
HCFC-142b	Vinylidene fluoride (HFO-1132a)	Polymerised to poly-vinylidene fluoride or co-polymers.	Products are fluorinated elastomers and a fluororesin. Vinylidene fluoride is a very low temperature refrigerant
Bromochloromethane	2-(Thiocyanomethyl)-thiobenzothiazole (TCMTB)		TCMTB is a biocide used in the leather industry
HFC-152a*	HCFC-142b	Vinylidene fluoride, and subsequent polymerisation products (as above for HCFC-142b).	Photochlorination to obtain HCFC-142b, followed by dehydrochlorination to obtain vinylidene fluoride.
HFC-23	Production of Halon 1301 by bromination for use as a feedstock		HFC-23 is converted to bromotrifluoromethane by bromination. Bromotrifluoromethane is then used as feedstock in the preparation of chemicals including fipronil (insecticide), mefloquine (antimalarial), and DPP-IV inhibitor (antidiabetic). CF <sub>3</sub> generated from bromotrifluoromethane can be introduced into a wide range of organic molecules by nucleophilic substitution.

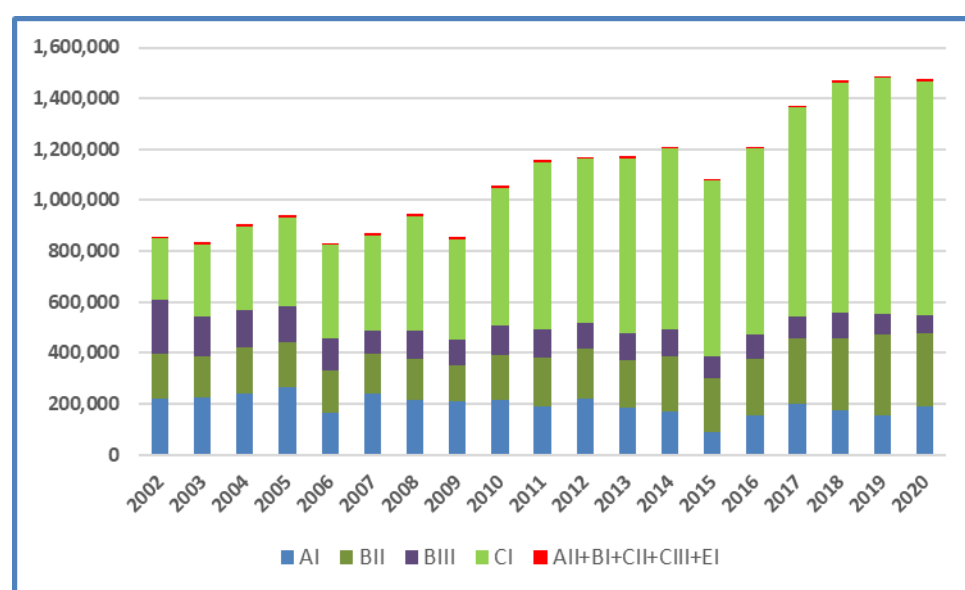
\* A more comprehensive list of HFC feedstock uses will be provided in the MCTOC 2022 Assessment Report.

### 6.1.6 Recent and historical trends in the production and use of controlled ODS as feedstock

Data reported by parties to the Ozone Secretariat on production and import of controlled ODS used as feedstock for the year 2020 was provided to the MCTOC. These also include quantities used as process agents because parties are required to report such consumption in a manner consistent to that for feedstock. In 2020, a total of 15 parties<sup>31</sup> reported feedstock use of ODS, while 12 of these parties also produced ODS for feedstock uses. In 2019, a total of 16 parties had reported use of ODS as feedstock. Two of these parties had reported imports of less than 0.1 metric tonne.

In 2020, total ODS production and import for feedstock uses was 1,475,007 tonnes, a small decrease compared to 2019 (2019: 1,486,288 tonnes<sup>32</sup>). Figure 6.1 shows that, comparing 2020 with 2019, only small changes have occurred for individual substances resulting in an overall small decrease. The 2020 reported total production and import of ODS for feedstock use in metric tonnes represents 554,116 ODP tonnes.<sup>33</sup> The overall increase in ODS feedstock uses through the last decade has been mostly due to the increase in feedstock uses of Annex C1 HCFCs, particularly HCFC-22, while uptake of HFOs is driving a more recent increase in CTC feedstock use. It is highly likely that the COVID pandemic had an impact on feedstock production and consumption in 2020.

**Fig. 6.1. Annual reported production of ODS for feedstock and process agent uses, categorised by Montreal Protocol Group, for the years 2002-2020 (metric tonnes)**<sup>34</sup>



<sup>31</sup> This total also includes the EU as an importer, EU Member States report their own production for feedstock use.

<sup>32</sup> The 2018 feedstock production was stated as 1,364,998 tonnes in the MCTOC 2019 progress report. Any data changes result from data revisions that can occur for historical years.

<sup>33</sup> While ODP tonnes are included, it should be noted that presenting production for feedstock use in ODP tonnes does not equate to emissions. From the total amount of ODS produced for feedstock use, only a relatively minor to insignificant quantity will be emitted depending on the abatement technologies and containment measures utilised.

<sup>34</sup> 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.

**Table 6.3. Amount of ODS used as feedstock in 2020**

Substance	ODP	Metric Tonnes
HCFC-22	0.055	713,536
Carbon Tetrachloride	1.1	288,935
HCFC-142b (reported as HCFC-142 and HCFC-142b)	0.065	166,966
CFC-113 and CFC-113a	0.8	138,443
1,1,1-trichloroethane (methyl chloroform)	0.1	>50,000
CFC-114	1	>20,000
HCFC-124	0.022	>20,000
HCFC-141b	0.11	>10,000
Halon 1301 (bromotrifluoromethane), Bromochloromethane, HCFC-123, Methyl Bromide		1,000 to 5,000
HCFC-133		10 to 1,000
Other substances		<10
<b>Total Metric Tonnes</b>		<b>1,475,007</b>
<i>(Total ODP tonnes*)</i>		<i>554,116</i>

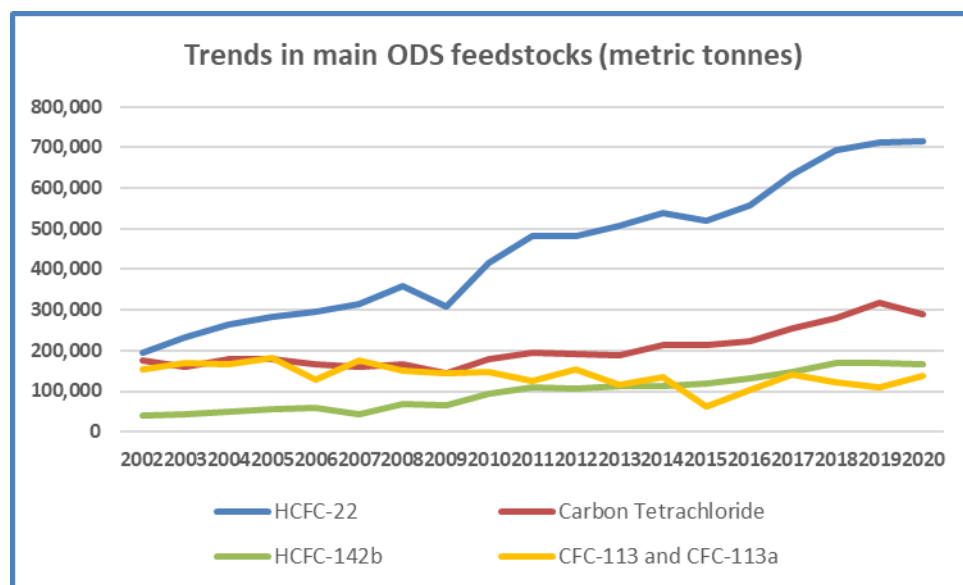
**Explanatory notes:** For some substances, due to the limited number of parties reporting production for feedstock use or imports for feedstock use, quantities have been approximated. For those substances used in relatively small quantities, a quantity range is indicated. \*While the corresponding ODP tonnes are shown, it should be noted that this does not equate to emissions. From the total amount of ODS used as feedstock, a relatively minor to insignificant quantity will be emitted depending on the abatement technologies and containment measures utilised. The ODP tonnes is calculated from the reported data but for some reports it is not certain that the correct isomer is identified.

The proportions of the largest ODS feedstocks in 2020 are very similar to 2019 HCFC-22 (48% of the total mass quantity), CTC (20%), and HCFC-142b (11%). HCFC-22 is mainly used to produce tetrafluoroethylene (TFE), which can be both homo- and co-polymerized to make stable, chemically resistant fluoropolymers with many applications, such as polytetrafluoroethylene. TFE may also be used to produce HFC-125, although alternative processes may be lower cost. Polyvinylidene fluoride is made from HCFC-142b. The feedstock use of CTC<sup>35</sup> has increased in recent years, due to growing demand for lower GWP HCFO/HFOs and perchloroethylene (PCE).

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<sup>35</sup> More information on CTC production and its uses as feedstock can be found in the TEAP Task Force Report on Unexpected Emissions of Trichlorofluoromethane (CFC-11) September 2019.

**Fig. 6.2. Trends in annual production of the current main ODS feedstocks for the years 2002-2020 (metric tonnes)**



#### 6.1.7 Production of HFCs used as feedstock

Following the entry into force of the Kigali Amendment, reporting of HFCs, including production and import for feedstock uses, is required for all parties that have ratified the amendment. In addition to feedstock data reported as part of HFC baseline submissions, obligatory annual HFC data reporting starts with data for 2019 for countries that became party to the Kigali Amendment before the end of 2019, and that 2019 Article 7 data was reported during 2020. Data submissions for 2020 for countries that became parties in 2020 are required before the end of 2021. The feedstock data reported for 2020 is incomplete due to the timing of reporting obligations, for example, depending on when some parties ratified. The available HFC feedstock data for 2021 is about 5000 tonnes.<sup>36</sup> The two largest feedstocks are HFC-23 and HFC-152a, with five other HFC feedstocks also reported.

Historically, some of the HFC-23 generated as a by-product during the manufacture of HCFC-22 was recovered and used as a feedstock to produce halon 1301 (bromotrifluoromethane). When production of halon 1301 ceased in non-Article 5 parties in 1994, in accordance with the Montreal Protocol, this demand for HFC-23 also largely ceased. However, HFC-23 is still used as a feedstock to produce halon 1301, which is still used as a feedstock for the manufacture of the pesticide fipronil and other chemicals.<sup>37, 38</sup>

According to a recent paper<sup>39</sup>, the dehydrofluorination of 1,1-difluoroethane (HFC-152a) is the most broadly used chemical process for the production of vinyl fluoride (used to produce polyvinylfluoride,

<sup>36</sup> The total metric tonnes of ODS reported for feedstock use in 2020 is over 1.4 million tonnes (see table 5.2). The feedstock uses of HFCs have much more limited application than ODS.

<sup>37</sup> TEAP Report, September 2019, Volume 1 Decision XXX/3 TEAP Task Force Report on Unexpected Emissions of CFC-11 page 69.

<sup>38</sup> CF<sub>3</sub> generated from Halon 1301 can be introduced into a wide range of organic molecules by nucleophilic substitution to produce chemicals, including fipronil (insecticide), mefloquine (antimalarial), and DPP-IV inhibitor (antidiabetic).

<sup>39</sup> Haodong Tang, Mingming Dang, Yuzhen Li, Lichun Li, Wenfeng Han, Zongjian Liu, Ying Li and Xiaonian Li, Rational design of MgF<sub>2</sub> catalysts with long-term stability for the dehydrofluorination of 1,1-difluoroethane (HFC-152a), *RSC Advances*, 2019, **9**, 23744-23751. <https://doi.org/10.1039/C9RA04250D>

a polymer used mainly in low flammability coatings). HFC-152a can also be used as a feedstock to produce vinylidene fluoride ( $\text{CH}_2\text{CF}_2$ ), via photo-chlorination to obtain HCFC-142b followed by dehydrochlorination.

### **6.1.8 HFC-23 by-production and emissions**

HFC-23 is a by-product from the production of HCFC-22. Destruction technologies for HFC-23 have been evaluated by TEAP<sup>40</sup> and approved by parties under decision XXX/6, and the ExCom have published several reports<sup>41</sup> on aspects of HFC-23 by-product control technologies. According to a recent paper<sup>42</sup>, global HFC-23 emissions derived from atmospheric measurements were historically at their highest level in 2018, in contrast to expected emissions of HFC-23 by-product, primarily from reported HCFC-22 production, that were much lower. The paper concludes that the discrepancy between expected emissions and observation-inferred emissions makes it possible that planned reductions in HFC-23 emissions may not have been fully realised or there may be substantial unreported production of HCFC-22, both or either of which would result in unaccounted for HFC-23 by-product emissions.

