MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MAY 2023

VOLUME 1: PROGRESS REPORT

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Co-ordination:	Technology and Economic Assessment Panel
Composition of the report:	Bella Maranion, Marta Pizano, Ashley Woodcock
Layout and formatting:	Marta Pizano, Bella Maranion, , Ashley Woodcock
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Foreword

The 2023 TEAP Report

The 2023 TEAP Report consists of three volumes:

Volume 1: *TEAP 2023 Progress Report*
Supplement to the TEAP 2023 Progress Report: Decision XXXIV/3 Energy Efficiency Working Group Report

Volume 2: *Evaluation of 2023 critical use nominations for methyl bromide and related issues - Interim Report – May 2023*

Volume 3: *Decision XXXIV/2: Assessment of the funding requirement for the replenishment of the Multilateral Fund for the period 2024-2026*

This is Volume 1

The UNEP Technology and Economic Assessment Panel (TEAP):

Bella Maranion, co-chair	US	Kei-ichi Ohnishi	JP
Marta Pizano, co-chair	COL	Roberto Peixoto	BRA
Ashley Woodcock, co-chair	UK	Fabio Polonara	IT
Omar Abdelaziz	EGY	Ian Porter	AUS
Paulo Altoe	BRA	Helen Tope	AUS
Suely Machado Carvalho	BRA	Dan Verdonik	US
Adam Chattaway	UK	Helen Walter-Terrinoni	US
Ray Gluckman	UK	Shiqiu Zhang	PRC
Marco Gonzalez	CR	Jianjun Zhang	PRC
Sergey Kopylov	RF		

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1 Introduction

This is volume 1 of 3 of the 2023 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), Fire Suppression TOC (FSTOC), Methyl Bromide TOC (MBTOC), Medical and Chemicals TOC (MCTOC) and Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC). The TEAP and its TOCs only recently completed and published their quadrennial Assessment Reports. Therefore, the following chapters present progress and developments identified by TOCs since January 2023.

The following decisions are also addressed in the corresponding chapters and/or sections of this report:

- **Decision XXXIV/3**: Enabling enhanced access and facilitating the transition to energy-efficient and low- or zero-global warming potential technologies (see Supplement to the 2023 Progress Report)
- **Decision XXXIV/5**: Identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options for enhancing such monitoring (see Chapter 5, section 5.3)
- **Decision XXXIV/6**: Ongoing emissions of carbon tetrachloride (see Chapter 5, section 5.4)
- **Decision XXXIV/10**: Stocks and quarantine and pre-shipment uses of methyl bromide (see Chapter 4, section 4.2)
- **Decision XXXIV/11**: Composition, balance and workload of the Technology and Economic Assessment Panel and its technical options committees (see Chapter 8)

This report also contains the TEAP and TOC membership lists, as of 30 April 2023, including each member and their term of appointment, and a matrix of needed expertise for the TEAP and its TOCs appear in annexes at the end of this document.

TEAP would like to express its sincere gratitude for the voluntary service and contributions of members of its TOCs and Task Forces. TEAP held a hybrid meeting, 24-28 April 2023, in London. We are grateful to the United Kingdom for their support with the meeting venue. We want to express our sincere appreciation to the Ozone Secretariat for its continuing support and assistance and in providing the TEAP with access to its virtual meeting platform for TEAP meetings.

1.1 Key messages from Technical Options Committees

Key messages arising from TOC progress reports are presented in this section.

1.1.1 FTOC

In non-Article 5 (non-A5) parties, regulations are driving transitions away from high global warming potential (GWP) hydrofluorocarbons (HFCs), whereas in Article 5 (A5) parties, Hydrochlorofluorocarbon (HCFC) Phase-out Management Plans (HPMPs) continue to drive transitions out of HCFCs with emphasis on avoiding adoption of high-GWP HFCs where possible. Significant resources are spent optimising the characteristics and costs of new foam blowing agents (FBAs) and foam systems.

Shortages of low-GWP FBAs have improved in both A5 and non-A5 parties. In addition, there were also shortages of hydrocarbons, such as cyclopentane, of sufficient quality to use as a FBA. As a result of the previous shortages, there had been a significant increase in the use of higher GWP HFCs with 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.

The transition away from ozone-depleting FBAs in some regions and market segments (e.g., spray foam and extruded polystyrene [XPS]) has been delayed because of increased costs of FBAs, as well as additional safety requirements, especially where local codes require higher thermal performance.

It is possible that consolidation among foam manufacturing companies will occur during the phase-out of HCFC blowing agents in A5 parties, as it did in non-A5 parties.

1.1.2 FSTOC

Estimated available halon 1301 supplies continue to decline and as a consequence, projected run-out dates have moved earlier. The latest estimates of run-out dates for halon 1301 range from 2030 (worst case) to 2049 (best case).

Proposed PFAS restrictions have introduced uncertainties and may delay or stop ongoing or planned halon replacement efforts and impact viability of in-kind, high-GWP HFC alternatives.

Estimates of available supplies of halon 1211 continue to diverge between the FSTOC model, which has lower emissions and a larger global bank, and estimates derived from atmospheric concentrations, which have considerably higher emissions and a significantly smaller global bank. This is particularly of concern to civil aviation, which has enduring uses of halon 1211 for existing onboard, portable fire extinguishers required to meet international flight safety standards. This may be further impacted by PFAS restrictions on the only approved alternative, 3,3,3-trifluoro-2-bromo-prop-1-ene (2-BTP).

1.1.3 MBTOC

Controlled uses of MB are reportedly almost completely phased out and the focus now is to ensure that all remaining production is for quarantine and pre-shipment (QPS) uses and that no non-compliant uses under the Protocol are occurring.

Only one non-A5 and no A5 parties applied for critical use nominations (CUNs) in 2023. Methyl iodide (MI) was registered in Australia at the end of 2022 as a pre-plant fumigant for strawberry runner production. However, research conducted in Australia shows that MI only provides the required control of pests and pathogens when formulated and used in combination with chloropicrin and the MI/Pic formulation is not yet registered (but registration is in process). The phase out of MB in Australia for this use appears reliant on the MI/Pic registration.

Canada has made significant progress with adoption of substrate production of strawberry nursery plants and tips for some production and a policy approach to phase out MB with a potential phase out by 2026.

Significant progress is being made on alternatives to MB for QPS uses, particularly the Pre-shipment (PS) uses where many of the alternatives adopted for the controlled uses of MB are also effective.

Sulfuryl Fluoride (SF), a widely adopted key alternative to MB for treatment of structures and commodities as well as QPS uses has been listed under Annex II of the proposed F-gas regulation of the European Union (EU). This adds to concern expressed by MBTOC in relation to the high GWP of 4630 of SF as it may further increase the cost of treatment with SF and possibly restrict its use.

Ethanedinitrile (EDN) continues to be considered for fumigation of timber products including those where MB is used for quarantine applications owing to its greater volatility and penetration capability than MB.

Hydrogen cyanide (HCN) is being registered in various countries as an alternative for a variety of QPS and non-QPS uses (structures, fruits and vegetables, commodities).

Ethyl formate is under review for initial registration with the US Environmental Protection Agency (USEPA) with potential to replace MB for the biggest QPS use of MB for import of Chilean grapes and for US citrus exports. Registration is expected to happen by June 2023.

Other international agreements continue to show concern over MB use owing to its potential adverse health effects and environmental impacts. For instance, the Chemical Review Committee (CRC-18) of the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, recommended that MB be listed in Annex III to the Convention. If approved, MB will become subject to the PIC procedure, which enables the 165 Parties to the Rotterdam Convention to share responsibility on and take informed decisions on potential future imports.

Atmospheric concentrations of MB are no longer falling and appear to have stabilized in the atmosphere above the natural baseline due to continued anthropogenic use, predominantly for QPS uses. Significant implementation of emission controls by recapture of MB or adoption of alternatives would lead to further decline in MB concentrations and a benefit to ozone layer recovery.

Response to Decision XXXIV/10: Stocks and quarantine and pre-shipment uses of methyl bromide

In Chapter 4, section 4.2, of this report, the MBTOC has responded to Decision XXXIV/10 on MB uses for QPS purposes to the best of its ability within the context of only one party voluntarily submitted information. MBTOC has provided clarification on QPS definitions and examples of typical MB uses that fall into these categories together with examples of cases that often are erroneously classified as Q or PS and may actually fall under the controlled use definition. Analyses of the main categories of use, the main pests controlled, and alternatives currently adopted or being researched and trialled are also provided.

1.1.4 MCTOC

Production and use of controlled substances for chemical feedstock

In 2021, total ozone depleting substance (ODS) production and import reported for feedstock uses was 1,755,171 tonnes, a significant increase compared to 2020 (2020: 1,477,644 metric tonnes). An overall increase of about 50% in ODS feedstock uses over the last decade is mostly due to the increase in feedstock uses of HCFCs, particularly HCFC-22, while increased production of HFOs is driving a more recent increase in carbon tetrachloride (CTC) feedstock use. The largest reported HFC feedstock is HFC-152a (in the thousands of tonnes).

Pressurised metered dose inhalers

In its 2022 Assessment Report, MCTOC reported on a range of issues and potential challenges that could emerge in the transition away from high-GWP propellant pressurised metered dose inhalers (pMDIs) to inhalers with lower GWPs and with the continued supply of technical- and pharmaceutical-grade HFC-134a and HFC-227ea. This Progress Report elaborates further on some of these potential challenges.

Theoretically, there are two possible options for the provision of pharmaceutical-grade propellant in future years if technical-grade feedstock plants can no longer supply HFC-134a just-in-time. Firstly, pharmaceutical-grade HFC (134a or 227ea) could be produced in earlier years and stored in a way that retains its purity and medical status. Secondly, technical-grade HFC could be stockpiled and later converted to pharmaceutical-grade by passing through a medical purifier plant. Planning for both options would be very challenging, considering the cost, regulatory, and practical issues. There is a risk that insufficient time may be left between when decisions are made to build stock and when technical-grade HFC manufacturing assets must shut down, so that stock building may become impractical.

As global HFC production diminishes with implementation of the Kigali Amendment, pMDI manufacturers, including in A5 parties, may find bulk pharmaceutical-grade high-GWP propellant sourced from the United Kingdom (UK) increasingly difficult to obtain, while the cost increases. These pMDI manufacturers may have to switch to propellant sourced from India or China. Gaining qualification for an alternative propellant source can take months to years.

For pMDI manufacturers in A5 parties that export to non- 5 parties, a switch of propellant manufacturer requires additional studies to gain pMDI regulatory approval, which would take time and could potentially impact the continued supply of these pMDIs to markets in non-A5 parties. There will be incremental costs for pMDI manufacturers in A5 parties in the transition from high GWP pMDIs to pMDIs with lower GWP propellants that parties may need to consider.

These and other market-based challenges and uncertainties, within the context of the HFC phase-down, reinforce the need for a well-planned transition to ensure patients do not face critical shortages or price increases that make pMDIs unaffordable.

Response to decision XXXIV/5 on the identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options for enhancing such monitoring

In Chapter 5, section 5.3 of this report, MCTOC provides its response to Decision XXXIV/5. MCTOC has assigned chemical pathways into associated global production bands and emission rates for relevant controlled substance for each chemical pathway. This enabled an assessment of which chemical pathways are likely able to produce "*substantial emissions*" of controlled substances, i.e., those having a sufficiently high combination of likely emission rate and annual global production. A reasonable criterion for *chemical pathways in which substantial emissions of controlled substances are likely* is considered to equate to greater than 1,000 tonnes of controlled substance emitted per year.

Twenty-four chemical pathways are considered likely to have "*substantial emissions*" of controlled substances, i.e., CFC-113, CFC-113a, CFC-114, CFC-115, CTC, HCFC-22, HCFC-124, HCFC-141b, HCFC-142b, HFC-23, HFC-32, HFC-125, HFC-134a, HFC-125, HFC-143a, HFC-152a, HFC-245fa, HFC-227ea, 1,1,1-trichloroethane.

Most production processes will only have "*substantial*" quantities of emissions of controlled substances when they are producing controlled substances or using them as feedstocks. Any other controlled substances involved in the process will only be produced and then released in much smaller quantities, which may be negligible. There are a few noted exceptions where unwanted by-products or intermediates could be emitted in significant quantities in some chemical pathways, including HFC-23 from the chloroform to HCFC-22 pathway and CTC from the methyl chloride, dichloromethane, chloroform pathway. Another exception is where there are non-trivial side reactions and emissions from production processes, e.g., the formation of HFC-23 in HFC-32, and HFC-23 in HCFC-22 pyrolysis to TFE/HFP (tetrafluoroethylene/hexafluoropropene), which when considering production quantities have emissions per year on the boundary of the "*substantial emissions*" criteria used in this assessment. Taking into account the production quantities, CFC-115 produced by a non-trivial side reaction during HFC-125 production results in likely CFC-115 emissions meeting the "*substantial emissions*" criteria used in this assessment.