MCTOC reported further on potential sources of HFC-23 in the 2021 TEAP Progress Report and will report further in MCTOC's 2022 Assessment Report.

## **6.2 Destruction technologies**

Decision XXX/6 on destruction technologies for controlled substances requests TEAP to assess destruction technologies listed (in annex II to the report of the Thirtieth Meeting of the Parties) as not approved or not determined, as well as any other technologies, and to report to the Open-ended Working Group prior to the Thirty-Third Meeting of the Parties. Decision XXX/15 paragraph 5 further requests TEAP, following submission of its response to Decision XXX/6, to provide a review of destruction technologies if new compelling information becomes available.

In consultation with the Ozone Secretariat, TEAP and its MCTOC reported in the 2021 TEAP Progress Report that an assessment in response to decision XXX/6 will be included in MCTOC's 2022 Assessment Report based on available information.

MCTOC outlined preparations for its assessment of destruction technologies under this decision in the 2020 and 2021 TEAP Progress Reports, including suggested guidance on the type of relevant information needed for assessment. The 2020 and 2021 TEAP Progress Reports invited parties to submit this type of information in response to decision XXX/6 paragraph 3. Information from parties was requested to be submitted no later than January 2022 to allow time for assessment. No information has been submitted by parties. The opportunity has now passed for MCTOC to assess any emerging new data in time for its 2022 Assessment Report, based on its report drafting schedule.

MCTOC is not currently aware of new information, such as test data, relating to already approved destruction technologies (Table 5.4, based on Annex II, MOP-30 list of technologies subject to review that are either not approved, not determined), or new technologies that would allow an assessment.

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<sup>40</sup> 2018 TEAP Report, Supplement to the April 2018 Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances.

<sup>41</sup> See for example UNEP/OzL.Pro/ExCom/83/44, 11 May 2019, Key aspects related to HFC-23 by-product control technologies (Decision 82/85).

<sup>42</sup> K. M. Stanley, D. Say, J. Mühle, C. M. Harth, P. B. Krummel, D. Young, S. J. O'Doherty, P. K. Salameh, P. G. Simmonds, R. F. Weiss, R. G. Prinn, P. J. Fraser, M. Rigby, Increase in global emissions of HFC-23 despite near-total expected reductions, *Nature Communications*, **11**, Article number: 397 (2020), <https://doi.org/10.1038/s41467-019-13899-4>.

MCTOC notes that several mainstream destruction technologies continue to lack specific data on demonstration of DRE for Annex F HFCs. MCTOC is aware of some developments in the scale and application of existing approved destruction technologies and emerging interest in chemical conversion that are noteworthy to report in the 2022 Assessment Report in response to this decision, for example, portable nitrogen plasma arc.

MCTOC is taking this opportunity to outline again its approach to the assessment of destruction technologies (presented in 2021, updated from 2020) and to provide suggested guidance for parties on the type of relevant information they are invited to submit in future for TEAP assessment. In future, parties may wish to consider providing any new information for TEAP assessment of destruction technologies in January of the same year in which its assessment would be reported either as part of the annual TEAP Progress Report or the quadrennial Assessment Report.

MCTOC will report further on destruction technologies and end-of-life management of controlled substances in its 2022 Assessment Report.



**Table 6.4. Based on Annex II, MOP-30 list of technologies subject to this review that are either not approved or not determined\***

Technology	Applicability										
	Concentrated Sources									Dilute Sources	
	Annex A		Annex B			Annex C	Annex E	Annex F			Annex F
	Group 1	Group 2	Group 1	Group 2	Group 3	Group 1	Group 1	Group 1	Group 2		Group 1
	Primary CFCs	Halons	Other CFCs	Carbon Tetrachloride	Methyl Chloroform	HCFCs	Methyl Bromide	HFCs	HFC-23	ODS	HFCs
<b>DRE</b>	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	99.99%	95%	95%
<b>Cement Kilns</b>	Approved	Not Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
<b>Gaseous/Fume Oxidation</b>	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
<b>Liquid Injection Incineration</b>	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
<b>Municipal Solid Waste Incineration</b>										Approved	Approved
<b>Porous Thermal Reactor</b>	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
<b>Reactor Cracking</b>	Approved	Not Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
<b>Rotary Kiln Incineration</b>	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved	Approved	Approved
<b>Thermal Decay of Methyl Bromide</b>	Not Determined	Not Determined	Not Determined	Not Determined	Not Determined	Not Determined	Approved	Not Determined	Not Determined		
<b>Argon Plasma Arc</b>	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
<b>Inductively coupled radio frequency plasma</b>	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		
<b>Microwave Plasma</b>	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		
<b>Nitrogen Plasma Arc</b>	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
<b>Portable Plasma Arc</b>	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
<b>Chemical Reaction with H<sub>2</sub> and CO<sub>2</sub></b>	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		

Technology	Applicability										
	Concentrated Sources									Dilute Sources	
	Annex A		Annex B			Annex C	Annex E	Annex F			Annex F
	Group 1	Group 2	Group 1	Group 2	Group 3	Group 1	Group 1	Group 1	Group 2		Group 1
	Primary CFCs	Halons	Other CFCs	Carbon Tetrachloride	Methyl Chloroform	HCFCs	Methyl Bromide	HFCs	HFC-23	ODS	HFCs
Gas Phase Catalytic De-halogenation	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Not Determined		
Superheated steam reactor	Approved	Not Determined	Approved	Approved	Approved	Approved	Not Determined	Approved	Approved		
Thermal Reaction with Methane	Approved	Approved	Approved	Approved	Approved	Approved	Not Determined	Not Determined	Not Determined		

\*Orange shaded cells indicated those destruction technologies subject to review under decision XXX/6, excluding any new technology for which information might become available.

### **6.2.1 Definitions and categories of destruction technologies**

The Montreal Protocol's Article 1, paragraph 5, and subsequent clarifying decisions of parties, have defined a destruction process as, "...one which, when applied to controlled substances, results in the permanent transformation, or decomposition of all or a significant portion of such substances", and "relates to the input and output of the destruction process itself, not to the destruction facility as a whole."

Destruction technologies can be grouped into three general categories: thermal oxidation, plasma technologies, and conversion (or non-incineration) technologies. Approved destruction technologies are those that are proven to result in the permanent transformation or decomposition of all or a significant portion of the substance being destroyed.

As a general category, conversion (or non-incineration) technologies are those that primarily rely on chemical transformation to convert halocarbons, sometimes to potentially useful chemicals (e.g., acids, vinyl monomers etc.). Conversion (transformation) as a destruction process differs from the conversion processes involving feedstock uses because, generally, a feedstock is specifically produced to manufacture a desired chemical and is not considered a waste. A waste by-product or substance at end-of-life may be destroyed by thermal oxidation or plasma technologies, without producing useful chemicals.<sup>43</sup>

### **6.2.2 Destruction technologies approved by parties**

Environmentally sound destruction of surplus or contaminated ODS and HFCs at end-of-life is encouraged by the Montreal Protocol because it avoids unnecessary emissions and helps protect the stratospheric ozone layer and/or the climate.

The Montreal Protocol does not mandate the destruction of ODS or Annex F Group I HFCs. The exception is HFC-23 (Annex F, Group II) generated in manufacturing facilities, from which emissions must be destroyed to the extent practicable using technologies approved by parties.

The Protocol's definition of 'production' of controlled substances subtracts the amounts destroyed from the amounts produced. The use of destruction technologies approved by parties applies to the amounts of controlled substances destroyed and accounted for within the Protocol's definition of 'production'. Article 7 data reporting requires production data to be reported by parties, including the amounts of controlled substances destroyed by technologies approved by parties. The Protocol also allows Parties to manufacture an amount of controlled substance almost equivalent to the quantity destroyed with technology listed as approved, within the same year as destruction, and within the same group of substances.

Parties have taken several decisions to approve destruction technologies for the purposes of Montreal Protocol production data reporting requirements. Over time, the list of destruction technologies approved by parties has been updated, with the most recent list of approved destruction processes contained in Annex II to the 30th MOP under decision XXX/6, reproduced in Table 5.4 above.

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<sup>43</sup> The definition of conversion applies to non-incineration technologies, and these might not always produce useful products. Incineration technologies can also produce useful products, for example reactor cracking produces technical-grade quality HF and HCl.

### 6.2.3 Background to TEAP assessment of destruction technologies

In the preamble to decision XXX/6, parties:

- Noted that Destruction and Removal Efficiency (DRE) is the criterion considered in their approval of destruction technologies, and
- Suggested that parties also consider TEAP's other technical advice on emissions of substances other than controlled substances in the development and implementation of their domestic regulations.

For its assessment under decision XXX/6 or future assessments, TEAP will assess destruction technologies for their destruction and removal efficiency and make recommendations to parties for potential approval for inclusion on the list of approved technologies.

TEAP will also provide technical advice about emissions of other pollutants and the technical capability of destruction technologies as part of its assessment. In addition to providing parties with technical guidance, this will also ensure internal consistency with previous assessments.

The TEAP assessment will consider the following parameters:

1. Destruction and Removal Efficiency (DRE)<sup>44</sup>, which is a minimum of 99.99% for concentrated sources and 95% for dilute sources (e.g., foams)
2. Emissions of halogenated dioxins and furans<sup>45</sup>
3. Emissions of other pollutants: acid gases (HCl, HF, HBr/Br<sub>2</sub>), particulate matter (total suspended particles, TSP), and carbon monoxide (CO)
4. Technical capability, where the technology has demonstrated destruction on at least a pilot scale or demonstration scale, and for which the processing capacity is no less than 1.0 kg/hr of the substance to be destroyed, whether ODS or a suitable surrogate.

The DRE is a measure of the efficiency of destruction and is the basis of TEAP's recommendations to parties. The 99.99% DRE minimum for concentrated sources of controlled substances is considered protective for minimising ozone depletion and climate impact. In the case of controlled substances contained in products such as closed cell foams and considered dilute sources, a DRE of 95% minimum is adopted for assessment purposes.

The technical performance advisory criteria for other pollutant emissions are measures of potential impacts of the technology on human health and the environment. The destruction technologies will be assessed against advisory criteria, which are consistent with previous assessments, and technical advice provided in relation to destruction technologies recommended on the basis of DRE.

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<sup>44</sup> Destruction and Removal Efficiency (DRE) is determined by subtracting from the mass of a chemical fed into a destruction system during a specific period of time the mass of that chemical alone that is released in stack gases and expressing that difference as a percentage of the mass of that chemical fed into the system. If interconversion to other controlled species is possible, it is recommended that analysis is used to measure emissions and that any controlled species is taken into account when determining DRE.

<sup>45</sup> Depending on the waste stream, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polybrominated dibenzodioxins (PBDDs), polybrominated dibenzofurans (PBDFs), polyfluorinated dibenzodioxins (PFDDs), polyfluorinated dibenzofurans (PFDFs). For mixed substance destruction, mixed halogenated dioxins and furans can be formed.

The technical capability advisory criterion considers the extent to which the technology has been demonstrated to destroy ODS/HFCs (or a comparable recalcitrant halogenated organic substance such as polychlorinated biphenyl (PCB)) effectively and is technically capable of commercial-scale destruction.

To undertake its assessment and provide its technical advice, and in order to provide advice that the technology has the *minimum* level of technical capability to destroy ODS/HFCs efficiently and safely, TEAP will seek information for all of these parameters.

The following technical performance assessment and advisory criteria will be used for TEAP assessments of destruction technologies. These represent a minimum DRE for destroying ODS/HFCs and maximum advisory levels of emissions of pollutants to the atmosphere that would be considered as an acceptable *minimum* level of technical capability.

**Table 6.5: Technical Performance Assessment and Advisory Criteria**

Performance Qualification	Units	Concentrated Sources	Diluted Sources (e.g., foams)
DRE	%	99.99	95
Dioxins/furans	ng-ITEQ/Nm <sup>3</sup>	0.2	0.5
HCl/Cl <sub>2</sub>	mg/Nm <sup>3</sup>	100	100
HF	mg/Nm <sup>3</sup>	5	5
HBr/Br <sub>2</sub>	mg/Nm <sup>3</sup>	5	5
Particulates (TSP)	mg/Nm <sup>3</sup>	50	50
CO	mg/Nm <sup>3</sup>	100	100

Notes to the table:

All concentrations of pollutants in stack gases and stack gas flow rates are expressed on the basis of dry gas at normal conditions of 0°C and 101.3 kPa, and with the stack gas corrected to 11% O<sub>2</sub> (as referred to by normal cubic metre, Nm<sup>3</sup>). NB. Different stack gas conditions may apply in different countries for different technologies. ITEQ: International Toxic Equivalents.<sup>46</sup>

Acid gases will be assessed based on the specific halogen species present in the waste stream.

TSP – total suspended particles

The technical performance assessment (DRE) and advisory criteria (for pollutants other than controlled substances) serve as a benchmark used by TEAP for comparison purposes. They do not constitute standards, nor do they necessarily meet internationally accepted emissions guidance for pollutants, such as those adopted by the Basel Convention.<sup>47</sup> They were developed only for the purposes of the Montreal Protocol for screening and recommending generic technologies that might be considered technically capable of meeting basic acceptable limits of pollutant emissions.

Operators of destruction technologies are required to meet local DRE requirements and pollutant emissions controls. In addition, the performance of technologies are plant and operation specific. Emissions management is a matter for operators and government agencies

<sup>46</sup> The International Toxic Equivalents (ITEQ) scheme was established by NATO in 1988. More recently the TEFs were re-evaluated by the World Health Organisation and the revised TEQ scheme is generally universally accepted, with the updated TEFs used in the TEQ calculation. Some of the data reviewed by the 2018 TFDT quotes TEQ values. A detailed discussion of ITEQ and TEQ is on page 13 of 2018 TEAP Report, Volume 2: Decision XXIX/4 TEAP Task Force Report on Destruction Technologies for Controlled Substances

<sup>47</sup> General technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants, UNEP/CHW.14/7/Add.1/Rev.1, Para 161, May 2019, <http://www.basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/TechnicalGuidelines/tabid/8025/Default.aspx> (accessed April 2020).

within national regulatory frameworks. A recommendation by TEAP or an approval by parties of a destruction technology under the Montreal Protocol does not guarantee that local emissions requirements can or will be met on a specific facility employing an approved technology. There may be other concerns or emissions of interest to governments at their national or local levels.

Waste ODS/HFCs may be classified as hazardous wastes, with additional requirements imposed through relevant legislation, nationally, or regionally (European Union). Waste ODS/HFCs may also be subject to international reference guidance (such as adopted by the Basel Convention) in terms of emissions performance, including more comprehensive measures of destruction efficiency, other potential emissions, and sources of emissions and monitoring.

#### **6.2.4 Suggested information requirements for TEAP assessment**

Below is a suggested list of information requirements for TEAP assessment of destruction technologies. In future, parties may wish to consider providing any new information as outlined below for TEAP assessment of destruction technologies in January of the same year in which its assessment would be reported either as part of the annual TEAP Progress Report or the quadrennial Assessment Report.

1. Please provide a description of the process, including whether the destruction technology would be considered thermal oxidation, plasma arc, or chemical conversion<sup>48</sup> technology, and associated scrubbing systems. Please include a schematic of the process, with information on the analysis points.
2. At the current stage of development, would you describe the technology as being a demonstration system with all of the characteristics of a commercial system, or a commercially ready system? Note that a demonstration system should achieve >1kg/hour throughput to qualify for assessment.<sup>49</sup>
3. Which ODS or HFC (CFC, CTC, halon, HCFC, methyl bromide, HFC, and specify Annex and Group relevant to controlled substance) wastes are being destroyed by the technology? Does destruction include mixed waste streams and, if so, is the DRE measured for individual substances or mixtures (either is acceptable)?
4. What other non-ODS or non-HFC waste streams have been destroyed using the technology? If these are a comparable recalcitrant halogenated organic substance such as polychlorinated biphenyl (PCB), what is the DRE for these waste streams?
5. For the destruction technology, provide the operating conditions and associated results of analyses of pollutant emissions in the table below, specifying to which controlled substance the data is relevant. Unless advised otherwise, data may be published in a TEAP report; please let us know if this is acceptable or not.

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<sup>48</sup> Conversion technologies transform halocarbons under a range of operating conditions, often at lower temperature than incineration, using specific reactants to achieve the conversion of ODS or HFCs (including conversion to saleable products like acids, vinyl monomer etc.).

<sup>49</sup> The technology must demonstrate destruction on at least a pilot scale or demonstration scale, where the processing capacity is no less than 1.0 kg/hr of the substance to be destroyed, whether ODS/HFC or a suitable surrogate.

**Table 6.6: Results of analyses of emissions and associated operating conditions for each controlled substance destroyed**

Operating Conditions and Destruction Efficiency			Atmospheric Emissions		
ODS/HFC Feed Rate <sup>50</sup>	kg/hr		Dioxins/Furans <sup>51</sup>	ng ITEQ/Nm <sup>3</sup>	
Temperature <sup>52</sup>	C		HCl/Cl <sub>2</sub> <sup>53</sup>	mg/Nm <sup>3</sup>	
Residence Time <sup>54</sup>	Sec.		HF <sup>55</sup>	mg/Nm <sup>3</sup>	
DRE <sup>56</sup>	%		HBr <sup>57</sup>	mg/Nm <sup>3</sup>	
Oxygen Content in Exhaust Gas	%		Particulates	mg/Nm <sup>3</sup>	
			CO	mg/Nm <sup>3</sup>	
			Stack gas flow rate <sup>58</sup>	Nm <sup>3</sup>	

6. Describe how the DRE has been measured and calculated.
7. For a high temperature destruction technology, provide details of the quench conditions and flue gas treatment facilities as these are important in controlling dioxin/furan formation and emissions.
8. For a conversion technology, provide a mass balance<sup>59</sup>, also called a material balance, of the process.

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<sup>50</sup> A range is acceptable.

<sup>51</sup> The specific dioxins/furans to be tested should be relevant to the halogenated species in the waste feed, e.g., chlorinated PCDD/PCDF for CFCs; fluorinated PFDD/PFDF for HFCs; brominated PBDD/PBDF for halons and methyl bromide; mixed halogenated species for mixed waste feeds. The analytical methods for chlorinated dioxins and furans are well established and widely available. Analytical capability for brominated species is also available. If brominated species analysis is not available, it is recommended that a chlorinated ODS or chlorinated recalcitrant organic substance is used to measure the dioxin/furan emissions. Under the same conditions, fluorinated dioxins/furans are less readily formed, allowing a chlorinated species to be used to establish dioxin/furan emissions if fluorinated species analysis is not available.

<sup>52</sup> A range is acceptable.

<sup>53</sup> The specific acid gases to be tested should be relevant to the halogenated species in the waste feed (e.g., HCl/Cl<sub>2</sub> and HF for CFCs), and mixed halogenated species tested for mixed waste streams.

<sup>54</sup> A range is acceptable.

<sup>55</sup> The specific acid gases to be tested should be relevant to the halogenated species in the waste feed (e.g., HCl/Cl<sub>2</sub> and HF for CFCs), and mixed halogenated species tested for mixed waste streams.

<sup>56</sup> The 2002 Task Force on Destruction Technologies Report Appendix F: Sampling and Analytical Methods states 'Note that in determining DREs, it is necessary to test both the input to a destruction technology and the exhaust gas stream.'

<sup>57</sup> The specific acid gases to be tested should be relevant to the halogenated species in the waste feed (e.g., HCl/Cl<sub>2</sub> and HF for CFCs), and mixed halogenated species tested for mixed waste streams.

<sup>58</sup> All concentrations of pollutants in stack gases and stack gas flow rates are expressed based on dry gas at normal conditions of 0°C and 101.3 kPa, and with the stack gas corrected to 11% O<sub>2</sub> (as referred to by normal cubic metre, Nm<sup>3</sup>). Different stack gas conditions may apply in different countries for different technologies and so stack gas may need to be corrected to 11% O<sub>2</sub>.

<sup>59</sup> A mass balance is an application of the conservation of mass to the analysis of physical systems associated with the process, by accounting for material entering and leaving the system and by which mass flows can be identified.

9. Describe what methods have been used for sampling and analysis, including details on the number/sampling rate of analyses carried out and whether this is automated, and limits of detection.
10. Describe any procedures during start up or shut down to avoid emissions of the controlled substances.
11. Provide information about other environmental pollutant emissions of concern resulting from the process (e.g., fluorocarbons with high GWP, such as CF<sub>4</sub>, corrosive salts in effluent, Persistent Organic Pollutants controlled under Annex C (Unintentional Production) of the Stockholm Convention, etc.) and measures in place to control those pollutant emissions.

### 6.3 Process agents

MCTOC has reviewed the information reported to the Ozone Secretariat under decisions X/14(4) and XXI/3(1) by China, EU, Israel, and the USA. Considering decision XXXI/6(3), MCTOC has not identified compelling new information to report to parties in this progress report. MCTOC will report further on process agents in its 2022 Assessment Report.

### 6.4 Laboratory and analytical uses

MCTOC has reviewed the information reported to the Ozone Secretariat on production and import of controlled substances used for laboratory and analytical uses. Considering decision XXXI/5(7), MCTOC has not identified compelling new information to report to parties in this progress report. MCTOC will report further on laboratory and analytical uses in its 2022 Assessment Report.

### 6.5 *n*-Propyl bromide

MCTOC has considered available information on *n*-propyl bromide. Considering decision XXX/15 (6), MCTOC has not identified compelling new information to report to parties in this progress report. MCTOC will report further on *n*-propyl bromide in its 2022 Assessment Report.

### 6.6 Metered dose inhalers

Metered dose inhalers (MDIs), dry powder inhalers (DPIs), aqueous soft mist inhalers (SMIs), and other delivery systems all play an important role in the treatment of asthma and COPD. New alternative propellant technologies to high-GWP HFC MDIs are under development.

Several pharmaceutical companies have now publicly committed to developing inhalers that contain alternative propellants (HFC-152a and HFO-1234ze) with significantly lower GWP than existing propellants (HFC-134a and HFC-227ea).<sup>60,61,62</sup> These new alternatives will

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This will also help identify if there are any leakages or losses in the system.

<sup>60</sup> AstraZeneca announcement, January 2022: <https://www.astrazeneca.com/media-centre/press-releases/2022/astrazeneca-progresses-ambition-zero-carbon-programme-with-honeywell-partnership-to-develop-next-generation-respiratory-inhalers.html>

<sup>61</sup> Chiesi Farmaceutici S.p.A announcement, December 2019: <https://www.chiesi.com/en/chiesi-outlines-350-million-investment-and-announces-first-carbon-minimal-pressurised-metered-dose-inhaler-pmdi-for-asthma-and-copd/>; Chiesi announcement, January 2022: <https://www.chiesi.com/en/the-way-towards-a-sustainable-and-resilient-healthcare/>.

<sup>62</sup> GSK announcement, September 2021: <https://www.gsk.com/en-gb/media/press-releases/gsk-announces-major->



support the introduction of MDI products with carbon footprints reduced by 85% or more<sup>63</sup>. Contract development and manufacturing organisations are now also offering development and manufacturing capabilities for MDIs with alternative propellants.<sup>64</sup>

Progress in development is demonstrated by steps forward in the completion of the toxicology package for these alternative propellants, with long-term toxicology testing and the Drug Master File (DMF) for HFC-152a expected to be completed by mid-2022.<sup>65</sup> The pharmaceutical industry has also achieved important progress with the commencement of the first clinical studies of MDI products containing one of the new propellants.<sup>66</sup>

Considerable work has also been performed to establish or adapt manufacturing facilities, both at the pharmaceutical product and propellant supply level, to safely handle the two new propellants. One chemical company recently announced the opening of a new facility to produce pharmaceutical-grade HFC-152a that will be available at commercial scale by mid-2022.<sup>67</sup> Pharmaceutical companies are planning first launches from as early as 2025. However, as with any new drug product development, there are risks and challenges still to be overcome. A detailed launch schedule has not yet been announced by the companies involved.

DPIs, soft mist inhalers and nebulisers are already available for most molecules and combinations as alternatives to high-GWP MDIs, offering a lower carbon footprint. One company has launched a new range of single capsule DPIs delivered from a re-usable inhaler, making it the lowest GWP of all inhalers yet tested.<sup>68</sup> Nebulisers may offer an alternative to MDIs in some uses.

MCTOC will report further in its 2022 Assessment Report.

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[renewable-energy-investment-and-low-carbon-inhaler-programme-alongside-life-sciences-sector-race-to-zero-breakthrough-at-nyc-climate-week/](#)

<sup>63</sup> Panigone S, Sandri F, Ferri R, Ferri R, Volpato A, Nudo E, Nicolini G, Environmental impact of inhalers for respiratory diseases: decreasing the carbon footprint while preserving patient-tailored treatment, *BMJ Open Respiratory Research*, 2020;7:e000571. doi: 10.1136/bmjresp-2020-000571.

<sup>64</sup> Kindeva announcement February 2022: <https://www.kindevadd.com/news/kindeva-drug-delivery-to-manufacture-new-greener-inhalers-at-uk-manufacturing-site-to-help-cut-carbon-emissions/>

<sup>65</sup> Stuart Corr, Koura UK, HFA-152a as a Sustainable pMDI Propellant, *Respiratory Drug Delivery 2020*, <https://www.zephex.com/wp-content/uploads/2020/07/Corr-2020-1.pdf>

<sup>66</sup> <https://www.astrazeneca.com/content/astraz/media-centre/press-releases/2022/astrazeneca-progresses-ambition-zero-carbon-programme-with-honeywell-partnership-to-develop-next-generation-respiratory-inhalers.html>

<sup>67</sup> Koura opens world's first HFA 152a medical propellant production facility, <https://www.kouraglobal.com/5899/>, 31 March 2022. Accessed April 2022.