There are many gaps in understanding the sources of emissions from chemical pathways with substantial emissions. The main reasons are the existing gaps in publicly available data, some of which may be unavailable due to commercial confidentiality.

Response to decision XXXIV/6 on ongoing emissions of CTC

In Chapter 5, section 5.4 of this report, MCTOC provides its response to this decision. In response to Decision XXXIV/6, information was submitted by five parties: China, the EU, Japan, UK, and the US. MCTOC provides a generic summary of the information in the submissions, identifying similar elements of national procedures and frameworks that have been established by this sample of parties. A non-exhaustive list of national procedures and frameworks included in the submissions is also reported.

1.1.5 RTOC

No new information is available since publication of the 2022 Assessment Report, so RTOC provides no further updates in this report.

An Energy Efficiency Working Group was established within RTOC with 15 of its members, to provide information to parties on energy efficiency during HFC phase-down; also included were one TEAP co-chair and one FTOC co-chair, to address cross-cutting issues. Energy efficiency as a system is a growing trend and is an important consideration for energy consumption and refrigerant size reduction.

2 Flexible and Rigid Foams TOC (FTOC) Progress Report

2.1 Major Issues Influencing the Global Foams Market

In non-A5 parties, regulations are driving transitions away from high GWP HFCs, whereas in A5 parties, HPMPs continue to drive transitions out of HCFCs with emphasis on avoiding adoption of high GWP HFCs where possible. Significant resources are spent optimizing desired characteristics and costs of FBAs and foam systems.

Shortages of low-GWP blowing agent have improved in both A5 and non-A5 parties. In addition, there were also shortages of hydrocarbons, such as cyclopentane, of sufficient quality to use as a foam blowing agent. As a result of the previous shortages, there had been a significant increase in the use of higher GWP HFCs with 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.

The transition away from ozone depleting FBAs in some regions and market segments (e.g., spray foam and extruded polystyrene [XPS]) has been delayed because of increased costs of FBAs, as well as additional safety requirements, especially where local codes require higher thermal performance.

It is possible that consolidation among foam manufacturing companies will occur during the phase-out of HCFC blowing agents in A5 parties, as it did in non-A5 parties.[1]

2.1.1 Major Issues Influencing the Foam Blowing Agent Market for A5 parties

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-ozone depletion potential (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 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 SMEs consuming 1000 tonnes or more to self-formulate blends for their own systems especially in Asia.

As had always been intended, the limited availability and increasing price of HCFCs will continue to drive the selection of other foam blowing agents as the phase-down progresses. The availability of high-GWP HFCs, particularly HFC-365mfc/HFC-227ea (which is banned in many non-A5 parties), is discouraging the transition to low GWP substances. However, it has been recently announced that the HFC-365 manufacturing plant will be shuttered in late 2023, which means that manufacturers that invested in developing formulations containing HFC-365 will have to evaluate alternate FBAs and develop foams using replacements,

China's Ministry of Housing, Urban, and Rural Development (MoHURD) is streamlining the existing 3,000 building standards into 300. Significant revisions have been made to existing fire standards - allowing for additional use of rigid polyurethane foam which can be applied in various ways including spray foam and panels. This may increase the use of rigid polyurethane and phenolic foam. It may also present a significant challenge to some SMEs on the choice of blowing agents.

[1] 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.

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 of 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. 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_2 (water), methyl formate, methylal (dimethoxymethane), and blends). The use of hydrocarbons pre-blended in formulations continues to be of concern, as their use requires safety measures and plant modifications for blending facilities, particularly impacting SMEs.

In India, approximately 70% of companies are using non-ODS/low-GWP technologies. The remainder are using HFCs. HCFC- 141b has been completely phased out in the country by January 1, 2020, and no companies are currently using it. Around 175 foam manufacturing enterprises have been covered under the HPMP out of which, 163 enterprises are covered under stage II of HPMP.

In some A5 parties, there has been an increase in the use of methylal, methylene chloride[2] 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.

2.1.2 Major Issues Influencing the Foam Blowing Agent Market for Non-A5 parties

In the EU, high-GWP fluorinated gases are being phased down under F-Gas Regulations through a quota system. In 2015 in the EU, all HFCs with GWP greater than 150 were banned for foam manufacturing for use in domestic appliances. As of January 2023, all HFCs with GWP greater than 150 had ceased being used in other forms of 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. Product standards are under review 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 2014 F-Gas Regulation is currently under review and the impact on the future use of fluorocarbons of any description (including HFOs/HCFOs) in the foam sector is still currently uncertain.

Local environmental regulation of HFOs and HCFOs varies 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, because of its chlorine content. However, the law provides a mechanism for obtaining exemption based on the low-GWP value and its energy efficiency.

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 100 GWP by 2024. Recently commercialised HCFO-1224yd(Z), is also used as a refrigerant and a solvent, which may limit access for use as a blowing agent.

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[2] Methylene chloride is a controlled substance in some parties due to its use in processing cocaine.

In the United States, it is anticipated that a 150 GWP limit will be set for most, if not all, FBAs effective January 2025 under the American Innovation and Manufacturing (AIM) Act Technology Transition Rule, if the regulation is finalised as proposed in October 2023.

2.2 Foam Blowing Agent Selection

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 among chemical producers and their foam manufacturer customers and regulators could be helpful to ensure that there is adequate supply as regulations are implemented. There have been significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations enabling the successful commercialisation 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. As an example, the Multilateral Fund published outcomes from a demonstration project at foam system houses[3] to formulate pre-blended polyols for spray polyurethane foam applications using a low-GWP blowing agent HFOs with proper choice of catalyst package that could yield foam with properties comparable to those blown with HCFC-141b but at an increased cost (22-46%) 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.

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 additive FA188 is a highly fluorinated olefin whose GWP is close to 100 and has been viewed technically as a nucleating agent. 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 it is also classified as a blowing agent with the potential to be regulated under the proposed PFAS Restrictions in the EU.

A patented chemical blowing agent (trade named CFA8[4][12]) is being promoted, as a FBA, to the polyurethane market by China's Butian New Materials and Technology Company.

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[5][13] blowing agents requires approximately18 to 36 months for capital investment and product qualification based on the specific end use (e.g. walls, roofs,

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[3] http://www.multilateralfund.org/Our%20Work/DemonProject/Document%20Library/8311ax5_Thailand.pdf

[4] PCT/CN2017/083948 (WO2017206692 A1) 201610393108.0 (CN107089927A)

[5] 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

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.

In China there are Chinese equipment vendors offering both CO_2 based and HFC solutions for medium to large enterprises. It is expected that CO_2 based systems will predominate for the phase out of HCFCs.

3 Fire Suppression TOC (FSTOC) Progress Report

The Fire Suppression Technical Options Committee (FSTOC) met 7-9 March in Cairo, Egypt. The meeting was attended in person by 13 representatives from the following countries: Australia, Brazil, Egypt, India, Japan, Kuwait, the United Kingdom, and the United States. Members from Denmark, Italy, Russia, and Sweden also participated remotely.

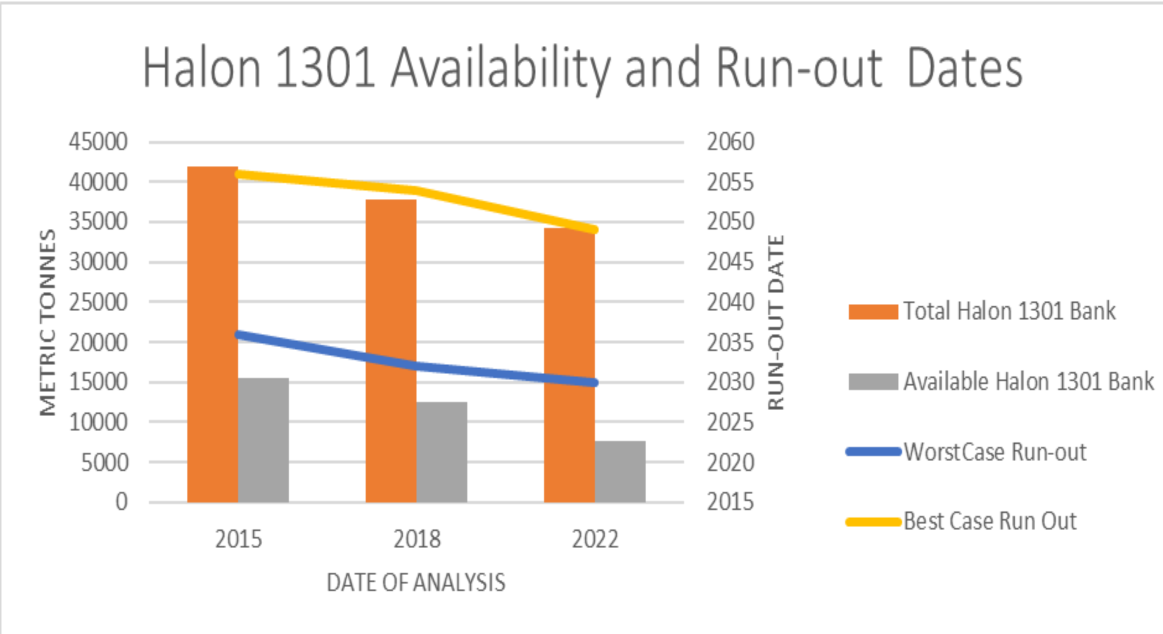
3.1 Halon 1301 run-out date

The FSTOC has responded to three Decisions of the parties regarding future availability of halon 1301. A summary if its findings is included in the table and figure below.

Table 3-1. Halon 1301 availability and run-out dates

Decision	Date of Analysis	Total Halon 1301 Bank (Metric tonnes)	Available Halon 1301 Bank (Metric tonnes)	Worst case Run-out date	Best case Run-out date
XXVI-7	2015	42,000	15,500	2036	2056
XXIX-8	2018	37,750	12,500	2032	2054
XXX-7	2022	34,310	7,620	2030	2049

Fig 3-1. Halon 1301 availability and run-out dates



The worst-case (earliest) run-out date for halon 1301 is now predicted to be 2030. The latest run-out date is 2049, which is still within the economic lifetime of all enduring uses of halon 1301 (i.e., oil & gas, nuclear power plants, civil aviation, and military). The FSTOC is not aware of any regional shortages currently but continues to monitor the situation.

An important source of recovered halon 1301 is from ship breaking. The latest data from Bangladesh[6] show that approximately five metric tonnes of halon 1301 were recovered from ship breaking in 2022. This is considerably less than the 32 metric tonnes recovered in 2021, which itself was significantly less than what would be expected based on the estimated size of the marine halon 1301 bank and the rate of ship breaking. There are two possible reasons for this decrease: either the supply of halon 1301 has been exhausted or the halon is being removed from more ships before they are sent to the breakers' yards. If the latter is the case, then it will be much harder for the FSTOC to monitor and analyse the amount of halon 1301 recovered from the merchant shipping sector.

A new factor that may affect the halon 1301 and 1211 run-out dates is the proposed PFAS regulations. There are many fluorine containing fire suppression agents which may be regulated under the pending PFAS regulations that only have halon as an alternative. Destruction of PFAS fire suppressants in lieu of recovery and re-use or a reluctance to decommission existing halon systems and convert to alternatives that would be considered PFAS may put additional pressure to continue reliance on halons.