<sup>68</sup> Woodcock A, Beeh KM, Sagara H, Aumônier S, Addo-Yobo E, Khan J, Vestbo J, Tope H, The environmental impact of inhaled therapy: making informed treatment choices, *Eur Respir J.*, 2021, Dec 16:2102106. doi: 10.1183/13993003.02106-2021. Epub ahead of print. PMID: 34916263.



## **7 Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC) Progress Report**

### **7.1 Introduction**

In 2021, RTOC reached consensus regarding the structure of the 2022 RTOC Assessment Report (AR2022) and will maintain the Chapter Lead Authors and Chapters Authors organisation. RTOC members devoted time in developing the Second Order Draft (SOD) of the report which will be followed by a Third Order Draft (TOD), to be completed in the course of June 2022.

### **7.2 Refrigerants**

Since the publication of the RTOC 2018 Assessment Report, one new single component refrigerant and eighteen refrigerant blends have received a designation and/or classification from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 34 and/or from the International Standards Organisation (ISO) 817. These eighteen refrigerants are listed in tables 7.1, 7.2 and 7.3 below. Their GWP and ODP values are calculated in the same way as the ones given in the RTOC 2018 Assessment Report.

One of the refrigerants is a single-component refrigerant, trifluoroiodomethane – IFC-13I1. Although this fluid had not yet received a designation from one of the refrigerant standards, it had already been mentioned in the RTOC 2018 Assessment Report. IFC-13I1 is now classified as non-flammable and with low chronic toxicity (safety class A1) in ASHRAE 34, while it is not listed in ISO 817. The boiling point is -21.9°C, and IFC-13I1 has the potential, when used as a component in refrigerant blends (such as R-466A), to produce low flammability refrigerant blends with a lower GWP. There are concerns about the stability of IFC-13I1 and there is therefore ongoing research on this topic. The ODP of IFC-13I1 is less than 0.09, but the impact on the ozone layer varies significantly with the geographical location of the release, due to its short atmospheric lifetime. More details on the ODP of IFC-13I1 were already given in the RTOC 2018 Assessment Report.

The remaining refrigerants are blends:

- R-427B, 427C, and R-467A are blends of “traditional” high GWP fluids.
- R-448B, R-457B, and R-475A are blends containing HFO-1234yf or HFO-1234ze
- R-466A is a blend containing IFC-13I1.
- R-468A, R-468B, R-468C, and R-473A are blends containing HFO-1132a,
- R-471A is a blend containing HFO-1234ze(E) and HFO-1336mzz(E).
- R-469A, R-470A, R-470B, R-472A, R-472B, and 473A all contain CO<sub>2</sub>, which composition lowers the GWP, lowers the boiling point and results in relatively large temperature glides.
- R-515B is very similar to the existing R-515A and is also an azeotropic blend of HFO-1234ze(E) and HFC-227ea.

It is worth noting from the tables below, that most of the new refrigerants are non-flammable and of low toxicity, furthermore they have boiling points similar to traditional refrigerants such as HFC-23, HFC-134a, R-404A, R-507, and R-410A.

**Table 7.1: 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 <sup>2</sup> /ppm)	GWP 100 Year	GWP 20 Year	ODP
IFC-131I	CF <sub>3</sub> I	trifluoroiodomethane	195.9	-21.9	A1	<5 days	0.23	0.4	1	<0.09

**Table 7.2: 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	ODP
R-427B	HFC-32/HFC-125/HFC-143a/HFC-134a (20.6/25.6/19.0/34.8)	85.0	-46.2/-40.1	A1	2,500	4,800	
R-427C	He-32/HFC-125/HFC-143a/HFC-134a (25.0/25.0/10.0/40.0)	83.3	-45.9/-39.4	A1	2,100	4,400	
R-448B	HFC-32/ HFC-125/ HFO-1234yf/ HFC-134a/ HFO-1234ze(E) (21.0/21.0/20.0/31.0/7.0)	89.3	-44.1/-37.4	A1	1,300	3,000	
R-457B	HFC-32/HFO-1234yf/HFC-152a (35.0/55.0/10.0)	76.5	-46.4/-40.4	A2L	260	940	
R-466A	HFC-32/HFC-125/131I (49.0/11.5/39.5)	80.7	-51.7/-51.0	A1	740	2,000	<0.04
R-467A	HFC-32/HFC-125/HFC-134a/HC-600a (22.0/5.0/72.4/0.6)	84.4	-40.5/-33.3	A1	1,300	3,600	
R-468A	HFO-1132a/HFC-32/HFO-1234yf (3.5/21.5/75.0)	88.8	-51.3/-39.0	A2L	150	540	
R-468B	HFO-1132a/HFC-32/HFO-1234yf (6.0/13.0/81.0)	94.9	-52.4/-36.8	A2L	93	330	
R-468C	HFO-1132a/HFC-32/HFO-1234yf (6.0/42.0/52.0)	73.7	-56.6/-46.2	A2L	300	1,100	
R-469A	R-744/HFC- 32/HFC-125 (35.0/32.5/32.5)	59.1	-78.5/-61.5	A2L	1,400	2,900	
R-470A	R-744/32/HFC-125/HFC-134a/HFO-1234ze(E)/HFC-227ea (10.0/17.0/19.0/7.0/44.0/3.0)	84.4	-62.7/-35.6	A1	970	2,000	
R-470B	R-744/HFC-32/HFC-125/HFC-134a/HFO-1234ze(E)/HFC- 227ea (10.0/11.5/11.5/3.0/57.0/7.0)	89.7	-61.7/-31.4	A1	740	1,500	
R-471A	HFO-1234ze(E)/HFC-227ea/HFO-1336mzz(E) (78.7/4.3/17.0)	122.1	-16.9/-13.8	A1	140	240	
R-472A	R-744/HFC-32/HFC-134a (69.0/12.0/19.0)	50.4	-84.3/-61.5	A1	340	1,000	
R-472B	R-744/HFC-32/HFC-134a (58.0/10.0/32.0)	54.8	-82.9/-54.8	A1	510	1,500	
R-473A	HFO-1132a/ HFC-23/R-744/ HFC-125 (20.0/10.0/60.0/10.0)	52.6	-87.6/-83.0	A1	1,600	1,700	
R-475A	HFO-1234yf/HFC-134a/HFO-1234ze(E) (45.0/43.0/12.0)	108.5	-28.8/-28.3	A1	590	1,600	

**Table 7.3: 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-515B	HFO-1234ze(E)/HFC-227ea (91,1/8,9)	117.5	−19.0/−19.0	A1	280	470

### 7.3 Factory sealed domestic and commercial refrigeration appliances

Currently, the entire global new production of domestic refrigerators is based on non-ODS refrigerants, predominantly HC-600a and to some extent still HFC-134a. Refrigerant migration from HFC-134a to HC-600a is expected to continue, driven by Kigali Amendment phase-down schedules or local regulations on HFCs. It is estimated that by 2020 about 75% of new refrigerator production were using HC-600a and the rest was still applying HFC-134a.

Commercial systems are predominantly produced with HFCs, particularly HFC-134a. Migrations are taking place to HC-290 and HC-600a in several European and US companies. The application of R-744 has gained a lot of interest in some niche markets. This trend is spreading to some of the Article 5 countries too.

The most commonly used refrigerants in HPTDs are HFC-134a, R-407C, and R-410A. Large European manufacturers, motivated by the reduction of refrigerant quotas under the EU F-Gas regulation, have already switched to HC-290 for better efficiency while complying with safety standards.

For most appliances and components used in appliances, particular safety standards are available within the IEC 60335 framework. Applicable standards include:

- 60335-2-11 Household and similar electrical appliances - Safety for tumble dryers
- 60335-2-24 Household and similar electrical appliances - Safety for refrigerating appliances, ice-cream appliances and ice makers
- 60335-2-75 Household and similar electrical appliances - Safety for commercial dispensing appliances and vending machines
- 60335-2-89 Household and similar electrical appliances - Safety for commercial refrigerating appliances and icemakers with an incorporated or remote refrigerant unit or motor-compressor
- 60335-2-118 Household and similar electrical appliances - Safety for professional ice-cream makers

The regulatory schemes and standards on energy efficiency seem to drive manufacturers to innovate products for better energy efficiency at lower costs.

### 7.4 Food retail and food service refrigeration

The trend of adopting some form of a GWP limit on the use of high GWP HFC gases in food retail and food service applications continues across the world. The F-gas regulation 517/2014 in Europe is in the process of being updated and in the U.S., the American Innovation and Manufacturing Act of 2020 (AIM Act) signed into law on 27 December 2020, is being

implemented. According to ICAP (India Cooling Action Plan), in India and around the world, a combined energy and refrigerant use metric may be considered for the labelling of equipment

The commonly used HFCs in existing food retail and food service are R-404A (GWP 3922) and HFC-134a (GWP 1430) and in many A5 parties HCFC-22 (GWP 1810) is still being used. Much lower GWP alternatives for these refrigerants are now widely available in the European Union and North American markets. In non-A5 parties, R-448A and R-449A are being used widely to replace R-404A and HCFC-22 in both existing systems and new systems wherever permitted by regulations. Lower GWP refrigerants, which are mostly A2L, are also gaining acceptance. Commercial stand-alone systems, which are commonly used in food retail and food service establishments, have for the most part transitioned to R-290, with some exceptions where the properties of the halocarbon blends are needed for achieving performance.

Non-halocarbon refrigerants such as R-744 continue to make gains in many regions, particularly in Europe and North America. Regardless of the refrigerant, the awareness of the need for leak detection and leak prevention is growing worldwide.

## **7.5 Transport refrigeration**

In the past year, a progressive conversion from HFC-404A to R-452A continued, together with an exploration of alternatives.

It was supported by a progress in relevant safety standards, in particular ISO 20854 (2019) for marine containers and a parallel activity on trucks and trailers.

The industry is experiencing inflation and disruptions in the supply chain after the global pandemic.

## **7.6 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 80 million units per year (in 2020). All products sold within non-A5 parties use non-ODS refrigerants. There is an increasing proportion of production of air conditioners in A5 countries that do not use HCFCs. Globally more than four-fifths all units produced globally use non-ODP refrigerants.

Conversion of the HCFC-22 production of equipment is continuing and in most non-A5 parties the use of HCFC-22 has been prohibited in new systems. For A5 parties less than a third of ACs are produced with HCFC-22. In addition to the widespread use of R-410A, the extensive introduction of HFC-32 in residential split air conditioners continues in many countries around the world, accounting for nearly half of the total production of split room air conditioners in 2021.

Enterprises in A5 parties and also mainly those in non-A5 regions, are continuing to evaluate and develop products with various HFC/unsaturated HFC blends, such as those comprising HFC-32, HFC-125, HFC-134a, HFC-1234yf and HFC-1234ze; primarily R-454B and R-452B. Further conversion of production lines to HC-290 in China, South East Asia and South America is underway, and (except for small and portable units) there is limited market introduction, which is due to restrictive requirements of safety standards. In China, more models are now being offered, and in India, the production of HC-290 split air conditioners

continues. At least one company has introduced a range of products with R-463A and models with R-454A are anticipated elsewhere. Some enterprises in the Middle East still see R-407C and HFC-134a --and in some applications R410A-- as the most favourable alternatives to HCFC-22.

The new edition of the standard IEC 60335-2-4069 was approved in April 2022 by the International Electrotechnical Commission. The approved revised version will allow HC-290 (propane), and other flammable refrigerants, to be used in many air conditioning systems and heat pumps that were previously prohibited by the previous version of the standard from using these refrigerants.

The revised safety standard allows for the use of a larger charge of flammable refrigerants (up to 988g of HC-290 in a standard split air conditioning system). This will be possible on new equipment that must have additional safety requirements to ensure the same high level of safety as equipment that does not use flammable refrigerants.

The use of flammable refrigerants in air conditioning equipment will lead to a reduction in direct climate emissions compared to systems using R410A.

## **7.7 Commercial comfort air conditioning**

There are now complete lines of all chiller types in all major markets that use refrigerants having lower GWP than their predecessors; see the Table 7.4 below. Additionally, non-fluorinated refrigerants, such as ammonia, are available in some chiller types, albeit in select sizes and not in (from) complete product lines.

Existing products using high GWP refrigerants have not been discontinued, and in fact are still the dominant products being sold in most markets. Normal market forces will cause this to slowly change. The Kigali Amendment to the Montreal Protocol is providing some regulation to cause a more rapid change. However, there is little else in terms of regulation or incentives that are accelerating change. Products using the existing refrigerants will continue to be sold and the installed base of these products will remain in service for years to come. Despite the new refrigerant choices including that are now available for new and existing equipment, they may not be the final choices.

There is continued pressure from regulators to move to yet another generation of zero ODP and near zero GWP refrigerants, if technically possible and economically reasonable.

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<sup>69</sup> **Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers**

**Table 7.4 Refrigerants used within chillers**

	Low Pressure <sup>1</sup>			Medium Pressure <sup>2</sup>					High Pressure <sup>3</sup>					
Refrigerant	R-123 <sup>4</sup>	R-1233zd	R-514A	R-134a	R-513A	R-515B	R-1234ze	R-1234yf	R-22 <sup>4</sup>	R-410A	R-466A	R-452B	R-454B	R-32
Flammability >	1	1	1	1	1	1	2L	2L	1	1	1	2L	2L	2L
ASHRAE Safety Class	B	A	B	A	A	A	A	A	A	A	A	A	A	A
ASHRAE Toxicity Class	B	A	B	A	A	A	A	A	A	A	A	A	A	A
GWP <sup>5</sup>	79	1	2	1300	573	299	1	1	1760	1924	703	675	466	677
GWP Classification <sup>7</sup>	Very Low	Ultralow	Ultralow	High	Medium	Low	Ultralow	Ultralow	High	High	Medium	Medium	Medium	Medium

Notes:

- 1 Low Pressure Refrigerants are used in Centrifugal Chillers
- 2 Medium Pressure Refrigerants are used in Centrifugal and Screw Chillers
- 3 High Pressure Refrigerants are used in chillers using Scroll or other positive displacement compressors
- 4 Refrigerant is only available in Article 5 countries
- 5 GWP Values are per the 5th Assessment Report of the IPCC
- 6 A = lower toxicity B = higher toxicity
- 7 GWP Classification is given in Chapter 3, Table 3-1

New refrigerant choices, notably replacements for HFC-134a (medium pressure) and R-410A (high pressure), include flammable refrigerants, safety class A2L. Safety regulations that allow use of A2L refrigerants, supported by recent research, are being written, but are not uniform nor adopted in all regions. This is not a trivial matter, since health, safety and property issues are involved. Adoption and enforcement of revised codes and standards may slow the adoption new flammable refrigerants.

In the face of ever-increasing energy demand from the use of comfort air conditioning, customers and regulators alike are interested in less energy consumption. Global warming effects from chillers are dominated by their energy use, rather than the direct emissions from refrigerants. Regardless of any future refrigerant change, new products must improve full and part load or seasonal energy consumption.

## 7.8 Mobile AC/HP

At present, more than one refrigerant is used for new cars and light trucks air conditioning and heavy-duty off-road vehicles: HFC-134a will remain to be used world-wide while, as a consequence of current regulations, HFO-1234yf replaced it in Europe, US, and Japan. The progressive electrification of road transport in Europe, China and North America is leading to the implementation of a heat pump function and for this R-744 is taken as the (most promising) alternative. In Europe there is a movement led by several countries asking for limiting the use of PFAS-related substances. Several countries developed a new, broader definition for PFAS -related substances. With this new definition many HFCs, HFOs and polymeric materials (such as hoses) would now be included in this revised definition. Even if the study is at an early stage, new scenarios considering alternative refrigerants are re-evaluated.

In A5 parties, the availability and cost of low GWP refrigerants (e.g., HFO-1234yf) is still a barrier and options based on the use of dual loop system combined with HFC-152a or hydrocarbons remains under evaluation (e.g., in India).

The mobile air conditioning system increases the annual average vehicle energy demand of about the 20% leading to an estimated GHG indirect emissions of about 280 Mt CO<sub>2</sub>-eq. per year. Road transport electrification could reduce this amount from 0% to 40% dependent on the electrification rate and on the average energy mix of electric energy production (the current worldwide ratio is 475 g CO<sub>2</sub>/kWh).



## **7.9 Industrial refrigeration, heat pumps and heat engines**

Since the 2018 Assessment Report there is more focus on energy efficiency and heat recovery in industrial refrigeration. Regarding heat recovery, the industrial sector, including industrial refrigeration, accounts for approximately 30% of the global total energy consumption and up to 50% of it is lost as waste heat (Thorsson, 2020). The waste heat can be recovered in various ways. For the industrial producer it means that what was regarded as waste heat in the past, has become an asset that has a value for other purposes. This heat can be the natural heat source for a heat pump producing 90°C hot water for chemical free cleaning or may serve as source for a heat pump that produces even higher temperature water or steam. It is expected that innovative solutions for heat recovery will continue to emerge.

Industrial companies are focused on improving the efficiency of their process, and thereby reducing energy consumption. This is accomplished by improving the efficiency of individual pieces of equipment and the total process or system, but also by employing non-traditional approaches. As the transition from fossil fuel based electrical production to sustainable electrical production advances, electrically driven heat pumps are more widely used.

The Kigali Amendment to the Montreal Protocol has stimulated the broader use of lower GWP refrigerants. Industrial systems with ammonia are seeing more competition from CO<sub>2</sub> rather than from HFCs and HCFCs, especially HCFC-22.

## **7.10 Heating-only heat pumps**

In general, heating-only heat pumps represent a fast-growing equipment type in several regions in the world. The growth is driven by decarbonisation and pollution targets. Currently, Europe, Japan and China are leading the way. In Europe and US there are recently several strong initiatives to replace fossil fuel combustion heating by heat pumps.

Energy efficiency and product cost are the most important characteristics, as heat pumps compete mainly with combusting type water heating equipment. Regulation is driving the adoption of lower GWP refrigerants, and noise level is becoming an important characteristic. The need to achieve high efficiency, low cost, low GWP and low noise represents a major challenge for equipment manufacturers.

As the heating-only heat pumps subsector does not represent a mature market yet, the availability of components at competitive price is critical. Specifically, compressors must be able to operate at specific heating operation conditions, and refrigerants must be chosen accordingly. For very high-pressure refrigerants, such as R-744, there is a need for specific components and control features that are able to operate at very high pressure. Sometimes the other applications in which the same compressor is used (such as commercial refrigeration and air conditioners) drives the refrigerant selection.

In recent years, some new refrigerant trends have emerged. For new developments, there is a general tendency to move away from high-GWP refrigerants. For water heating appliances there is a growing usage of R-744, R-290 and HFC-32 as a refrigerant. Where safety restrictions allow to use it, R-290 is growing in monobloc equipment. R-744 is applied for heating water for storage at high temperature, since R-744 shows good performance for this application. However, cost and performance for broader heating applications are limiting adoption of R-744, particularly in Europe. There is an extensive introduction of refrigerant HFC-32 for heat pumps as they use several common components with the air-to-air air-conditioners and heat pumps. Also, for larger water heating heat pumps, as well as for combined space - plus hot water heating heat pumps, HFC-32 is seeing a very high growth in consumption due to the broad availability of refrigerant and components already qualified for these applications. For those areas in the world where there are restrictions on the use of

flammable refrigerants, HFCs with higher GWPs are used. Based on upcoming regulations for the phase-down of HFCs, continued transition to low and medium GWP refrigerants is expected in the next few years.

As reported in the 2020 progress report, R-454C had been introduced for water heating heat-pumps by one manufacturer. Recently, R-454B has also been introduced for the use in water heating heat-pumps. Besides the adaptations for using an A2L flammable refrigerant, design changes and production process impacts for using R-454B are limited when converting from R-410A.

## 8 Decision XXXI/8 and TEAP matters

### 8.1 Nomination and appointment process

This section includes information previously provided in the 2020 and 2021 TEAP Progress Reports as these processes are relevant to TEAP's recommendations in this section of the report.

At the 31st MOP, decision XXXI/8, "Terms of reference of the Technology and Economic Assessment Panel and its technical options committees and temporary subsidiary bodies – procedures relevant to nominations," states the following:

*"...To request the Panel to provide, as part of its annual progress report, a summary outlining the procedures that the Panel and its technical options committees have undertaken to ensure adherence to the Panel's terms of reference through clear and transparent procedures, including full consultations with the focal points, in line with the terms of reference, regarding:*

- a) nomination processes, taking into account the matrix of needed expertise and already available expertise;*
- b) proposed nominations and appointment decisions;*
- c) termination of appointments; and*
- d) replacements;*

Under TEAP's mandates from parties, TEAP continuously works to identifying appropriate expertise and finding qualified candidates who are interested and available to serve. TEAP takes into consideration of its current pool of experts, with the potential loss of expertise, through attrition or lack of support, and the need for specific and cross-cutting expertise within TOCs and the TEAP itself. TEAP communicates these needs to parties through its annual progress reports and the matrix of needed expertise.

To facilitate the submission of nominations by the parties, the terms of reference instruct the Panel and its TOCs to draw up guidelines for the nomination of experts. It is stipulated that "the TEAP/TOCs will publicize a matrix of expertise available, and the expertise needed in the TEAP/TOCs so as to facilitate submission of appropriate nominations by the parties. The matrix must include the need for geographic and expertise balance and provide consistent information on expertise that is available and required. The matrix would include the name and affiliation and the specific expertise required including on different alternatives. The TEAP/TOCs, acting through their respective co-chairs, shall ensure that the matrix is updated at least once a year and shall publish the matrix on the Secretariat website and in the Panel's annual progress reports. The TEAP/TOCs shall also ensure that the information in the matrix is clear, sufficient and consistent as far as is appropriate between the TEAP and TOCs and balanced to allow a full understanding of needed expertise" (TOR 2.9).

Annex 1 of this report provides updated TOC membership lists, including the current terms of appointment for all members. Each TOC describes the expertise that is currently available and the expertise that is needed.

The TOR specify that "nominations of members to the TEAP, including co-chairs of the TEAP and TOCs, must be made by individual parties to the Secretariat through their respective national focal points. Such nominations will be forwarded to the Meeting of the Parties for consideration. The TEAP co-chairs shall ensure that any potential nominee identified by TEAP for appointment to the Panel, including co-chairs of TEAP and the TOCs, is agreed to by the national focal points of the relevant party. A member of TEAP, the TOCs or the TSBs shall not be a current representative of a party to the Montreal Protocol" (TOR 2.2.1).

For TOCs or temporary subsidiary bodies (TSBs), the TOR require all nominations to be made in full consultation with the national focal point of the relevant party. The TOR further state that “all nominations to the TOCs and TSBs shall be made in full consultation with the national focal point of the relevant party. Nominations of members to a TOC (other than TOC co-chairs) may also be made by individual parties, or TEAP and TOC co-chairs may suggest to individual parties experts to consider nominating. Nominations to a TSB (including TSB co-chairs) can be made by the TEAP co-chairs” (TOR 2.2.2).

### ***8.1.1 Proposed nominations and appointment decisions***

Ensuring relevant and sufficient technical expertise is the priority consideration for the Panel and its committees. The need to maintain a reasonable size and balance, to avoid the duplication of expertise and to ensure that particular gaps in expertise are filled, means that experts nominated by parties may sometimes be declined or that their consideration may be deferred by the committee co-chairs in consultation with the Panel co-chairs. Although the committee co-chairs take into account A5/non-A5, gender and geographical balance, relevant technical expertise can outweigh those other considerations.

Nominations are currently made through a standardised nomination form (Annex 3), that may include a curriculum vitae, and which is also available on the Ozone Secretariat’s website<sup>70</sup>. If information is not already included in the curriculum vitae of the nominee, the standardised form requests relevant information such as education and other qualifications, relevant employment history, publications, awards, memberships, and references.

It is helpful when there is consultation between the parties and the co-chairs of the Panel and/or the relevant committee on potential nominations for the positions of co-chairs of the Panel or the committees. In the case of nominations or nominations for reappointment for the position of members in a committee, the committee co-chairs consult with the Panel co-chairs and the relevant national focal points.

The TOCs committees also receive nominations for the position of members directly from parties. In determining whether to accept or decline a nomination, the committee co-chairs, in consultation with the Panel as appropriate, consider the expertise of the nominee taking into account the expertise needed by the relevant committee, and also the balance of A5/non-A5, geographical and gender. The gaps in the expertise within the committees are presented in the matrix of needed expertise and annual progress reports. It has been the practice that nominations for committee membership and appointments to the committee can be made at any time, which has worked well in promptly sourcing the needed expertise and flexibly responding to the constant and yet changing workloads of some committees.

As specified in section 2.3 of the TOR, upon nomination by the relevant party, parties appoint members of the panel upon nomination by the relevant party for periods of up to four years each. As specified in section 2.5 of the TOR, the “TOC members are appointed by the TOC co-chairs, in consultation with TEAP, for a period of no more than four years.”

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<sup>70</sup> <https://ozone.unep.org/science/assessment/teap>

## **8.2 TEAP and TOCs organisational and other matters**

TEAP takes this opportunity to bring to parties' attention information relevant to each TOC:

### **8.2.1 FTOC**

FTOC meets regularly, virtually, due to the pandemic, and has increased the frequency to biweekly meetings to prepare for the 2022 Assessment Report.