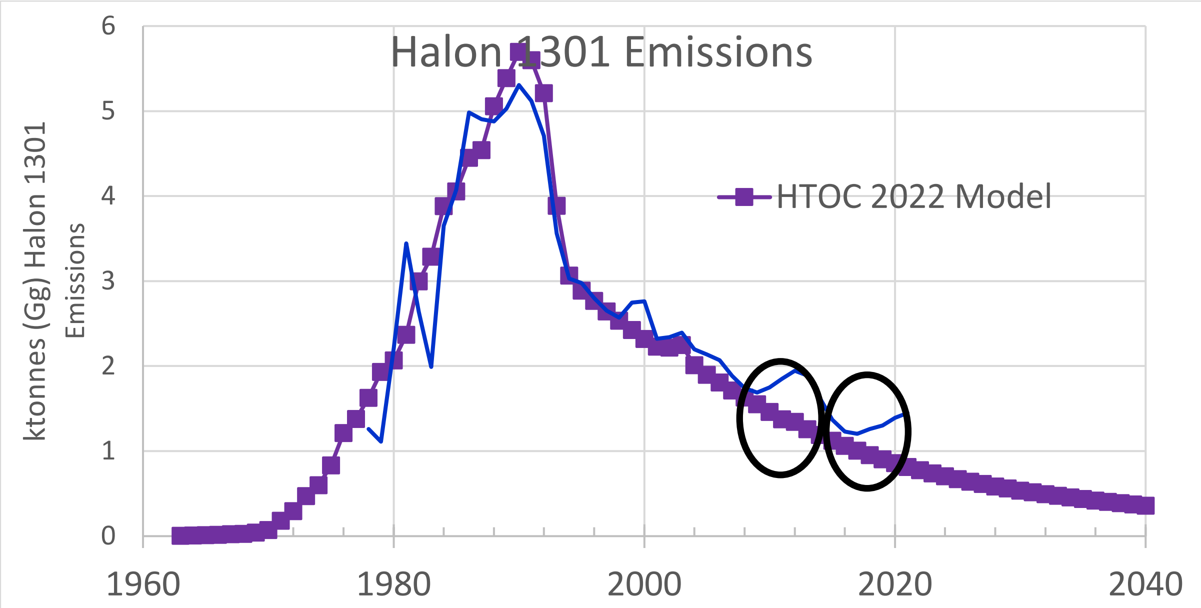
For halon 1301, there is a significant difference between emissions derived from atmospheric measurements versus from the FSTOC model. Atmospheric concentration derived emissions show periods of increasing and then decreasing emissions but they are always greater than the FSTOC model estimates (Fig.3-2). The FSTOC is aware that halon 1301 is being used as a feedstock for the manufacture of the insecticide fipronil and other chemicals. FSTOC is seeking additional information on quantities produced and the likely emissions from its production as well as its use as a process agent. Parties may wish to consider providing this information to the FSTOC for use in modelling. The parties may also wish to consider requesting the Scientific Assessment Panel (SAP) to analyse and provide yearly regionalized halon 1301, 1211, and 2402 data to better understand where global emissions are coming from and to understand the differences between emissions derived from atmospheric measurements versus those from the FSTOC model.

Emissions from civil aviation during maintenance, repair, and overhaul (MRO) activities are a key driver affecting the run-out date. The FSTOC has started gathering halon emissions data from MRO operators and continues to liaise with International Civil Aviation Organisation (ICAO). Parties may wish to consider disseminating the halon management guidance document developed by the Halon Alternatives Research Corporation (HARC) to all National Ozone Units (NOUs).

Parties may wish to consider requesting ICAO provide the following: an analysis of how these proposed PFAS regulations will affect civil aviation's ability to meet halon phase-out requirements for new aircraft as required by current ICAO regulations, an analysis of the potential impacts to continued halon use and emissions and impacts to the run-out dates for halons 1211 and 1301 from their member states based on implementation of the proposed OECD definition in regulations.

[6] In 2021 Bangladesh was responsible for approximately 33% of the number of ships broken globally, but 50% of the gross tonnage, since the shipyards in Bangladesh specialize in larger ships.

Figure 3-2. Halon 1301 Emissions: FSTOC Model vs. Emissions Derived from Atmospheric Measurements



3.2 Halon 1211

Halon 1211 emissions derived from atmospheric concentrations are equal to or greater than the total reported production plus estimates from production emissions. This suggests that the global bank of available halon 1211 may have diminished at a faster pace than previously estimated and/or that production emissions are greater than currently estimated. The FSTOC is not aware of any reports of national or regional shortages currently.

4 Methyl Bromide TOC (MBTOC) Progress Report

Given the recent publication of the MBTOC 2022 Assessment Report in January 2023, (MBTOC, 2023), this progress report focuses on very recent developments only.

4.1 Update since the 2022 Assessment

4.1.1 Rotterdam Convention recommendation on Methyl Bromide

In September 2022, the Chemical Review Committee (CRC-18) of the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, recommended that methyl bromide (MB) be listed in Annex III to the Convention. Annex III includes 52 chemicals, 35 of which are pesticides (the rest are industrial chemicals) that have been banned or severely restricted for health or environmental reasons and which the Conference of the Parties has decided to subject to the PIC procedure. Justification provided by the CRC reads:

"Although under the Montreal Protocol, methyl bromide use was limited to that of quarantine and pre-shipment, the volume of trade in the chemical had raised concerns and there was a need to ensure that methyl bromide was not still being used as a pesticide".

The proposal — promoted by the Netherlands and supported by Colombia and Indonesia — will be considered during the Conference of the Parties in May 2023. If approved, MB will become subject to the PIC procedure, which enables the 165 Parties to the Rotterdam Convention to share responsibility on and take informed decisions on potential future imports. MBTOC will continue to follow-up on this issue and analyses implications for MB use as permitted under the Montreal Protocol (CRC 2022; UNEP/FAO/CRC 2022).

4.1.2 F-gas regulation and Sulfuryl Fluoride

Sulfuryl fluoride (SF), a widely adopted key alternative to MB for treatment of structures and commodities as well as QPS uses has been listed under Annex II of the proposed F-gas regulation of the EU. This regulation mandates recapture whenever feasible and adds to concern expressed by MBTOC in relation to the high GWP of 4630 of SF. If approved, the regulation may further increase the cost of treatment with SF and possibly restrict its use (European Parliament 2023).

4.1.3 Update on registration of alternatives for controlled and exempted uses

Hydrogen cyanide (HCN) is an effective fumigant alternative to MB for a variety of controlled and QPS uses including structures and commodities as well as fresh fruits and vegetables. It is currently registered in the United Kingdom, Malaysia, Morocco and the EU (Austria, Belgium, Croatia, Czech Republic, France, Germany, Italy, Netherlands, New Zealand Portugal, Romania, Slovakia and Spain) and most recently Australia. HCN can be supplied in either cylinders or cans of cardboard impregnated with HCN.

Ethanedinitrile (EDN) continues to be considered for fumigation of timber products including those where MB is used for quarantine applications owing to its greater volatility and penetration capability than MB.

Methyl iodide (MI) was registered in Australia on 12 December 2022 (APVMA 2022) as a pre-plant fumigant for strawberry runner production. However, information submitted by Australia for support of their CUN states that MI only provides the required control of pests and pathogens when formulated and used in combination with chloropicrin and the MI/Pic formulation is not yet registered. The party did not submit a CUN for strawberry runners in 2023 but could submit one in 2024 if the mixture is not registered this year.

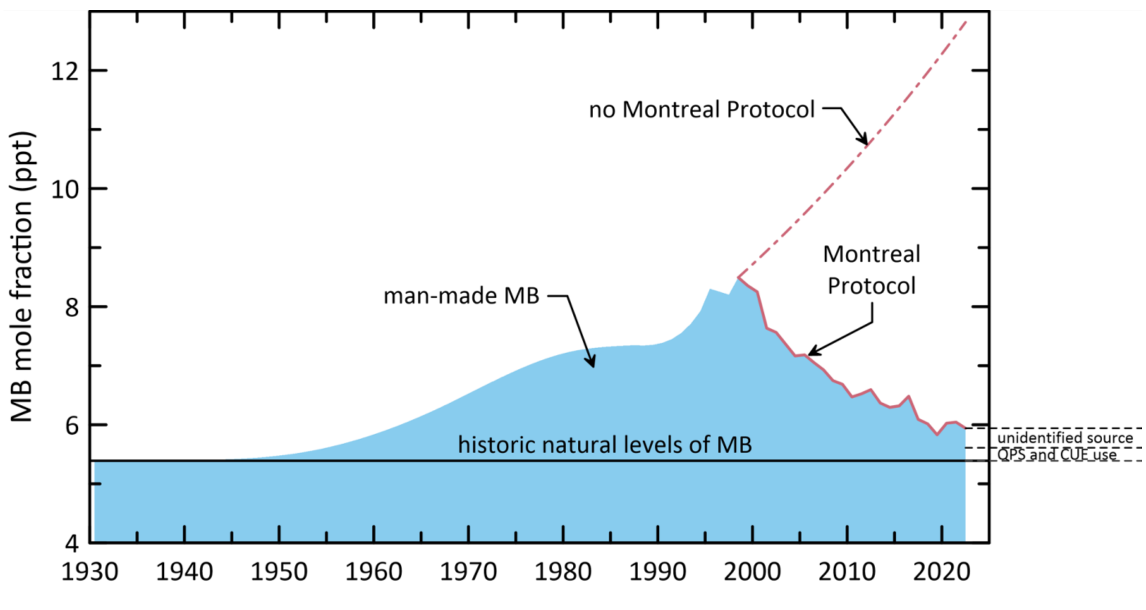
Ethyl formate (EF) is under final review process with the US EPA for registration for use on Chilean grapes imported into the US and citrus exports from that country. EF is accepted as a replacement for MB used as a QPS treatment in these fruits. MBTOC visited the port of Philadelphia in March 2023, where the bulk of Chilean fruit imports enter the USA and learned that EF is the preferred option for fumigation as it is not only considered effective, but reduces concerns related to emissions and associated human health hazards. Registration of this fumigant is expected to occur by June 2023 (Holt Industries, Philadelphia, PA, USA 2023).

4.1.4 Update on the impact of MB use on emissions of methyl bromide

Atmospheric concentrations of MB are no longer falling and appear to have stabilized in the atmosphere above the natural baseline due to continued anthropogenic use, predominantly for QPS uses (Fig 4.1). Significant implementation of emission controls by recapture of MB or adoption of alternatives would lead to further decline in MB concentrations and a benefit to ozone layer recovery.

As MB use under the critical use exemption has fallen to a very low level, the atmospheric concentration should now be influenced entirely by emissions from QPS and other anthropogenic sources as well as the normal natural sources. As has been shown in the 2022 Assessment report the amount of MB for QPS has remained relatively constant recently (since the 2018 Assessment report). This correlates with the MB levels in the southern hemisphere (as measured at Cape Grim) which have been approximately constant at about 6.0 ppt for the past 6 years (2017–2022) and constant globally for the past 4 years (2019–2022) at about 6.5 ppt (Salzman *et al*, 2022). The difference between the southern and global concentration is due to a greater source of anthropogenic MB in the northern hemisphere. The schematic below shows the recent molar concentration of MB in the atmosphere in the southern hemisphere. It also shows the impact of the large reduction of use of MB for CUNs and the remaining impact of QPS use in the atmosphere as measured at Cape Grim, Australia.

Fig 4-1. Impact of MB restrictions in non-QPS uses on MB concentrations in the troposphere of the southern hemisphere since the late-1990s (Red line).



(Source: CSIRO Australia, Fraser, Krummel and Derek, 2023)

4.2 Decision XXXIV/10: Stocks and quarantine and pre-shipment uses of methyl bromide

The MBTOC 2022 Assessment Report (MBTOC, 2023) provided information on MB uses for QPS, a remaining, emissive use which exempted from Montreal Protocol control. Annual consumption of MB for QPS purposes has remained relatively constant over more than 20 years, at around 10,000 tonnes, with phase-out or reductions in some parties offset by increase in others. Currently, seventeen parties use about 94% of the yearly reported QPS consumption and only 55 of 198 parties report use of MB for QPS. Information submitted under Article 7 of the Protocol also shows that in 2021, A5 parties accounted for 57% of global MB consumption for QPS purposes (5,922 tonnes), down from 67% in 2017. Non-A5 party consumption of 4,479 tonnes was 43%, up from 31% in 2017. As stated previously in other reports, MBTOC reiterates that alternatives are available for most pre-shipment uses of MB which, if adopted, could result in replacing 30-40% (i.e., 3,000-4,000 tonnes) of total MB consumption for QPS.

Eliminating emissions from QPS uses is considered the single largest short-term gain that could be made to further reduce Equivalent Effective Stratospheric Chlorine (EESC). An approximate further 10% of the recent possible gain in EESC could be made with a clear benefit to the ozone layer. This is one of the very few measures available to Parties that would result in an immediate gain of this magnitude to a rapid reduction in the stratosphere.

Despite conducting several surveys amongst parties, MBTOC still is notable to clarify what percentages of the QPS consumption category are for quarantine or which are for pre-shipment. Surveys reveal that there is confusion in some parties as to what satisfies the pre-shipment use category, which under the Montreal Protocol comprises officially controlled, endemic or non-quarantine pests. It is possible that some uses have been incorrectly categorized and should fall under controlled uses and thus considered under the Critical Use Exemption process.