FTOC members currently have expertise in: producing and handling foam blowing agents; foam formulation; foam production (XPS, Spray Foam, appliance etc.) and life cycle analysis; emissions and banks modelling; certification testing for foams; regulations related to foams; global foam markets including forecasting future production; historical knowledge of foams, foam blowing agents, regulations, and the Montreal Protocol; the building envelope and reducing energy demand from buildings; appliance design and production energy efficiency.

### **8.2.2 HTOC**

Following the Kigali Amendment to the Montreal Protocol, the role of the Halons Technical Options Committee (HTOC) has broadened to cover low/no-GWP alternatives to halons, HCFCs, and high-GWP HFCs. However, the Kigali amendment does not necessarily bring the need for any additional areas of expertise in fire protection because the uses remain unchanged, although additional expertise for regional or sub-regional considerations will be needed. From a fire safety standpoint, the HTOC remains concerned that the flammability of refrigerants, foam blowing agents and solvents requires fire protection expertise which almost exclusively resides in the HTOC within the TEAP. The HTOC remains available to assist in this area.

Generally speaking, the HTOC maintains expertise in the following five main areas:

- 1) a fundamental scientific understanding of fire chemistry and the process of combustion and fire extinguishment, and technical and economic expertise in fire protection needs, active and passive methods, system maintenance and personnel training.
- 2) the use of halons, HCFCs, high-GWP HFCs and their alternatives in fire protection, including emissions and installed amounts (bank estimates),
- 3) “banking” i.e., collection, recycling/reclamation, and re-deployment of fire extinguishants including their application standards, purity requirements, and destruction issues,
- 4) issues impacting current and future use, e.g., continued reliance on halons for existing uses in military, oil and gas, merchant shipping, etc., and for existing/new installations in civil aviation, and phase-down requirements of fire protections uses of high GWP HFCs. This includes modelling of remaining quantities and emissions of halons, and growth of HCFCs and high-GWP HFCs.
- 5) In addition, the HTOC maintains an understanding of the workings of the Montreal Protocol and how lessons learned in phasing out production and consumption of halons, for example, on some applications could be reapplied in phasing out the production and consumption of HCFCs and phasing down the high-GWP HFCs under the Kigali Amendment.

Within the five main areas, the expertise is further divided into sectoral expertise and regional expertise. From a sectoral perspective, the HTOC has experts on fire protection requirements for on-going uses of halons, HCFCs, high-GWP HFCs and their alternatives within civil

aviation, military, telecommunications, oil and gas, power generation, merchant shipping, explosion protection, etc. The HTOC also maintains expertise in banking and recycling of halons, HCFCs, high GWP HFCs and their alternatives. HTOC recently added expertise on halon recovery (amounts, quantity and quality) from active and historic shipbreaking activities.

From a regional standpoint, the HTOC has expertise covering North America, Eastern and Western Europe, Australia, and Japan, with some limited expertise in Anglophone North Africa (Egypt), the Middle East (Kuwait), South America (Brazil), Asia (India and World Bank expertise on halon production phase-out in China). As noted in the matrix of expertise needed, the HTOC is continuing to look for additional experts to promote A5/non-A5 and regional balance while also being mindful of gender balance.

### **8.2.3 MBTOC**

MBTOC met virtually at the beginning of April 2022 to conduct assessment of CUNs for methyl bromide submitted by parties, and to prepare its 2022 Progress Report. A face-to-face meeting is planned in September 2022 to finalize the 2022 Assessment Report.

MBTOC currently has two co-chairs (one A5, one non-A5) and fourteen members, 5 from A5 countries and 8 from non-A5. MBTOC is seeking new members who are QPS experts preferably females from Asia and Latin America. Members with crossover links to the TPPT Committee of the IPPC would be most welcome.

Stocks of MB and illegal trade continue to be prominent issues, as well as emissions of MB. MBTOC further suggests that in response to the Rome Declaration, the increasing importance of the 2030 Agenda and its SDGs plus recent action taken by UNEA (e.g., nitrogen, use of plastics and others), the committee may in the near future work on a wider scope of issues where it has relevant expertise and where its expertise could be strengthened.

### **8.2.4 MCTOC**

Face-to-face meetings were impossible due to COVID-19 and MCTOC's Progress Report was developed online and through electronic means. 2022 MCTOC Assessment Report preparations are underway through online and electronic means.

At the end of 2021, MCTOC had 1 co-chair and 7 members whose terms of appointment ended, 6 of whom were appointed for additional terms of up to 4 years: William Auriemma (aerosols, US); B. Narsaiah (chemicals, India); Richard Cooke (destruction, Canada); Steve Burns (metered dose inhalers, UK); Maureen George (metered dose inhalers, US); Jørgen Vestbo (metered dose inhalers, Denmark). With sincere gratitude, MCTOC congratulates Rajiev Sharma on his retirement from MCTOC for his years of voluntary service to the Montreal Protocol. Considering additional expertise needs, a new member, Alex Wilkinson (metered dose inhalers, UK) has been appointed, following his nomination and in consultation with the national focal point of the relevant party, in accordance with TEAP's terms of reference.

MCTOC co-chairs continue to review and renew its membership and to consider its structure to ensure it can address current and future predicted challenges of the Montreal Protocol in medical and chemicals sectors. Some new areas of expansion in knowledge and expertise include: HFC semiconductor etchants, a sector which uses controlled substances, in the manufacture of semiconductors in etching processes and also in chemical vapour deposition, that are subject to the HFC phase down; and end-of-life waste management of controlled substances to address the status of banks and the options available for managing them so as to

avoid emissions and the associated systemic opportunities and challenges with their disposal and destruction.

MCTOC seeks new members to strengthen expertise in the following identified key knowledge areas: HFC semiconductor etchants; destruction technologies and end-of-life waste management; metered dose inhalers; and aerosols.

### **8.2.5 RTOC**

During the second half of 2021 and the first half of 2022 RTOC met twice virtually, during 27-29 September 2021 and 9-11 March 2022.

Consensus was reached in 2021 about the structure of the 2022 Assessment Report (AR2022), and the same vertical organisation of the previous RTOC AR2018 was maintained, including the Chapter Lead Authors and Chapters Authors structure.

During the 2021 meeting, the revision of the First Order Draft (FOD) of AR2022 and the release of the guidelines for the preparation of the Second Order Draft (SOD, were performed.

The revision of the SOD was worked on during the March 2022 meeting and the deadline for the Third Order Draft (TOD) was established for mid-June 2022. The TOD will be edited and completed by the RTOC co-chairs, it will then be submitted on September/October 2022 for peer review and RTOC members' review, to 18 international RACHP organisations and a few outside experts, as it was done for the RTOC 2018 Assessment Report.

During the 2020-2022 pandemic, the RTOC membership stood at 42 members (*i.e., as of January 2020*).

## **8.4 Organisational Matters – Recommendations**

### **8.4.1 Introduction**

TEAP continues to maintain or have access to the expertise, experience, and capacity to provide the parties with the technical and economic information they need to further the goals and objectives of the Vienna Convention and Montreal Protocol through reports, presentations, analyses, recommendations requested by the parties. The expertise and structure of TEAP and its TOCs are designed to address its current workload, including completing its Assessment Reports at the end of 2022. TEAP continues to review its organisation and structure to ensure that TEAP and its TOCS are structured in size and expertise to support future efforts of the parties to phase out ODS and phase down HFCs.

In its presentation to the high-level segment at MOP-33, TEAP noted some of the challenges to its work over the past few years:

- *The COVID pandemic has required Montreal Protocol processes to adapt (e.g., online comment forums, written responses to comments, extended technical sessions, repeated presentations, expanding scope over time).*
- *Despite the substantial additional workload and challenges with maintaining consensus and engagement virtually, TEAP has provided 14 reports since MOP-31.*
- *TEAP and TOC memberships are world-leading technical experts in their field, and we constantly strive to maintain that level of independent technical and economic expertise for the service of parties.*
- *TEAP is aware of the need to ensure that its membership meets the evolving needs of parties whilst ensuring continuity of its work under the Montreal Protocol.*

- *TEAP is planning face-to-face discussions in 2022 on its structure, membership, and future directions to present in its 2022 Progress Report.*

In May 2022, at its hybrid meeting in London, TEAP discussed its structure, memberships, particularly within its TOCs, and how best to meet the continuing trends and challenges that may impact the future efforts of the parties to ensure the phase out of ODS and phase down of HFCs. In particular, TEAP considered the increasing emphasis on food and vaccine cold chains and the overall health and performance of buildings especially during the pandemic, including energy efficiency, safety, and availability of alternatives during the transition to ODS and HFC alternatives. Based on its discussions at its meeting, TEAP is providing its recommendations for the consideration of parties to address these specific challenges through a restructuring of two TOCs: RTOC and FTOC. In addition, TEAP considered the scope of work for its three additional TOCs (MCTOC, MBTOC, HTOC).

According to the TEAP Terms of Reference (TOR), "[to] carry out its work programme, technical options committees (TOCs) are established and agreed to by a decision of the parties." These recommendations to parties follow a detailed consideration of work and reflect TEAP's continuing commitment to the aims of the parties so that its TOCs are structured to support current and future efforts under the Vienna Convention and Montreal Protocol.

#### **8.4.2 Considerations for RTOC and FTOC**

A synergistic approach to cold chains for food and other perishables as well as medicines would allow for more thoughtful consideration of the architecture of retail facilities and how that may impact foam blowing agent and refrigerant selection and safe, efficient use. Similarly, issues such as selection of ODS and HFC alternatives and energy demands in the context of ventilation needs and load reduction in buildings through insulation and design, could be examined in a holistic manner.

The TEAP is recommending the following to enhance its ability to provide necessary support to the Parties and provides further background information below.

1. In recognition of the timely opportunity to address these challenges, the TEAP would like the parties to consider forming two new TOCs in place of the current Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) and the Flexible and Rigid Foams Technical Options Committee (FTOC, to be called the
  - **Cold Chain TOC (CCTOC)**
  - **Building & Indoor Climate Control TOC (BICCTOC)**
2. TEAP understands that the terms of appointment for the existing co-chairs of the RTOC and FTOC would expire upon establishment of the new TOC. TEAP recommends the following co-chairs for these new TOCs:
  - For the CCTOC, that the parties consider appointing Roberto Piexoto and Fabio Polonara, co-chairs of the current RTOC, and Paulo Altoé, co-chair of the current FTOC, as co-chairs for a period not to exceed four years; and
  - For the BICCTOC, that the parties consider appointing Omar Abdelaziz, co-chair of the current RTOC, and Helen Walter-Terrinoni, co-chair of the current FTOC, as co-chairs for a period not to exceed four years.
3. With the formation of two new TOCs from the existing RTOC and FTOC, the terms of members of the current RTOC and FTOC are proposed to expire as of 31 December 2022. Co-chairs of the new TOCs will appoint members with terms beginning in 2023, ensuring compliance with the TEAP TOR, including:



- *Paragraph 2.1.2: TEAP, through its TOC co-chairs, shall compose its TOCs to reflect a balance of appropriate and anticipated expertise so that its reports are comprehensive, objective, and policy-neutral.*
- *Paragraph 2.2.2: All nominations to TOCs shall be made in full consultation with the national focal point of the relevant party. Nominations of members to a TOC may be made by individual parties or TEAP or TOC co-chairs may suggest to individual parties experts to consider nominating*
- *Paragraph 2.5: The TOC members are appointed by the TOC co-chairs, in consultation with TEAP, for a period of no more than four years.*

### **8.4.3 Background to Recommendations**

TEAP is very mindful of the ongoing operational and organisational constraints on its TOCs. From time to time, the Parties have re-organized TEAP to maintain an effective and efficient structure to provide the Parties with the technical and economic information they need. As part of this on-going process to meet changing needs, TEAP believes Parties may wish to consider adjustments to the current structure of TEAP and its TOCs with a restructuring of two of its key TOCs: the RTOC and the FTOC. TEAP believes this change now would support the ongoing efforts of parties to ensure the phaseout of ODS and meet the challenges to phase down HFCs, in the larger context of shifting technologies and market needs. TEAP has concluded that creation of a committee focused on the transition broadly in the refrigeration and air conditioning and foams sectors, in the context of the cold chain and overall indoor temperature control of buildings and transportation, is important to an effectively functioning body responsive to the needs of parties now and for the future. This structure allows identifying the needed expertise important to these sector transitions while remaining a cohesive organisation which can continue to effectively and efficiently coordinate responses to requests from parties.

TEAP believes that the proposed structure will allow for more collaboration between experts in load reduction in buildings and cold chain architecture design and in overarching system performance. There are also common considerations for ODS and HFC replacement selection for foam blowing agents and refrigerants, such as the safe use of flammable alternatives and use of some of the same replacements.

In recognition of the challenges to parties to achieve the phaseout of ODS and phasedown of HFCs, the TEAP would like Parties to consider integrating relevant issues such as energy efficiency into the formation into two new TOCs which would be formed starting from the existing RTOC and FTOC and would cover all sectors of the current RTOC and FTOC. These two new TOCs could be called the Cold Chain TOC or CCTOC and the Building & Indoor Climate Control TOC or BICCTOC. The functional areas served by each new TOC are as follows:

- **Cold Chain TOC:** Sectors to be covered include cold chains for food and other perishables including agriculture and fisheries, and medicines, such as vaccines, with a focus on sustainability; refrigeration including foam insulation and other foams and refrigerants. Examples of equipment include factory-sealed appliances, food retail and food service, transport refrigeration, industrial refrigeration. Expected coordination on cross-cutting issues, e.g., safety standards, with BICCTOC.
- **Building & Indoor Climate Control TOC:** Sectors to be covered include stationary and mobile AC, heat pumps (HP), construction foam), and refrigerants. Examples of equipment includes air to air AC and HP, commercial comfort AC, MAC, heating HP, heat engines. Expected coordination on cross-cutting issues with CCTOC.

TEAP recommends that the current RTOC and FTOC co-chairs be appointed as co-chairs to the new TOCs for a term of no longer than four years to provide continuity in this new structure. All current chairs hold significant institutional knowledge and excellent understanding of the expectations of the Montreal Protocol, meeting the standards expected of TEAP reports and presentations to the Parties, and program management of the TOC for Temporary Subsidiary Body (TSB) reports, assessment reports, etc. TEAP believes this new construct would provide increased capabilities to the Parties in an effective and efficient manner.

In recommending this restructuring of the RTOC and FTOC, TEAP wishes to recognize the significant contributions that all three RTOC co-chairs, Omar Abdelaziz, Roberto Peixoto, and Fabio Polonara, and the two FTOC co-chairs, Paulo Altoé and Helen Walter-Terrinoni, have made. TEAP recognizes that integrating two existing TOCs into two newly structured TOCs will be a significant commitment of effort for the co-chairs. TEAP believes that in the first year or so, these integration efforts will require significantly more time than would otherwise be the case. Regarding membership, TEAP is recommending that current members' terms of the RTOC and FTOC expire at the end of 2022, and new TOCs co-chairs would consider new appointments for the needed expertise (based on the TEAP Matrix of Needed Expertise) starting in 2023 following the requirements in the TEAP TOR for nominations and appointments to the TOCs.

TEAP also considered the forward roles and scope of work for HTOC, MBTOC, and MCTOC:

1. HTOC: reflecting the broad role of HTOC in fire safety, and the increasing range of fire suppressant options to Halons, we propose to re-name as **Fire Protection TOC (FPTOC)**.
2. MBTOC: Reflecting the broad importance of sustainability in food production and food safety as well as sustainable agriculture beyond methyl bromide, we propose to rename MBTOC as the **Methyl Bromide, Agriculture and Sustainability TOC (MBASTOC)**. This TOC would still address important MB uses - controlled (CUNs) and exempted (QPS) and their alternatives, but its scope of work would be much wider and relevant to sustainable production in agriculture (e.g., nitrogen management). Cross cutting issues will also be addressed jointly with other TOCs as appropriate (e.g., the impact of the cold chain on food security).
3. **Medical and Chemicals Technical Options Committee (MCTOC)**: no proposed change at this time.]

TEAP will provide an updated Matrix of Needed Expertise well ahead of MOP-34.

## 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: <https://ozone.unep.org/science/assessment/teap>. The disclosures are normally updated at the time of TEAP's annual meeting (normally in April/ May). 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 following tables.

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 31<sup>st</sup> December of the final year of appointment, up to four years.

### 1. Technology and Economic Assessment Panel (TEAP) 2022

TEAP is presently composed of three co-chairs, the co-chairs of the Technical Options Committees and five senior experts as indicated in Table 1 below.

**Table 1: TEAP Membership at May 2022**

Co-chairs	Affiliation	Country	Appointed through
Bella Maranion	U.S. Environmental Protection Agency	US	2024
Marta Pizano	Independent Expert	Colombia	2022*
Ashley Woodcock	Manchester University NHS Foundation Trust	UK	2022*
Senior Experts	Affiliation	Country	Appointed through
Suely Machado Carvalho	Independent Expert	Brazil	2023
Ray Gluckman	Gluckman Consulting	UK	2022*
Marco Gonzalez	Independent Expert	Costa Rica	2022*
Rajendra Shende	Terre Policy Centre	India	2022*
Shiqiu Zhang	Centre of Env. Sciences, Peking University	China	2022*
TOC Chairs	Affiliation	Country	Appointed through
Omar Abdelaziz	Zewail City of Science and Technology	Egypt	2023
Paulo Altoé	Independent Expert	Brazil	2024
Adam Chattaway	Collins Aerospace	UK	2024
Sergey Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2025
Kei-ichi Ohnishi	AGC, Inc.	Japan	2023
Roberto Peixoto	Maua Institute (IMT), Sao Paulo	Brazil	2023
Fabio Polonara	Università Politecnica delle Marche	Italy	2022*
Ian Porter	La Trobe University	Australia	2025
Helen Tope	Energy International Australia	Australia	2025
Daniel P. Verdonik	Jensen Hughes Inc	US	2024
Helen Walter-Terrinoni	Air conditioning, Heating and Refrigeration Institute	US	2025
Jianjun Zhang	Zhejiang Chemical Industry Research Institute	PRC	2023

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

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

FTOC members currently have expertise in: Producing and handling foam blowing agents; foam formulation; foam production (XPS, Spray Foam, appliance etc.) and life cycle analysis; emissions and banks modelling; certification testing for foams; regulations related to foams; global foam markets including forecasting future production; historical knowledge of foams, foam blowing agents, regulations, and the Montreal Protocol; the building envelope and reducing energy demand from buildings; appliance design and production energy efficiency.

**Table 2: FTOC Membership at May 2022**

Co-chairs	Affiliation	Country	Appointed through
Helen Walter-Terrinoni	The Air Conditioning, Heating and Refrigeration Institute	US	2025
Paulo Altoé	Independent Expert	Brazil	2024
Members	Affiliation	Country	Appointed through
Paul Ashford	Anthesis	UK	2023
Kultida Charoensawad	Covestro	Thailand	2024
Roy Chowdhury	Foam Supplies	Australia	2025
Joseph Costa	Arkema	US	2026
Gwyn Davis	Kingspan	UK	2024
Gabrielle Dreyfus	Climate Works	US	2025
Rick Duncan	Spray Polyurethane Association	US	2023
Ilhan Karaağaç	Kingspan	Turkey	2024
Shpresa Kotaji	Huntsman	Belgium	2023
Simon Lee	Independent Expert	US	2023
Yehia Lotfi	Technocom	Egypt	2024
Smita Mohanty	CIPET : School for Advanced Research in Polymers	India	2024
Miguel Quintero	Independent Expert	Colombia	2025
Sascha Rulhoff	Haltermann	Germany	2026
Enshan Sheng	Huntsman	China	2026
Koichi Wada	Japan Urethane Industry Institute	Japan	2024
Dave Williams	Honeywell	US	2023
Ernest Wysong	Natural Polymers	US	2024

## 3. TEAP Halons Technical Options Committee (HTOC)

Following the Kigali Amendment to the Montreal Protocol, the role of the Halons Technical Options Committee (HTOC) has broadened to cover low/no-GWP alternatives to halons, HCFCs, and high-GWP HFCs. However, the Kigali Amendment does not necessarily bring the need for any additional areas of expertise in fire protection because the uses remain unchanged, although additional expertise for regional or sub-regional considerations will be needed. From a fire safety standpoint, the HTOC remains concerned that the flammability of refrigerants, foam blowing agents and solvents requires fire protection expertise which almost exclusively resides in the HTOC within the TEAP. The HTOC remains available to assist in this area.

Generally speaking, the HTOC maintains expertise in the following five main areas:

1) a fundamental scientific understanding of fire chemistry and the process of combustion and fire extinguishment, and technical and economic expertise in fire protection needs, active and passive methods, system maintenance and personnel training.

- 2) the use of halons, HCFCs, high-GWP HFCs and their alternatives in fire protection, including emissions and installed amounts (bank estimates),
- 3) “banking” i.e., collection, recycling/reclamation, and re-deployment of fire extinguishants including their application standards, purity requirements, and destruction issues,
- 4) issues impacting current and future use, e.g., continued reliance on halons for existing uses in military, oil and gas, merchant shipping, etc., and for existing/new installations in civil aviation, and phase-down requirements of fire protections uses of high GWP HFCs. This includes modelling of remaining quantities and emissions of halons, and growth of HCFCs and high-GWP HFCs.
- 5) In addition, the HTOC maintains an understanding of the workings of the Montreal Protocol and how lessons learned in phasing out production and consumption of halons, for example, on some applications could be reapplied in phasing out the production and consumption of HCFCs and phasing down the high-GWP HFCs under the Kigali Amendment.

Within the five main areas, the expertise is further divided into sectoral expertise and regional expertise. From a sectoral perspective, the HTOC has experts on fire protection requirements for on-going uses of halons, HCFCs, high-GWP HFCs and their alternatives within civil aviation, military, telecommunications, oil and gas, power generation, merchant shipping, explosion protection, etc. The HTOC also maintains expertise in banking and recycling of halons, HCFCs, high GWP HFCs and their alternatives.

From a regional standpoint, the HTOC has expertise covering North America, Eastern and Western Europe, Australia, and Japan, with some limited expertise in Anglophone North Africa (Egypt), the Middle East (Kuwait), South America (Brazil), Asia (India and World Bank expertise on halon production phase-out in China). As noted in the matrix of expertise needed, the HTOC is continuing to look for additional experts to promote A5/non-A5 and regional balance while also being mindful of gender balance.

**Table 3: HTOC Membership at May 2022**

Co-chairs	Affiliation	Country	Appointed through
Adam Chattaway	Collins Aerospace	UK	2024
Sergey N. Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2025
Daniel P. Verdonik	Jensen Hughes, Inc.	USA	2024
Members	Affiliation	Country	Appointed through
Mohammed Jane Alam	Jahanabad Trading	Bangladesh	2024
Jamal Alfazaie	Independent Expert	Kuwait	2022*
Johan Åqvist	FMV	Sweden	2023
Youri Auroque	European Aviation Safety Agency	France	2023
Michelle M. Collins	Independent Expert - EECO International	USA	2022*
Khaled Effat	Modern Systems Engineering	Egypt	2025
Carlos Grandi	Independent Expert	Brazil	2022*
Laura Green	Hilcorp Alaska, LLC	USA	2024
Elvira Nigido	A-Gas Australia	Australia	2024
Emma Palumbo	Safety Hi-tech srl	Italy	2022*
Erik Pedersen	Independent Expert	Denmark	2024
R.P. Singh	CFEES, DRDO	India	2024
Donald Thomson	MOPIA	Canada	2022*
Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan	2024

Consulting Experts	Affiliation	Country	One-year renewable terms
Clare Bowens	Meridian Technical Services	UK	
Thomas Cortina	Halon Alternatives Research Corporation	USA	
Joshua R. Fritsch	United States Army	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 (alternate)	USA	
John G. Owens	3M Company	USA	
John J. O'Sullivan	Bureau Veritas	UK	
Mark L. Robin	Chemours	USA	
Joseph A. Senecal	FireMetrics LLC	USA	
Sidney de Brito Teixeira	Embraer	Brazil	

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

#### 4. TEAP Methyl Bromide Technical Options Committee (MBTOC)

The Methyl Bromide Technical Options Committee brings together expertise on controlled and exempted (QPS) uses of methyl bromide and their technically and economically feasible alternatives. Members are experts on the control and management of soilborne pests and pathogens attacking various crops where methyl bromide is used (currently under the Critical Use exemption) or was used in the past; pest control in a variety of stored commodities and structures; and alternatives for controlling quarantine pests and pathogens. Members have research, regulatory and commercial experience.