4.2.1 Response to Decision XXXIV/10 on QPS uses of MB

Decision XXXIV/10 from the 34th Meeting of the Parties in Montreal 2022 addresses stocks and QPS uses of MB. The Decision reads:

1. To invite parties to submit to the Ozone Secretariat, on a voluntary basis, by 1 June 2023, a list of the pest and commodity combinations in which MB is needed or used in their respective countries;
2. To invite parties to submit, on a voluntary basis, accessible data on the volumes of pre-phase-out MB stocks at the country level to the Ozone Secretariat by 1 June 2023;
3. To include the issue of MB stocks in the agenda of the 45th meeting of the OEWG;
4. **To request the TEAP and its MBTOC, in consultation with the secretariat of the IPPC, to provide updated information, as part of its progress report to the OEWG at its 45th meeting, on current QPS uses for which alternatives are available;**
5. To invite parties to take into account the standards and guidelines under the IPPC in their national processes and to consider the potential for uptake of practices to minimize the use of MB.

MBTOC provides its response to paragraph 4 of the Decision in this section.

At the time of finalising this report, only one party had submitted data to MBTOC in time for consideration during the preparation of MBTOC's response to Decision XXXIV/11. This same data had been previously provided to MBTOC and, together with information received earlier from other parties during preparation of the MBTOC 2022 Assessment Report (MBTOC 2023), was used to assist discussion when preparing this current report. One additional response was received from another party at the time of posting the TEAP Progress Report. As the Decision did not require parties to submit data until June 2023, MBTOC is unable to provide further information about the specific use of MB in QPS sectors at this time but has utilised the major categories and pests shown in recent surveys and past reports to discuss an update of alternatives.

MBTOC notes that despite the significant increase and expansion of international trade in agricultural products that may partially also be subject of MB-use for QPS-measures, the reported amounts of MB-use for this purpose remained relatively stable over the past years. This may be explained by increased adoption of MB alternatives for QPS uses.

Past surveys, similar to that requested under the present Decision, have shown that uncertainty remains with the correct interpretation of the QPS definitions. From responses received when preparing the 2022 Assessment Report (MBTOC 2023), it appears that some uses classified by parties as QPS do not fit within the definitions of the Montreal Protocol. To assist parties in clarifying what falls within or outside the QPS definitions under the Protocol, MBTOC thus provides Table 4.1. This is important as those uses of MB that do not fall within the definitions, should be using or seeking alternatives and, if these are unavailable, then parties would need to seek applications for use of MB under the 'Critical Use Exemption' provision of the Montreal Protocol. A list of alternatives suitable for these purposes and QPS uses has been updated below. MBTOC considers many of these alternatives are suitable and, in many cases, available in particular for replacing current pre-shipment uses of MB.

Parties may wish to request TEAP to develop a proforma/checklist for determining if each use satisfies criteria to be classified as a quarantine or pre-shipment use under the Montreal Protocol. A flow chart to assist this decision, including definitions, was first presented in the MBTOC 1998 Assessment Report (MBTOC 1999) and has been used in several instances since then; a simplified version is included in this report (see Fig 4.1)

4.2.2 Alignment of definitions of quarantine from the Montreal Protocol and the IPPC

The definition of plant quarantine pests under the Montreal Protocol aligns with that of the IPPC, but the IPPC does not have a definition for the pre-shipment pest; this category is unique to the MP. After Montreal Protocol definitions had been set, IPCC added a category to cover pests of seed and planting material under a category designated as regulated non-quarantine pests**.** This refers to *"…a non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party."*

MP definitions are also broader than those of the IPPC. They include human health and wider environmental considerations, for example, the of diseases from rodents found on ships, aircraft and other vehicles; the control of insects (e.g. mosquitoes) and specific microorganisms which are harmful to humans (MBTOC 2019, TEAP 2021; 2022).

4.2.3 Clarification of definitions

Decision VI/1of the MP defines the terms 'quarantine' and 'pre-shipment' and the controls agreed under Article 2H of the Protocol. These same terms are further defined under Decision VII/5, which reads, in part:

1. *"Quarantine applications"*, with respect to methyl bromide, are treatments to prevent the introduction, establishment and/or spread of quarantine pests (including diseases), or to ensure their official control, where:

    1. *Official control* is that performed by, or authorized by, a national plant, animal or environmental protection or health authority;

2. *Quarantine pests* are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled;

2. *"Pre-shipment applications"* are those treatments applied directly preceding and in relation to export, to meet the phytosanitary or sanitary requirements of the importing country or **existing** phytosanitary or sanitary requirements of the exporting country;

In applying these definitions, parties are urged to refrain from use of methyl bromide and to use non-ozone-depleting technologies wherever possible. Where MB is used, parties are urged to minimize emissions and use of methyl bromide through containment and recovery and recycling methodologies to the extent possible.

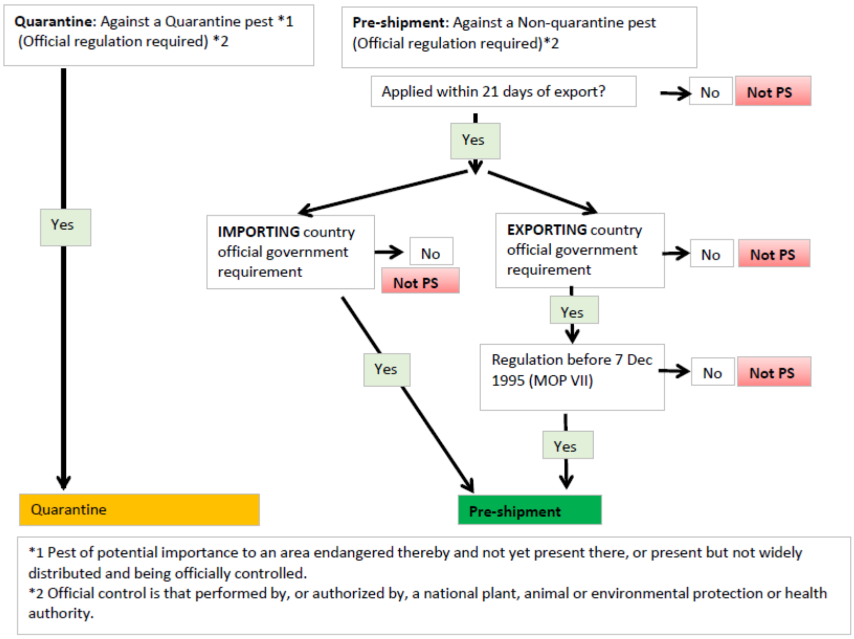
The scope of the QPS exemption in the Montreal Protocol set out in Article 2H paragraph 6, was clarified in Decisions VI/11, VII/5 and XI/12. MBTOC (1999) provided some discussion and examples of cases that might or might not fall within the QPS exemption. Thorough discussion on the scope of the exemption for QPS uses of MB under the Protocol is also provided in MBTOC reports (MBTOC 1999) and the UNEP/IPPC (2008) publication 'Methyl Bromide: Quarantine and Pre-shipment Uses'. UNEP (2016) further provides clear information on QPS uses of MB.

Differences in interpretation of the scope and application of the QPS exemption by individual parties have led to variations in the official report of such uses under Article 7. In some cases, it appears MB is used to control endemic pests, which are not under any form of official control, and thus should not be classified as QPS uses; these would need to be replaced by alternatives or to be considered under the Critical Use Exemption of the Protocol. In addition, the term "pre-shipment" causes confusion when the treatment is aimed at controlling a quarantine pest, but is applied within 21 days prior to shipment and is wrongly classified as PS. Pre-shipment applications, although also aimed against endemic pests, are allowed only where official control requirements are documented. The level of control required for endemic pests is less stringent than for quarantine pests, and a much broader range of alternatives is available for these pre-shipment applications (see section 4.9.1). Parties may thus want to consider separating pre-shipment applications out of the QPS exempted use category.

4.2.4 Quarantine or pre-shipment?

To assist Parties in a consistent application of these terms, MBTOC provides an updated flow chart previously produced for decision makers.

Fig 4-1. Flow diagram for determination of whether MB treatment meets the QPS criteria



Note: Official regulation required for quarantine pests applies to local, imported or export goods.

In addition, the following table (Table 4-1) provides examples for the three categories - Q, PS and non-PS to assist parties with clarification of these definitions. Use of this table will help identify which treatments fall within the definitions of the Protocol and which do not, and thus clarify where alternative treatments need to be sought or implemented.

Table 4-1. Example Situations of MB Classification under Quarantine, Pre-shipment on non-PS (see further MBTOC 1998 Assessment Report)

Commodity Traded		Q or non-Q Pest	Treatment prior to Export or in Import
	A. Examples which justify Quarantine Use		
1	Packed commodities (e.g. Rice, spices and wooden crates)	Quarantine pest: e.g. khapra beetle	Could be treated prior to export (e.g. Australia) or on interception on import (e.g. Japan)
2	Oak logs	Quarantine pest - Oak wilt fungus	Treated prior to export (e.g. USA to Europe)
4	Rice or Oranges	Restricted location of Quarantine pest, khapra beetle or * Fruit fly (e.g. *Ceratitis capitata*)	Precautionary treatment of product going from one region to another within a country (e.g. One state to another in Australia subject of official control)
5	Houses and other structures	Localized Quarantine Pest - Dry wood termite	Subject to official control
	B. Examples which justify Pre-shipment treatment (within 21 days prior to export)		

Commodity Traded		Q or non-Q Pest	Treatment prior to Export or in Import
1	Wheat, grain	Cosmopolitan Non quarantine grain pests	Export **to** a country with an official government regulation (e.g.to Kenya)
2	Wheat grain	Cosmopolitan Non quarantine grain pests	Export **from** a country with an official government regulation. (The regulation must be in place prior to Dec 1994 for non A5 and prior to Dec 1995 for A5 countries
3	Empty ship holds	After interception of cosmopolitan grain pests by inspection authorities (e.g. Canada, USA)	Must have an official government regulation prior to Dec 1994 for non A5 and prior to Dec 1995 for A5 countries
4	Milled rice in bags, in transit fumigation of freight containers at the rice mill Loaded on a train and subsequently exported by ship	Cosmopolitan pests	Must have an official government regulation prior to Dec 1994 for non A5 and prior to Dec 1995 for A5 countries
5	Treatment of land prior to nursery product being moved to another region	No quarantine pest, but may have regulated non quarantine pests.	May satisfy quarantine if party accepts and has known Regulated Non quarantine Pests
C. Examples which DO NOT justify Quarantine or Pre-shipment			
1	Cocoa beans	No pests nominated, no official document provided	
2	Pre-plant soil fumigation in nurseries to produce plants used within the same State or moved to another State	No quarantine pest, but may have regulated non quarantine pests as defined by the IPPC*.	Does not satisfy pre-shipment

* Regulated non quarantine pests only applies to planting material or seeds (IPPC 2016, Picard *et. al,* 2019)

4.2.5 Key sectors for QPS Use

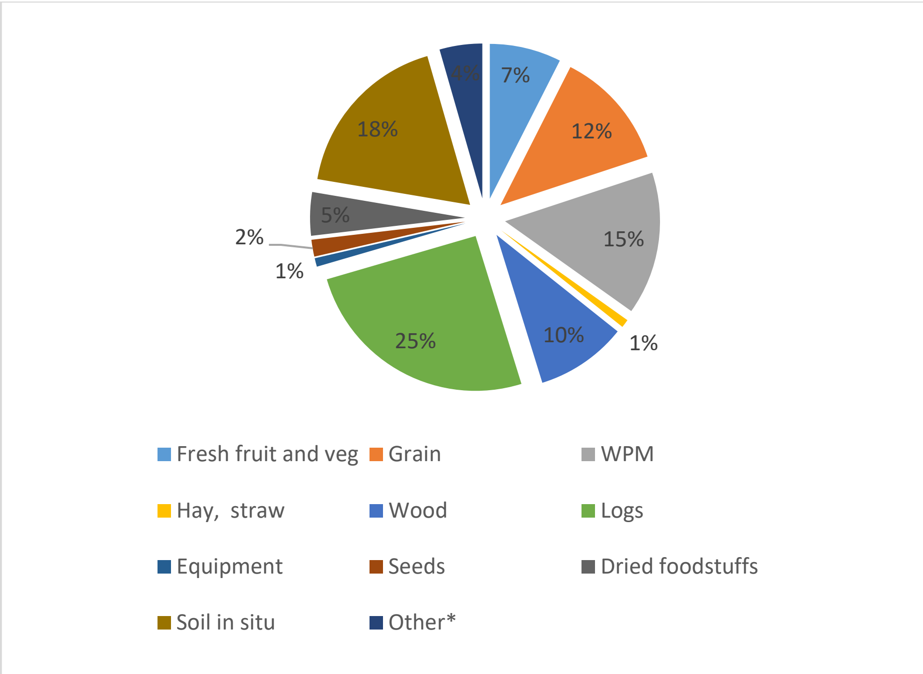
Key categories for QPS use have been determined from surveys conducted by MBTOC and presented in past reports (TEAP 2009, 2012; MBTOC 2011, 2015, 2019, 2023) based on responses received from a good representation of parties. MBTOC has also reported in the past that it has encountered very few regulations that require or specify treatments with MB exclusively, however MB use does tend to concentrate on some sectors, such as the log trade.