**Table 4: MBTOC Membership at May 2022**

Co-chairs	Affiliation	Country	Appointed through
Marta Pizano	Independent Expert	Colombia	2025
Ian Porter	La Trobe University	Australia	2025
Members	Affiliation	Country	Appointed through
Jonathan Banks	Independent Expert	Australia	2022*
Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II	Morocco	2025
Fred Bergwerff	Oxylow BV	Netherlands	2025
Aocheng Cao	Chinese Academy of Agricultural Sciences	China	2022*
Ayze Ozdem	Plant Protection Central Research Institute	Turkey	2022*
Ken Glassey	MAFF – NZ	New Zealand	2022*
Eduardo Gonzalez	Fumigator	Philippines	2022*
Takashi Misumi	MAFF – Japan	Japan	2022*
Christoph Reichmuth	Honorary Professor – Humboldt University	Germany	2022*
Jordi Riudavets	IRTA – Department of Plant Protection	Spain	2022*
Akio Tateya	Technical Adviser, Syngenta	Japan	2022*
Alejandro Valeiro	Nat. Institute for Ag. Technology	Argentina	2022*
Nick Vink	University of Stellenbosch	South Africa	2022*
Tim Widmer	USDA	US	2023

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

## 5. TEAP Medical and Chemicals Technical Options Committee (MCTOC)

The Medical and Chemicals Technical Options Committee brings together expertise on metered dose inhalers and their alternatives, aerosols, sterilants, production and feedstock uses of controlled substances, solvent and process agent applications, HFC semiconductor etchants, chemical substances of interest because of their ozone depletion or greenhouse warming potentials, laboratory and analytical uses, and destruction and end-of-life management of controlled substances. Members are experts in asthma and chronic obstructive pulmonary disease and their treatment, pharmaceutical manufacturing and marketing, aerosols manufacturing and markets, hospital and industrial sterilisation of medical equipment, chemicals manufacturing and markets, laboratory and analytical procedures, and destruction technologies and end-of-life waste management. Members have academic, research, clinical, regulatory, laboratory, industrial, business, consulting, and commercial experience.

**Table 5: MCTOC Membership as of May 2022**

Co-chairs	Affiliation	Country	Appointed through
Kei-ichi Ohnishi	AGC Inc.	Japan	2023
Helen Tope	Planet Futures	Australia	2025
Jianjun Zhang	Zhejiang Chemical Industry Research Institute	China	2023
Members	Affiliation	Country	Appointed through
Emmanuel Addo-Yobo	Kwame Nkrumah University of Science and Technology	Ghana	2022*
Fatima Al-Shatti	Consultant to the International Ozone Committee of the Kuwait Environmental Protection Authority	Kuwait	2022*
Paul Atkins	Inhaled Delivery Solutions	USA	2022*
Bill Auriemma	Diversified CPC International	USA	2025
Olga Blinova	St. Petersburg Pasteur Institute	Russia	2022*
Steve Burns	AstraZeneca	UK	2025
Nick Campbell	Arkema	France	2022*
Andrea Casazza	Chiesi Farmaceutici	Italy	2024
Nee Sun (Robert) Choong Kwet Yive	University of Mauritius	Mauritius	2022*
Rick Cooke	Man-West Environmental Group Ltd.	Canada	2025
Maureen George	Columbia University School of Nursing	USA	2025
Kathleen Hoffmann	Sotera Health Company	USA	2024
Jianxin Hu	College of Environmental Sciences & Engineering, Peking University	China	2022*
Ryan Hulse	Honeywell	USA	2024
Fang Jin	Guangzhou Medical University	China	2024
Rabinder Kaul	SRF Limited	India	2023
Javaid Khan	The Aga Khan University	Pakistan	2022*
Andrew Lindley	Independent consultant to Koura and European Fluorocarbon Technical Committee (EFCTC)	UK	2024
Gerald McDonnell	DePuy Synthes, Johnson & Johnson	Ireland	2022*
Robert Meyer	Consultant, Greenleaf Health	USA	2022*
B. Narsaiah	CSIR-Indian Institute of Chemical Technology (Retired)	India	2023
Timothy J. Noakes	Koura	UK	2022*
John G. Owens	3M	USA	2024
Jose Pons	Spray Quimica	Venezuela	2023
John Pritchard	Independent Consultant, Inspiring Strategies	UK	2022*
Rabbur Reza	Beximco Pharmaceuticals	Bangladesh	2022*
Christian Sekomo	University of Rwanda	Rwanda	2023
David Sherry	Nolan Sherry & Associates Ltd.	UK	2023
Peter Sleight	Koura	UK	2023



Jørgen Vestbo	Manchester University NHS Foundation Trust and Allergi- og Lungeklinikken, Vanløse	Denmark	2025
Kristine Whorlow	Non-Executive Director	Australia	2022*
Alex Wilkinson	East and North Hertfordshire NHS Trust	UK	2025
Gerallt Williams	Aptar Pharma	UK	2024
Ashley Woodcock	Manchester University NHS Foundation Trust	UK	2023
Lifei Zhang	National Research Center for Environmental Analysis and Measurement	China	2022*
Consulting Experts	Affiliation	Country	One-year renewable terms
Hideo Mori	Tokushima Regional Energy	Japan	
Yizhong You	Journal of Aerosol Communication	China	

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

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

The RTOC brings together expertise on Refrigeration, Air Conditioning and Heat Pumps (RACHP) sectors. Members are experts of: Refrigerants, Domestic refrigeration, Commercial refrigeration, Industrial refrigeration and heat pump systems, Transport refrigeration, Air-to-air conditioners and heat pumps, Water and space heating heat pumps, Chillers, Vehicle air conditioning, Energy efficiency and sustainability applied to refrigeration systems, Not-in-kind technologies, High-Ambient-Temperatures applications, Modelling of RACHP Systems. Members have research, industry activities regulatory and commercial experience.

**Table 6: RTOC Membership at May 2022**

	Co-chairs	Affiliation	Party	Appointed through
1	Abdelaziz, Omar	American University in Cairo.	Egypt	2023
2	Peixoto, Roberto de A.	Maua Institute, IMT, Sao Paulo	Brazil	2023
3	Polonara, Fabio	Univ. Politecnica Marche, Ancona	Italy	2022
	Members	Affiliation	Party	Appointed through
4	Maria C. Britto Bacellar	<u>Johnson Controls, JCI</u>	Brazil	2021*
5	Bhambure, Jitendra	Independent expert	India	2022*
6	Calm, James M.	Engineering Consultant	USA	2022*
7	Cermák, Radim	Ingersoll Rand	Czech Rep.	2022*
8	Chen, Guangming	Zhejiang University, Hangzhou	PR China	2022*
9	Colbourne, Daniel	Re-phridge Consultancy	UK	2022*
10	De Vos, Richard	GE Appliances	USA	2022*
11	Devotta, Sukumar	Independent Consultant	India	2022*
12	Dieryckx, Martin	Daikin Europe N.V,	Belgium	2022*
13	Dorman, Dennis	Trane Co.	USA	2022*
14	Elassaad, Bassam	Independent Expert	Lebanon	2022*
15	Gluckman Ray	Gluckman Consulting	UK	2022*
16	Godwin, Dave	U.S. EPA	USA	2022*
17	Grozdek, Marino	University of Zagreb	Croatia	2022*
18	Hamed, Samir	Petra Industries	Jordan	2022*
19	Herlianka Herlin	PTAWH	Indonesia	2021*
20	Janssen, Martien	Re/genT B.V.	The Netherl.	2022*
21	König, Holger	ref-tech consultancy	Germany	2022*
22	Kauffeld, Michael	Fachhochschule, Karlsruhe	Germany	2022*
23	Koban, Mary E.	Chemours Co	USA	2021*



24	Köhler, Jürgen	University of Braunschweig	Germany	2022*
25	Kuijpers, Lambert	A/gent B.V. Consultancy	The Netherl.	2022*
26	Lawton, Richard	Cambridge Refr. Technology CRT	UK	2022*
27	Li, Tingxun	Guangzhou San Yat Sen University	PR China	2022*
28	Malvicino, Carloandrea	FCA (Fiat)	Italy	2022*
29	Mohan Lal D.	Anna University, Chennai	India	2022*
30	Mousa, Maher	MHM Consultancy	Saudi Arabia	2022*
31	Nekså, Petter	SINTEF Energy Research	Norway	2022*
32	Nelson, Horace	Independent expert	Jamaica	2022*
33	Okada, Tetsuji	JRAIA	Japan	2022*
34	Olama, Alaa M.	Consultancy	Egypt	2022*
35	Pachai, Alexander C.	Johnson Controls, JCI	Denmark	2022*
36	Pedersen, Per Henrik	DTI, Consultant	Denmark	2022*
37	Rajendran, Rajan	Emerson	USA	2022*
38	Rochat, Helene	TopTen	Switzerland	2022*
39	Rusignuolo, Giorgio	UTC Carrier	USA	2022*
40	Vonsild, Asbjørn	Vonsild Consulting	Denmark	2022*
41	Yana Motta, Samuel	Honeywell (USA)	Peru	2022*
42	Yamaguchi, Hiroichi	Toshiba Carrier Co	Japan	2022*

\* Indicates members whose terms expire at the end of the current year or pending reappointment in view of reorganisation

## Annex 2: Nomination Form

### TEAP: Nomination Form

This form is to be completed by:

Parties nominating experts to the TEAP, Technical Options Committees (TOCs), or Temporary Subsidiary Bodies (TSBs)

Please provide a CV detailing the candidate's previous, relevant employment beginning with the most current one. Experience and expertise relevant to the Montreal Protocol are particularly important and a list of relevant publications is useful (do not provide copies of publications)

Position Nominated for:

### Expert Information

Please provide full names rather than only acronyms or initials

Title: ☐ Ms. ☐ Mr. ☐ Other: \_\_\_\_\_  
☐ Professor ☐ Dr

Name (underline family name):

Employer / Organisation:

Job Title:

Skype:

Email:

Web Site:

Nationality/ies:

### Applicant profile

Main Countries or Regions  
Worked or Experience in  
(with relevance to Montreal  
Protocol)

### **Employment History and/or Relevant Experience**

Please provide a short  
summary of the applicants'  
expertise and skills, as they  
relate to the position for which  
he/she is being nominated.

### **Publications**

Please give a list of relevant publications (do not attach) (No need to fill this section if already provided with CV)

### **English Proficiency and computer skills**

All meetings, correspondence and report writing are conducted in English so good command of English is essential. If English is not your mother tongue [native language] please describe briefly your proficiency to speak, read, and write in English. Basic computer literacy (Word, Excel, Power Point) for

### **References**

Please provide names of two persons who have worked with you on issues relevant to the Montreal

### **Confirmation and Agreement**

I hereby confirm that the above information is correct and agree for review by the TEAP. I have no objection to this information being made publicly available. I also confirm that, if appointed, I will review and agree to abide by TEAP's terms of reference, its code of conduct, operational procedures, and relevant decisions of the Parties as per Decision XXIV/8:  
<https://ozone.unep.org/node/1953>

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

### **Confirmation by Nominating Government**

This section must be completed by the national focal point of the relevant party.

Government: \_\_\_\_\_

Name of Government Representative: \_\_\_\_\_

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

**To be completed by the national focal point in the case of nomination by the party:**

*Has the matrix of needed expertise of TEAP been consulted?*

<https://ozone.unep.org/science/assessment/teap/teap-expertise-required>

**Yes No**

*Has TEAP been consulted on this nomination?*

**Yes No**

**PLEASE RETURN COMPLETED FORM TO: THE OZONE SECRETARIAT**

**ADDITIONAL INFORMATION - Expectations for members of TEAP, TOCs and TSBs**

Work done for TEAP, its TOCs and TSBs is on a voluntary basis and does not receive any remuneration [funding for their time]. Members from A 5 countries may be funded for their travel (flight) and per diem (UN DSA) only to relevant meetings, based on needed participation and availability of funding. Members are expected to attend meetings, engage in discussions, and devote time to the preparation of reports including finding and reviewing information to respond to the tasks set out by the Parties, drafting and formatting reports or sections of reports, reviewing reports and preparing presentations. TOC members attend at least annual meetings of that TOC. TOC co-chairs also attend the annual TEAP meeting, and typically two meetings per year of the Montreal Protocol. TSB members attend meetings of the TSB and may be asked to attend up to two meetings of the Montreal Protocol, based on needed participation and availability of funding.

All meetings, correspondence and report writing are conducted in English so good ability to read English plus good command of spoken and written English are essential.

Basic computer literacy (Word, Excel, Power Point) for drafting and editing products is required. Advanced computer/ document formatting skills are an asset.

All appointed members of TEAP, TOCs or TSBs should provide a “Declaration of Interest” prior to a meeting and at least once a year. The DOIs are posted at the Ozone Secretariat website.

In submitting a CV to support a nomination, Parties may wish to provide a short summary of the applicants’ expertise and skills, as they relate to the position for which he/she is being nominated, including the main countries or regions worked or experience in (with relevance to Montreal Protocol). Also please indicate if the nomination is in response to a specific category listed in the Matrix of Expertise published by TEAP

<https://ozone.unep.org/science/assessment/teap/teap-expertise-required>

Once appointed, members of TEAP, TOCs or TSBs provide a “Declaration of Interest” (DOI) at least once a year and prior to the group’s first meeting. Members provide updated DOIs within 30 days of any changes. The DOIs are posted on the Ozone Secretariat website.

Members review and agree to abide by TEAP’s terms of reference, its code of conduct, operational procedures, and relevant decisions of the Parties as per Decision XXIV/8:

<https://ozone.unep.org/node/1953>