Analyses of data reported from past surveys and the single reply received in response to the current Decision confirm that the five largest categories of MB use for QPS are:

1. Sawn timber and wood packaging material (ISPM-15)
2. Grains and similar foodstuffs
3. Pre-plant soils use
4. Logs
5. Fresh fruit and vegetables

The most recent survey conducted for the MBTOC 2022 Assessment Report (MBTOC 2023) showed that these continue to be the primary categories of QPS use; use for wood packaging materials (ISPM-15) seems to have decreased when compared to previous surveys (as conducted for earlier MBTOC Assessment Reports). This could however be influenced by the range of countries responding the survey on each occasion. It was noted that several countries indicated not having the information on categories of use available, and/or lacking the resources to gather it. Clearly, more detailed information on actual categories of MB use for QPS purposes and whether these are intended for quarantine or pre-shipment is needed, in order to allow fora more relevant analysis of feasible alternatives in the future.

Fig. 4-2. Estimated Global categories of MB use (QPS purposes) in 2021



Source: MBTOC surveys 2018 and 2022 for MBTOC Assessment Reports

Table 4-2 provides more detailed information on products and commodities which these categories of use comprise.

Table 4-2. Main categories of MB use for QPS purposes

Category	Uses
Commodities	Bulbs, corms, tubers and rhizomes (intended for planting)
	Cut flowers and branches (including foliage)
	Fresh fruit and vegetables
	Grain, cereals and oil seeds for consumption including rice (not intended for planting)
	Dried foodstuffs (including herbs, dried fruit, coffee, cocoa)
	Nursery stock (plants intended for planting other than seed), and associated soil and other growing media
	Seeds (intended for planting)
	Soil and other growing media as a commodity, including soil exports and soil associated with living material such as nursery stock*

Category	Uses
	Wood packaging materials
	Wood (including sawn wood and wood chips)
	Whole logs (with or without bark)
	Hay, straw, thatch grass, dried animal fodder (other than grains and cereals listed above)
	Cotton and other fibre crops and products
	Tree nuts (e.g. almonds, walnuts, hazelnuts)
Structures and equipment	Buildings with quarantine pests (including elevators, dwellings, factories, storage facilities)
	Equipment (including used machinery and vehicles) and empty shipping containers and reused packaging
Soil as agricultural land*	Pre-plant and disinfestation fumigation of agricultural land*
Miscellaneous small volume uses	Personal effects, furniture, air* and watercraft*, artifacts, hides, fur and skins

Source: IPPC (2008) list of categories; *Not on IPPC (2008) list

4.2.6 Key quarantine pests controlled with methyl bromide for Quarantine treatments

As past surveys conducted to assist preparation of MBTOC Assessment Reports only provided data on categories of use and not pests, MBTOC is not able to categorize the amount of MB used against particular pests. The 2022 Assessment Report (MBTOC 2023) gives a long list of examples of quarantine pests, however the key use of MB can be narrowed down to a smaller list of major quarantine pests of concern as shown below (Table 4-3). MBTOC considers it unnecessary to list specific pre-shipment pests treated with MB, since as stated previously they are common or endemic and more easily controlled with alternatives.

Table 4-3 shows the main target pests of quarantine significance in the major categories of MB use for QPS purposes together with key alternatives to MB developed in consultation with the IPPC's Technical Panel for Phytosanitary Treatments (TPPT).

Even though some major Q pests are common across many countries as stated above (e.g., Khapra Beetle affecting grain), target pests for Q treatments can vary from one country to another even for the same commodity and procedures for defining the target pests may also differ. For quarantine treatments, the National Plant Protection Organisations (NPPOs) of particular countries publish master lists of recognised quarantine pest species, which can be found on the IPPC portal. MB is the treatment of choice or exclusive approved treatment only in some cases.

Table 4-3. Main target pests of plant quarantine significance in the major categories of MB use for QPS purposes

Commodity or Situation	List of key Quarantine pests	Key Alternatives to MB
Whole logs, not debarked	Various species of bark beetles, wood borers, *Sirex* spp., pinewood nematodes, fungi (oak wilt **(***Bretziella fagacearum***)**, *Ceratocystis ulmi*).	Heat treatment, ethanedinitrile (EDN), irradiation, methyl iodide, removal of bark, phosphine, sulfuryl fluoride
Solid wood packaging materials	Various species of bark beetles, wood borers, *Sirex* spp., pinewood nematodes (*Bursaphelenchus xylophilus*).	Heat treatments and Sulfuryl fluoride (SF) EDN not ISPM 15 approved),
Grain and similar foodstuffs	*Trogoderma* spp., particularly *T. granarium*; *Prostephanus truncatus*; *Sitophilus granarius*; cotton boll worm, various snails.	Seed weevils on beans (*Phaseolus vulgaris*) ("smaller use")→ irradiation *Trogoderma granarium* on grains→ phosphine
Fresh fruit and vegetables	Numerous species of Tephritidae (fruit flies), thrips, aphids, scale insects and other sucking bugs, various Lepidoptera and Coleoptera, various mites, spiders.	*Brevipalpus chilensis* – grapes → irradiation Various pests on asparagus (Family Noctuidae)→irradiation *Anastrephaludens* on citrus ("smaller use")→irradiation, heat, cold treatments *Drosophila suzukii* on cherries and grapes →irradiation [possible cold treatments] Glassy-winged sharpshooter on grapes →irradiation, potential cold treatment, other fumigants Fruit flies on citrus → cold treatments Fruit flies on blueberries → cold treatments, irradiation
Cut flowers	Large number of pests	Possible irradiation, cold treatment or systems approach
Soil for crop production, including propagation material	Official control - Potato Cyst Nematodes (*Globodera pallida)* Golden nematode (*Globodera rostochiensis),Orobanche* spp. In USA only QPS covers production of some nursery materials.	Fumigants (methyl iodide, dazomet, 1,3 -dichloropropene, metham sodium,)
Wood packaging material, containers		Brown marmorated stink bug → Sulfuryl fluoride (SF), heat treatments, other fumigants
Bamboo, cane (grass, especially *Arundinaria* spp.)	Borers, Bostrichidae	Bamboo borers → heat treatments, SF, other fumigants Bostrichidae→ heat treatments, SF, other fumigants

In addition, there are key quarantine pests that are sometimes controlled in international trade with MB that lie outside the scope of the IPPC, but are relevant to the MP including various mosquito species (human and animal disease vectors, nuisance species), tramp ant species including the red imported fire ant (*Solenopsis invicta*) (animal and ecological health, invasive species), rodents (disease vectors, stored product pest), snakes (invasive species), and cockroaches (human health disease vectors).

4.2.7 Alternatives available in IPPC international agreements (standards)

International Standards for Phytosanitary Measures (ISPMs) issued by the IPPC, relate directly or indirectly to phytosanitary (quarantine) uses of MB and often refer to alternatives for full replacement of MB. These standards are regularly being reviewed and updated with new alternatives. Some recent key changes include:

- ISPM No. 15 (last revision 2021) Treatment of Wood Packaging Materials
- ISPM No. 18 (last revision 2023) Guidelines for the use of irradiation as a phytosanitary measure
- ISPM No. 28 (last revision 2023) Phytosanitary treatments for regulated pests. See Annex 2 at the end of this report
- ISPM No. 29 (last revision 2021) Recognition of pest free areas and areas of low pest prevalence
- ISPM No. 35 (last revision 2021) Systems approach for pest risk management of fruit flies
- ISPM No. 39 (last revision 2021) International movement of wood
- ISPM No 44 (2022) Requirements for the use of modified atmosphere treatments as phytosanitary measures

For a full list of ISPMs and pertinent revisions please visit https://www.ippc.int/en/core-activities/standards-setting/ispms/

The main ISPM that specifically deals with a major volume use of MB is ISPM 15. The standard deals with the disinfestation of wood packaging material (WPM) in international trade as a quarantine measure against various pests of wood and forests and contains specifications for heat treatment, MB fumigation (recognizing MB as an ODS) and more recently use of sulfuryl fluoride (GWP).

The MBTOC 2022 Assessment Report (MBTOC 2023) includes updated and thorough information on research and adoption of alternatives to MB for QPS uses. MBTOC thus focuses here on more recent or additional developments that it considers pertinent to Decision XXXIV/10.

4.2.8 QPS alternatives for wood packaging materials, wood, logs and timber

Logs, timber and wooden materials (e.g., sawn timber, wooden packaging materials) are notorious for their ability to carry a variety of pests of quarantine significance. Some of these pests potentially attack forests and amenity trees (urban standing timber), while others can attack timber in furniture, buildings and other structures.

This is a large category of MB use being approximately 50% of total Q and PS use, targeted at a wide variety of pests and diseases for which nevertheless a good range of alternatives exist and are now in use around the world (Table 4-4). In particular, targets of MB fumigation may be insects that infest green and dry wood, nematodes (particularly pinewood nematode, *Bursaphelenchus xylophilus*) and some fungal pests of wood, notably oak wilt fungus (*Ceratocystis fagacearum*). Fumigation with MB may also be directed at hitchhiker pests of quarantine significance, including pest insects and snails.

Log trade has increased substantially in recent years. As logs are a high volume, comparatively low value and are shipped long distances, the trade is very price sensitive to changes in freight costs, exchange rates and treatment costs. What may be an economic treatment for fruit may not be economic for logs. Non fumigant methods such as heat, microwaves and irradiation are normally cost prohibitive for logs, but heat is used for WPM.

Table 4-4. Alternatives to MB for wood packaging materials, logs and timber

Category of use	Alternative treatments
Wood packaging materials	Heat treatment, SF (contained in Annex 1 of ISPM 15 (2018)), EDN (not yet approved for ISPM 15).
Wood (including round wood, sawn wood, wood chips)	Heat treatment, kiln-drying, removal of bark, microwave, irradiation, MI, chemical impregnation or Immersion (not wood chips), phosphine, SF, EDN
Whole logs (with or without bark)	Heat treatment, EDN, irradiation, MI, removal of bark, phosphine, SF

A short update on alternative in use and new developments in these categories of MB use follows.

China has approved a specific treatment schedule for SF on logs for fumigation in Germany and other countries prior to export.

Heat in the form of vacuum steam and Joule heating (Heffernan et al 2018) have been trialled successfully and await commercial development. Phosphine in transit on those parts of the shipment carried under deck is the only commercially used alternative currently for under bark pests.

Ethanedinitrile (EDN) is accepted by Malaysia and used by Czechoslovakia, Russia and South Korea. It is also registered in Australia and New Zealand for use on logs and timber. Active research is undergoing on this fumigant for controlling pinewood nematodes (Arbuzova *et al* 2020; Cermak *et* al 2016; Hall et al 2023; Hall and Adlam 2023). If registrations and trade approval were in place around the world, it could potentially replace 100% of current MB used for treating whole logs although sometimes economic feasibility can be a concern. Annex 1 at the end of this report contains a list of pests that have been successfully controlled with EDN. Additional information on pests and alternatives for these MB uses can be found in the MBTOC 2022 Assessment Report (MBTOC 2023).

New Zealand has pioneered the use of phosphine for the in-transit fumigation of forest produce destined for China, but this fumigant currently can only be used for the logs shipped below deck in the holds, approximately two thirds of a shipment. It is now in routine use as a QPS measure, replacing MB use including logs exported from Uruguay. A main disadvantage of phosphine is the long exposure time required (10 days), but this can be overcome by fumigating in transit. Considerable efficacy data has been developed for phosphine (Oogita 1997; Pant 2012), however it is not yet available for the wood wasp, *Sirex noctilio,* a quarantine pest of concern for India.

Japan is imposing a requirement for all shipments of logs with bark; these will need to be accompanied by a phytosanitary certificate effective as of August 5, 2023. To avoid any trade disruption, the Canadian Food Inspection Agency (CFIA) will inspect export shipments of bark on logs destined to Japan and issue phytosanitary certificates for these consignments starting May 15th, 2023, at the request of exporters. A phytosanitary certificate will not be required for sawn wood (lumber) and de-barked logs (CFIA 2023).

The Canadian Visual Inspection Program (CVIP) for the export of logs to Japan is an alternative certification method. The program is based on the CFIA's *Integrated Agency Inspection Model*, which relies on a systems based approach to meet certification requirements. The program will be available in British Columbia prior to Japan's effective date as trade data shows that almost all logs exported to Japan originate from BC. As a condition of the CVIP, applicants are required to develop, implement, and maintain a preventive control plan. The plan must outline the control measures to comply with the export phytosanitary requirements (Canadian Food Inspection Agency (CFIA) notification 2023).

The requirement for mortality data showing a high level of effectiveness for wide range of pests is a major barrier to development and approval of additional alternative treatments for ISPM 15. Details of current requirements for submission of potential alternatives are given in ISPM 28. Criteria for future ISPM 15 treatment submissions are being considered by the TPPT and a draft has been published (IPPC 2023).

Hungary researched hydrogen cyanide (HCN) for the control of wood boring insects. There was collaboration between Hungary and a company in the Czech Republic that was the owner of the HCN formulation. There was interest in obtaining IPPC accreditation for the use of HCN, perhaps as one of the alternatives listed under ISPM 15 (Draslovka pers. comm.).

Some NPPOs recognise other treatments for wood packaging materials and similar products where ISPM is not applied. These treatments may be post entry or prior to export. Australia, for instance, accepts off-shore treatments of timber packaging and dunnage not treated in accordance with ISPM 15 must be applied at specified dosages of several alternatives, including fumigation with ethylene oxide, gamma irradiation or some timber preservatives (BICON 2023).

In addition, not-in-kind alternatives exist for wood pallets and other wooden packaging materials. These avoid the need for MB fumigation or heat treatment. Plastic pallets (often made from recycled plastic and reusable) are commercially available and are used by many companies in the EC, the US and many other regions of the world.

4.2.9 Alternatives for grain

4.2.9.1 Export cereal grains – Pre-shipment treatments

This section covers treatment of export cereal grains (e.g., wheat, rice) within 21 days of export against insect infestation (non-Quarantine) to meet official regulations of either the exporting country or the official requirements of the importing country or both as required under Decisions VI/1 and VII/5.

In the grain trade, official control is typically attested with an official phytosanitary certificate endorsed with 'sensibly free of injurious pests' or similar wording. It may also include treatment details if requested officially by the importing country.

Methyl bromide fumigation continues to be used as a Pre-shipment treatment in many grain-exporting countries in several specific situations for example:

- Where the importing country officially specifies the grain be MB fumigated and no alternatives are permitted.
- Where the importing country officially specifies treatment with MB or one or more alternatives (and MB is the preferred/ most appropriate option).
- Where the exporting country needs to provide a rapid means of disinfesting part or all of a grain cargo at port to meet its own export grain 'insect-free' quality regulations.

In-transit fumigations of containers and vessels with MB are no longer permitted under International Maritime Organisation (IMO) regulations. (IMO Circular MSC 1/Circ.1264) These treatments have been replaced by in-transit phosphine fumigation. There are suggestions known to MBTOC that MB may be used on grain on arrival in some countries against non-quarantine pests where such pests are detected or there is a risk they may be present, but these are not part of the present discussion. (Banks, personal communication)

Details of individual treatments, accepted or under development for disinfestation of stored bulk and bagged stored cereal grains can be found in MBTOC Assessment Reports (MBTOC 2023; 2015 and previous; TEAP 2009). MB fumigation may be used or preferred as cited in the previous section, however options are available to either minimize use or adopt alternatives.

Where the importing country officially specifies the grain be MB fumigated and no alternatives are permitted, there is still scope for ensuring MB use is minimised, unnecessary double treatments are avoided and recapture is used with best practice to mitigate MB emissions.

Where the importing country officially specifies MB treatment or one or more alternatives and MB is the most appropriate phosphine is typically given as an alternative. The exporting country, given this choice, typically chooses to fumigate with phosphine either at the port or up-country where space is less limited and there is time to carry out phosphine treatment with extended exposure times, the most effective system of phosphine use. MB, though more expensive, may be used where insect infestation is detected in grain at port and there is insufficient time or facilities to fumigate with phosphine.

Where control measures are unspecified and with appropriate registrations, procedures and bilateral agreement, SF fumigation is an alternative, with time taken to complete a treatment similar to MB. It also is effective against phosphine-resistant pests.

HCN and ethyl formate (EF) are also promising rapid-acting alternatives currently under discussion and development. EF appears promising as a rapid disinfectant for containerised export grain, where the exporting country needs to provide a rapid means of disinfesting part or all of a grain cargo at port to meet its own export grain 'insect-free' quality regulations.

In countries where export grain is stored above at 15°C and thus subject to infestation, at least one 'kill step' is incorporated after harvest with possibly a retreatment during the storage period, 'Insect-free' grain is then taken to port for export in large bulks. Some grains, e.g. milled (white) rice, may be containerised. Both bulk and containerised grain can be fumigated, usually with phosphine, and inspected before export. After effective phosphine treatment, the grain is typically to a standard where insect infestation is not found at export on inspection. In cases where insects are detected in a consignment, suspect lots may be treated with MB or other rapid acting fumigant. At this time, SF is the only available (registered, with trained workforce) fumigant replacing MB. Phosphine fumigation is not normally used because of space limitations and its slower action.

Controlled or modified atmosphere treatments - increased CO_2 or reduced O_2 , sometimes in combination with heat or cold to create an environment that is lethal to pests – are increasingly used around the world to clean grain. Vietnam for example, accepts controlled atmospheres as a QPS treatment for rice and coffee (Bergweff, pers. comm. 2023).

Canada has approved a policy "Ship Inspection Not Approved for Loading" indicating that the sanitary conditions of the holds listed do not meet the minimum standards to load grain. Corrective actions are then required (treatment, cleaning, scaling and/or drying) in the specified holds prior to re-inspection. The choice of the fumigant or spray must be determined by the licensed Pest Control Operator (PCO) and if done directly by the sipping company, will be verified by official inspectors. MB is only allowed where a quarantine pest occurs. The ship inspection policy can be found at PI-008: Inspecting Ships that Carry Grain and Grain Products for Export (CFIA 2023)

In summary, there are systems available now that can technically replace MB use for Pre-shipment of cereal grains. Trades usually require agreement of what treatments are acceptable. Negotiation of any change is likely to be a slow process.

4.2.9.2 Alternatives to MB for Quarantine treatment of export grains

Khapra beetle (*Trogoderma graniarum)* is the main quarantine pest affecting grain and the cause of major use of MB for QPS. It is carried out by 'khapra-free' countries with the aim if of preventing entry of this high risk pest in their national territories. Individual country NPPOs maintain lists of countries they recognise where khapra is endemic or, in their opinion, established and from where exports liable to carry khapra originate. Good examples are the "List of target-risk countries for host of Khapra beetle" (DAFF Australia 2021) and the CABI datasheet "*Trogoderma* granarium (Athanassiou 2022), which give a distribution maps for khapra and other useful information including treatment options. Dispersal, hosts, diagnosis, biology and others. Various NPPOs have their own lists which may be more extensive. Khapra is notably absent from North, Central and South America, most of Southern Africa south of the Sahara and Australia, Korea and Japan, and much or all of China.

Shipping containers may be chronically infested. Khapra has an unusual biology. The larvae can enter a resting stage when encountering adverse environmental conditions, lack of food or overcrowding, sometimes known as 'diapause'. Diapause larvae seek out crevices and other harbourage and may live for many years without food, resuming development and reproduction when conditions become favourable. Detection of khapra in a load in a shipping container at point of import does not necessarily reflect country of origin of the infestation.

Khapra beetle is known to infest a wide range of dry foodstuffs and similar commodities, notably milled and paddy rice, various pulses, and straw including some un-threshed grain.

MB is a mandatory fumigation for treatment of export dry foodstuffs and similar commodities from khapra countries. This is despite its comparatively poor effectiveness against active and diapause larvae, the most common stages typically encountered. High dosages of MB and unusually long exposure periods are required for full effectiveness (e.g. 80 g/m^3 for 48 h at 21 C).

Research on alternatives is undergoing, for example heat (Wilches *et al.,* 2019) or controlled atmospheres with low oxygen + CO_2 (Vassilakos *et al*., 2019). Some alternatives are already in use by NPPOs, for example:

- US has a heat treatment schedule for *T. granarium*
- Australia accepts 60C for 2 h measured at the core of the goods
- Australia has a Quarantine level Controlled Atmosphere (CA) procedure to be applied prior to shipment.
- In Russia, Sanzharova and Loy (2022) assessed the current state of the use of ionizing radiation for insect pests in grain and grain products during storage. Complete kill of khapra beetle larvae was achieved with gamma irradiation at doses of 50-100 Gy after 4 - 5 days, 350 and 450 Gy after 7 days, 100 and 300 Gy after 8 days and at other doses only after 14 - 17 days. Chemical composition of the irradiated grain of wheat and barley did not reveal any negative effect on the quality of the Rima wheat variety or Vladimir variety of barley. This technology can be easily integrated into the technological processes of grain storage and transportation.

However, alternatives are not widely adopted at this time due to reasons such as NPPOs lacking familiarity with alternatives (no training), alternatives often being more expensive than MB add changes in infrastructure required.

4.2.10 Alternatives for fresh fruit and vegetables

Research on alternatives to MB for QPS uses continues to be active around the world as can be seen from examples given in this section. The IPPC has also recently conducted significant revisions of ISPM-28 which are very relevant for treatment of fresh fruit and vegetables for controlling quarantine pests (see Annex 2).

In Japan, Soma *et al.*(2023) conducted a series of mortality tests to establish MI phytosanitary fumigation standards against the peach fruit moth, *Carposina sasakii* infesting apple. Aged instar larvae which are most tolerant stage of *Carposina sasakii* to methyl iodide fumigation infesting the 'Fuji' variety packed in export cartons were fumigated at 20 and 23 g/m³ for 2 hours at 15°C with 0.12 t/m³ loading. A total of 37,002 larvae was completely killed in 52 replications. No chemical injury was observed in 6 major varieties. The residual MI in the fruit was less than the quantification limit of 0.01ppm in 3 days after fumigation.

Hot water dips are in use in NZ and USA for asparagus, with excellent results as long as appropriate protocols are followed (i.e., transferring to cold water immediately after heating to avoid cooking). (Mahajan 2018).

HCN is used as a quarantine treatment for imported pineapples in New Zealand (MPI 2023) and the USA. Ethyl formate (EF) +CO_2 is now registered for pineapples as well but not in use yet (Widmer pers. comm.).

For Chilean grapes exported to the US, a "systems approach" where appropriate (depending on origin of grape production) and EF have the potential to replace all MB used for Chilean grapes exported to US (Rodríguez 2022).

E-beam (electron beam) irradiation systems have progressed to the point that their adoption is increasing for phytosanitary uses, often in fresh fruits and vegetables, supported by ample research around the world (MBTOC 2023). For example, the *Australia New Zealand Food Standards Code* allowed irradiation of fruit fly for from July 2021; Thailand uses irradiation for control of *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) and other pests of mango fruits (Srimartpirom *et al.* 2018); in South Korea, gamma-ray irradiation is being trialled for controlling whiteflies *Bemisia tabaci* and *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) on exported strawberry fruit (Cho *et al* 2019).

Verschoor *et al* (2015) have studied the efficacy of controlled atmosphere temperature treatments for control of quarantine pests in fresh plant products in the Netherlands, particularly the strawberry tarsonemid mite (*Phytonemus pallidus*) or plant parasitic nematodes *Meloidogyne hapla* affecting strawberry planting material.

4.2.11 Alternatives for pre-plant soil use

MB is used by one party for pre-plant soil fumigation as a quarantine treatment in the production of nursery materials such as strawberry runners and forest seedlings. Research in this area has been very extensive over the years and continues. All other parties producing similar materials do not consider this use to fall under the QPS exemption and have adopted a series of alternatives including (MBTOC 2023):

- Fumigants such as 1,3-Dichloropropene + chloropicrin (1,3-D/Pic), metham sodium, metham potassium, DMDS (dimethyl disulphide) or methyl iodide (in the case of Australia); EDN currently under research for this use.
- Non-chemical options such as production in soil-less substrates, grafting, biofumigation, anaerobic soil disinfestation
- Combinations of chemical and non-chemical alternatives

4.2.12 Barriers to QPS Alternatives Adoption

MBTOC considered some barriers or limitations that may hamper the adoption of alternatives to MB for QPS uses as follows:

- There is a need for clearer and more specific quarantine level efficacy data. Labels or efficacy requirements generally cite only "control"

- Small volume use of some alternatives impacts their economic feasibility as well as their wider availability and commercial viability
- Some alternatives are not yet registered in different locations and this can be a long, expensive and cumbersome process
- Local consents and trade partner approvals are necessary and are part of bilateral agreements, these can be time consuming
- Consumer resistance/ reluctance to change impacts the rate of adoption of alternatives, may require trials or demonstration ad information exchange to build confidence inn alternatives
- Training on safe handling, management/prevention of residues and others is required

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5 Medical and Chemicals TOC (MCTOC) Progress Report

5.1 Introduction

This report of the Medical and Chemicals Technical Options Committee provides information on: the production and use of controlled substances for chemical feedstock; an update to information on process agent uses; and information on metered dose inhalers to supplement that contained in MCTOC's 2022 Assessment Report; a response to decision XXXIV/5 on the identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options for enhancing such monitoring; a response to decision XXXIV/6 on ongoing emissions of CTC.

5.2 Updates to 2022 Assessment

5.2.1 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 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. Handling ODS and HFC feedstocks in a responsible, environmentally sound manner requires significant investments and effort by industry. Emissions are regulated through pollution control measures. Global emissions from the reported production and use of feedstocks are estimated in the following sections.

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.[7] 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.

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

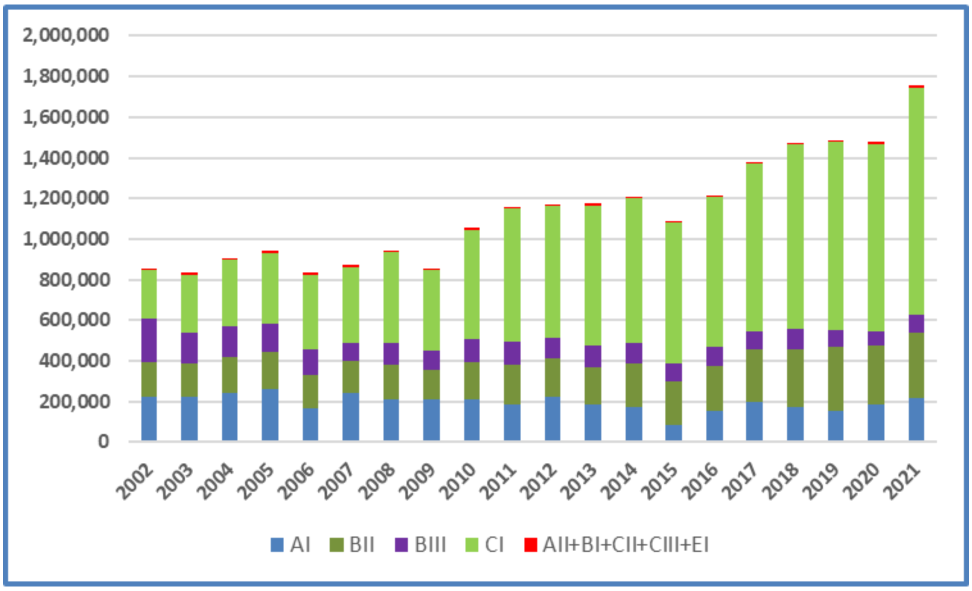
Data reported by parties to the Ozone Secretariat on production and import of controlled ODS used as feedstock for the year 2021 was provided to the MCTOC. These include quantities used as process agents because parties are required to report such consumption in a manner consistent to that for feedstock. In 2021, a total of 15 parties[8] reported feedstock use of ODS, while ten of these parties also produced ODS for feedstock uses. In 2020, a total of 15 parties had reported use of ODS as feedstock.

[7] Montreal Protocol, Article 7, paragraph 3.

[8] This total includes all parties that imported ODS feedstock, one of these parties reported <0.1 tonne. It also includes the EU as an importer, EU Member States report their own production for feedstock use, and in.

In 2021, total ODS production and import reported for feedstock uses was 1,755,171 metric tonnes, a significant increase compared to 2020 (2020: 1,477,644 metric tonnes[9]), and an increase of about 50% over the last decade. Figure 5.1 shows that, comparing 2021 with 2020, the most notable difference is the increase in Annex C1 (HCFCs). The 2021 reported total production and import of ODS for feedstock use in metric tonnes represents 629,732 ODP tonnes.[10] 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 carbon tetrachloride (CTC) feedstock use.

Figure 5-1. Annual reported production of ODS for feedstock and process agent uses, categorised by Montreal Protocol Group, 2002–2021 (metric tonnes)[11]



[9] The 2020 feedstock production was stated as 1,475,007 tonnes in the MCTOC 2022 progress and assessment reports. Any data changes result from data revisions that can occur for historical years.

[10] 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.

[11] 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 5-1. Amount of ODS used as feedstock in 2021

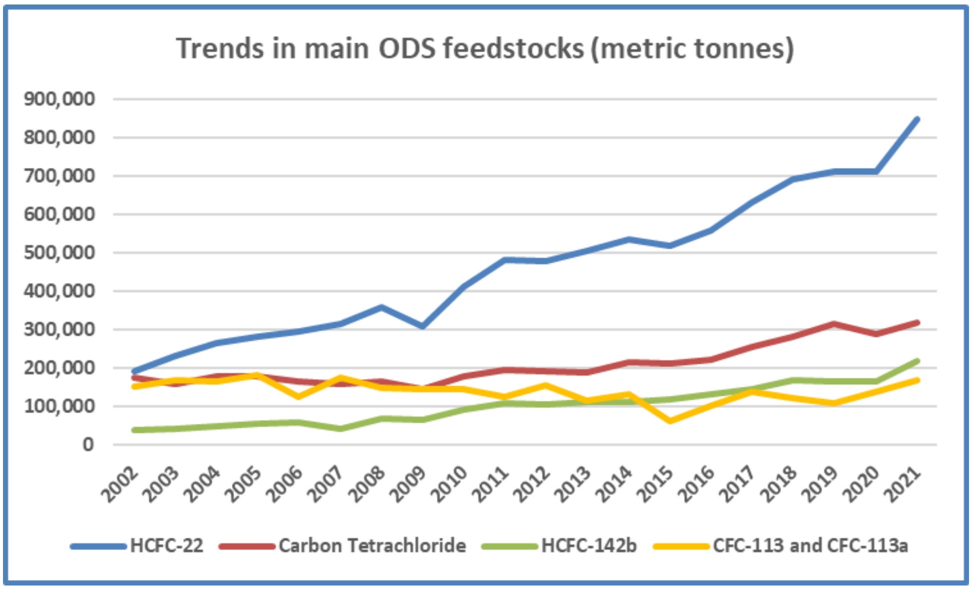
Substance	ODP	Metric Tonnes
HCFC-22	0.055	847,248
Carbon tetrachloride	1.1	319,792
HCFC-142b	0.065	220,212
CFC-113 and CFC-113a	0.8	169,875
1,1,1-trichloroethane (methyl chloroform) Annex BIII	0.1	86,889
Bromochloromethane Annex CIII	0.12	5094
Methyl bromide Annex EI	0.6	3337
CFC-114, HCFC-124, HCFC-141b		10,000 to 100,000
HCFC-123, Halon 1301 (bromotrifluoromethane), HCFC-133a, HCFC-21, HCFC-242		1,000 to 10,000
CFC-12, HCFC-124a, HCFC-133, HCFC-225CA, HCFC-225CB, HCFC-226, HCFC-241, HCFC-243, HCFC-244		10 to 1,000
Other substances		<10
Total Metric Tonnes		1,750,516
(Total ODP tonnes)*		*629,732*

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. CFC-113 and CFC-113a have been grouped together to maintain confidentiality. For those substances that are the only substance in an Annex, the quantity is given, irrespective of the number of parties because this information is published by the Ozone Secretariat in its annual report to the MOP. This applies to 1,1,1-trichloroethane (methyl chloroform), bromochloromethane and methyl bromide. *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 2021 were very similar to 2020: HCFC-22 (48% of the total mass quantity), CTC (18%), and HCFC-142b (13%). HCFC-22 is by a considerable margin the largest feedstock used, with 847,248 metric tonnes reported in 2021, compared to 713,536 metric tonnes in 2020. Several other feedstocks have increased quantities in 2021 compared to 2020, which explains why HCFC-22 percentage share is the same as 2020 (48%). 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. Vinylidene fluoride (VDF, 1,1-difluoroethylene, HFO-1132a) is made from HCFC-142b. VDF is used as a monomer for poly-vinylidene fluoride (PVDF) derived polymers and is also used as a component in refrigerant blends. The feedstock use of CTC[12] has increased in recent years, due to growing demand for lower GWP HCFO/HFOs and perchloroethylene (PCE). The trends in the production for feedstock use for the main ODS feedstocks are shown in Figure 5.2.

[12] More information on CTC production and its uses as feedstock can be found in the 2022 MCTOC Assessment Report.

Figure 5-2. Trends in annual production of the current main ODS feedstocks for the years 2002–2021 (metric tonnes)



5.2.3 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, with that 2019 Article 7 data reported during 2020. The feedstock data reported for 2021 is incomplete due to the timing of reporting obligations, for example, depending on when some parties ratified. The largest reported HFC feedstock is HFC-152a (thousands of tonnes). Other HFCs reported in 2021 in much smaller quantities are HFC-23, HFC-32, HFC-41, HFC-125, HFC-134a, HFC-236ea and HFC-365mfc. The total reported quantities of HFC feedstocks are considerably lower than ODS feedstock.

According to a recent paper[13], the dehydrofluorination of 1,1-difluoroethane (HFC-152a) is the most broadly used chemical process to produce vinyl fluoride (used to produce polyvinylfluoride, a polymer used mainly in low flammability coatings). HFC-152a can also be used as a feedstock to produce vinylidene fluoride (CH_2=CF_2), via photo-chlorination, to obtain HCFC-142b followed by dehydrochlorination.

5.2.4 Process agents

MCTOC reviewed the process agents data for 2021 reported to the Ozone Secretariat under decisions X/14(4) and XXI/3(1) by China, EU, and the USA and reported these in its 2022 Assessment Report. Process agents data for 2021 for Israel was subsequently reported to the Ozone Secretariat, which MCTOC has reviewed for this Progress Report.

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[13] Haodong Tang, Mingming Dang, Yuzhen Li, Lichun Li, Wenfeng Han, Zongjian Liu, Ying Li and Xiaonian Li, Rational design of MgF_2 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

Table 5.2 presents the quantities of make-up or consumption for process agents reported by parties for 2009 to 2021, and Table 5.3 presents the emissions reported by parties for 2009 to 2021. These tables update Tables 3.3 and 3.4 of the 2022 MCTOC Assessment Report for the same periods to include data for Israel for 2021.

MCTOC reported further on process agents in its 2022 Assessment Report.

Table 5-2. Data reported by parties on make-up or consumption associated with process agent uses for 2009–2021

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

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

Party	Reported make-up or consumption (metric tonnes)				
	2017	2018	2019	2020	2021
Brazil	-	-			
China	175.96	176.74	179.8	179.22	179.16
Colombia	-	-			
European Union	324.301	351.675	273.876	292.39	290.712
Israel	0	0	0	5.665	7.12
Mexico	-	-			
United States of America	NR	NR	NR	NR	NR
Nominal Total	500.261*	528.415*	453.676*	477.275*	476.992*

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

Table 5-3. Data reported by parties on emissions associated with process agent uses for 2009–2021

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

*Nominal totals in metric tonnes exclude data reported in ODP-weighted metric tonnes by the United States. Nominal totals exclude data not reported by parties, as indicated by NR.

Party	Reported emissions in metric tonnes *[ODP tonnes given in square brackets]*				
	2017	2018	2019	2020	2021
Brazil	-	-			
China	104.19 *[114.6]*	104.65 *[115.12]*	106.46 *[117.106]*	106.116 *[116.728]*	106.080 *[116.688]*
Colombia					
European Union	4.143 *[4.548]*	2.619 *[2.87]*	3.529 *[3.874]*	3.629 *[3.984]*	2.795 *[3.070]*
Israel	0.0055 *[0.006]*	0.0042965 *[0.0047]*	0	0.09 *[0.099]*	0.0912 *[0.100]*
Mexico					
United States of America	*[24.65]*	*[34.01]*	*[28.79]*	*[25.7]*	*[28.99]*
Total	108.34* *[143.8]*	107.27* *[149.19]*	109.99* *[149.95]*	109.84* *[146.51]*	108.9662* *[148.848]*

* Nominal totals in metric tonnes exclude data reported in ODP-weighted metric tonnes by the United States. Nominal totals exclude data not reported by parties, as indicated by NR.

5.2.5 Laboratory and analytical uses

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

5.2.6 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 reported further on *n*-propyl bromide in its 2022 Assessment Report.

5.2.7 End-of-life management and destruction of controlled substances

In its 2022 Assessment Report, MCTOC reported its response to decision XXX/6 on an assessment of those 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. MCTOC reported further on end-of-life management and destruction in its 2022 Assessment Report, including on the status and effective management of banks of ODS and HFCs, potential financing approaches, and barriers to effective management, such as requirements for the transboundary movement of hazardous wastes.

Decision XXX/15 (5) requests the Technology and Economic Assessment Panel, following the submission of the report called for in decision XXX/6, to provide a review of destruction technologies, if new compelling information becomes available. MCTOC has considered available information on destruction technologies and has not identified any compelling new information to report to parties in this progress report, other than increasing interest in application of already approved destruction technologies at smaller scales, which may facilitate increased destruction of controlled substances closer to source.

5.2.8 Introduction to metered dose inhalers

Pressurised metered dose inhalers (pMDIs), dry powder inhalers (DPIs), aqueous soft mist inhalers (SMIs), and other delivery systems such as nebulisers all play a role in the treatment of asthma and COPD. New propellants for pMDIs are under development as alternatives to high-GWP HFC pMDIs.

MCTOC reported extensively on pMDIs in its 2022 Assessment Report. There is a range of issues and potential challenges that could emerge in the transition away from high-GWP propellant pMDIs to inhalers with lower GWPs, which could create risks to inhaler markets and patient health. These include the current lack of global and national frameworks that address transition challenges; continuity in, and stability of, the supply of pharmaceutical-grade HFCs; rising cost of bulk HFC-134a and HFC-227ea propellants; regulatory approvals; exports of pMDIs; patent protections; manufacturing capacity for pMDIs with the new propellants, DPIs and SMIs; patient and physician information. This section elaborates further on some of these potential challenges.

pMDIs are manufactured at numerous locations around the world in both A5 and non-A5 parties. Table 5.4 summarises manufacturing for annual production above 500,000 pMDIs. Smaller scale manufacture is not included.

Table 5-4. pMDI manufacturing in A5 and non-A5 parties above 500,000 per annum (p.a.)

pMDI Production	Non-A5 locations	A5 locations
500,000–12 million p.a.	13	36
>=12 million p.a.	8	6

5.2.9 Emerging potential issues and challenges with pMDI transition in A5 parties

The 2022 MCTOC Assessment Report identified several issues and challenges for A5 parties, including that access to affordable inhaled medicines is severely limited in low- and middle-income countries. This section provides some additional information for consideration.

There are three chemical manufacturers of pharmaceutical-grade HFC-134a used in pMDIs. One chemical manufacturer located in the United Kingdom is the main supplier for pharmaceutical companies based in non-A5 parties and some also in A5 parties. One chemical manufacturer in India supplies customers mostly in A5 parties, although a limited amount has also been supplied to customers in non-A5 parties. One other chemical manufacturer is based in China and largely supplies the domestic market, with limited exports to customers mainly in A5 parties. Due to the varying requirements of medical registration/qualification processes in differing territories, getting an alternative source of propellant qualified can be a slow process, taking months to years, in certain countries.

Some pMDI manufacturers, notably those in India, have launched pMDIs in Europe and North America in recent years. These products provide additional options for prescribers and contribute to a competitive market, thereby supporting affordability. The import of such products is not currently controlled by the EU F-gas Regulations or the US AIM Act.

In addition, as Kigali Amendment targets for HFCs are implemented, pMDI manufacturers in A5 parties may find bulk pharmaceutical-grade high-GWP propellant sourced from the United Kingdom increasingly difficult to obtain due to diminishing global production of suitable technical-grade feedstock, while the cost increases.[14] This means that these pMDI manufacturers may have to switch to propellant sourced from India or China. For pMDI manufacturers that export to non-A5 parties, a switch of propellant manufacturer requires additional studies to gain regulatory approval for the change, which would take time and could potentially impact the continued supply of these pMDIs to markets in non-A5 parties. An alternative approach could be consideration of HFC propellant stockpiling, if feasible (see below).

pMDI manufacturers in A5 parties that export to non-A5 parties are mindful of HFC phase-down implementation in non-A5 parties, their switch to lower-GWP pMDIs, and whether the import of high GWP pMDIs into those markets might be impacted. Those pMDI manufacturers in A5 parties that are planning to maintain pMDI products in non-A5 markets, but with a lower GWP propellant, will face the same challenges as manufacturers in non-A5 parties when it comes to the choice of propellant, formulation, and valve components.

There will be incremental costs for pMDI manufacturers in A5 parties moving from high GWP pMDIs to pMDIs with lower GWP propellants that parties may need to consider. The development of pMDIs with new propellants will incur costs including reformulation (formulations will need to be optimised for the new propellants), stability studies, clinical

[14] 2022 Report of the Medical and Chemical Technical Options Committee; Section 10.2.6.4.

trials, packaging components, regulatory submissions, storage of bulk propellant, etc. Furthermore, those planning to use HFC-152a will need to invest an estimated further 10-15 % or more of their original capital expenditure to modify production lines to cope with the risks associated with the use of a more flammable propellant.

5.2.10 Regulatory approval position for lower GWP pMDIs in the European Union and other countries

Since the publication of the 2022 MCTOC Assessment Report, the European Medicines Agency (EMA) has recently issued draft guidance on the data requirements when replacing HFC propellants in oral pMDIs.[15] With such guidance information becoming available for pharmaceutical companies, those companies can review the projected timing of their development and launch of pMDIs for the EU. No guidance has yet been published by the US Food and Drug Administration or agencies in other countries.

5.2.11 The potential impacts of pMDI supply issues on inhaler markets

Given that salbutamol HFC-134a pMDIs account for over half of total global pMDI use, care is needed to ensure continued supply of salbutamol pMDIs for patients worldwide. The absence of a coordinated policy and timetable for a transition away from HFC-134a in salbutamol pMDIs, leaves the transition at present subject to market forces. There is the potential for significant disruptions in supply by allowing the transition to lower GWP salbutamol pMDIs to be driven primarily by market forces. This contrasts with the CFC pMDI phase-out, which was carefully managed during the full transition to non-CFC alternative pMDIs.

The fragile nature of the supply of salbutamol pMDIs, and the unreliability of market forces in assuring supply meets the market needs, were made evident in recent years. For example, in the United States, during the COVID pandemic, there was increased use of inhalers at the same time as the withdrawal of two brands of salbutamol pMDIs, both which led to a shortage of supply.[16] From late 2022 into 2023, there has also been a shortage of nebulised salbutamol (albuterol inhalation solution) in the United States due to the bankruptcy of a major manufacturer.[17] These recent examples of supply issues have complex contributing factors (economics, changes in demand, unplanned supply disruptions). Nevertheless, these examples indicate how poorly market forces alone anticipate and respond with agility to sudden changes in demand and/or supply. These instances exemplify the complex factors that could impact the continuous supply of affordable pMDIs during the phase-down of HFC production.

There could also be market-based economic challenges that disrupt pMDI transition. For example, in the United States, HFC-134a salbutamol (albuterol) pMDIs are now available as generics. This could make it economically challenging to launch reformulated branded low-GWP salbutamol pMDIs when lower cost generic HFC-134a pMDIs remain in competition

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[15] European Medicines Agency, Committee for Medicinal Products for Human Use (CHMP), 2023, *Questions and answers on data requirements when replacing hydrofluorocarbons as propellants in oral pressurised metered dose inhalers*, EMA/CHMP/83033/2023, 30 March 2023.

[16] https://acaai.org/news/a-message-to-asthma-sufferers-about-a-shortage-of-albuterol-metered-dose-inhalers/

[17] https://www.accessdata.fda.gov/scripts/drugshortages/dsp_ActiveIngredientDetails.cfm?AI=Albuterol%20Sulfate%20Inhalation%20Solution,%200.5per&st=c&tab=tabs-1

on the market. Meanwhile, in the potential absence of generic lower GWP salbutamol pMDIs, the cost to patients of salbutamol pMDIs could increase.

Market uncertainties, within the context of the HFC phase-down, reinforce the need for a well-planned transition to ensure patients do not face critical shortages or price increases that make salbutamol pMDIs unaffordable.

5.2.12 Stockpiling of HFC propellant for pMDI manufacturing

In its 2022 Assessment Report, MCTOC reported on potential issues with the continued supply of technical and pharmaceutical-grade HFC-134a and HFC-227ea. This section outlines the technical and economic issues associated with stockpiling technical- or pharmaceutical-grade HFC propellant for pMDI manufacturing.

Theoretically, there are two possible options for the provision of pharmaceutical-grade propellant[18] in future years if technical-grade feedstock plants can no longer supply HFC-134a just-in-time. Firstly, pharmaceutical-grade HFC (134a or 227ea) could be produced in earlier years and stored in a way that retains its purity and medical status. Secondly, technical grade HFC could be stockpiled and later converted to pharmaceutical grade by passing through a medical purifier plant. Both options could be used to supply pharmaceutical-grade HFCs towards the end of transition away from high GWP propellant pMDIs. Planning for both options would be very challenging considering the cost and practical issues. There is a risk that insufficient time may be left between when decisions are made to build stock and when technical-grade HFC manufacturing assets must shut down, so that stock building may become impractical.

5.2.12.1 Option 1: Stockpiling of finished pharmaceutical-grade HFC-134a and HFC-227ea

Storing additional large quantities of pharmaceutical propellants can be difficult and demanding on both time and resources. At the time of the CFC to HFC transition, some bulk pharmaceutical-grade CFC storage occurred in both the United Kingdom and the United States. However, since then, handling and regulatory compliance standards have tightened, making this approach very challenging.

Factors common to all pharmaceutical-grade HFC storage options include:

- Pharmaceutical-grade propellant shelf life is 5 years, and current practice does not allow extension of this period.
- The need for national authorities to make available quota to allow the manufacture of this ‘additional’ material.
- Product availability— The main supplier to markets in non-A5 parties is currently running close to capacity. This supplier is unlikely to have the capacity to make excess HFC-134a for stock until demand decreases as the transition to the new propellants gathers pace.
- Quality risk— While bulk storage of pharmaceutical-grade propellant has occurred in the past, pharmaceutical-grade HFC-134a specifications are much more stringent than the previous CFC specifications, for example the level of impurities allowable in HFC-134a is less than 100ppm, whereas impurities in CFCs were allowable up to

[18] Pharmaceutical-grade propellant is propellant that meets quality requirements suitable for use in pMDIs.

2000ppm. All steps of the storage process would be conducted under GMP.[19] However, there remains a low risk of contamination of the HFC in storage (moisture, particulates, non-volatile material) or the development of odour, making the stored material out of specification and unusable. Contaminated HFC is likely to be irretrievable, causing an irreplaceable shortage and a significant financial loss.

- Cost and cashflow— Due to the likely impact of regulations to control HFCs, the cost of both the existing high GWP HFC pharmaceutical-grade propellants is rising sharply and is forecast to continue. Investments by pharmaceutical companies in building stocks to manage their needs during inhaler transition would be very substantial, consisting of the storage facilities, the HFC to fill them, any associated HFC quotas, and destruction of any unused HFC.

For the storage facilities, there are two potential options for pharmaceutical companies that wish to build pharmaceutical-grade HFC propellant stockpiles[20]:

1. *Lower quantity bulk storage up to around 300-500 tonnes*— Bulk storage in this lower quantity range occurs in 20-tonne stainless steel specialist Isotanks, like those currently used to deliver these products. Isotanks must be pressure tested every 2.5 years to allow them to travel on the road, which necessitates removal of the medical contents, and loss of validated status. Therefore, an Isotank 'stockpile', covering longer than around 2 years, would most probably have to be held at the pMDI manufacturing site, which may be limited due to issues with space and local authority permits.

   Also, there is currently limited availability of 'spare' Isotanks for this purpose. They would need to be newly manufactured at ~$100,000 each, with a lead time currently 60 weeks. A large order might cause substantial further delays because Isotank manufacturers only have a certain production capacity.

2. *Higher quantity bulk storage, around 500 tonnes upwards*— Bulk storage in this higher quantity range would occur in dedicated stainless steel grounded stock tanks in a tank farm. MCTOC is not aware of any such suitable and available GMP facility suitable for pharmaceutical-grade HFCs. The design, construction, commissioning/validation time would be around 2 years minimum before filling could commence, and the additional delays and issues related to obtaining local authority permissions for construction of such a facility should not be underestimated. Significant quantities of pharmaceutical-grade HFC (~ 1 tonne per 20 tonnes stored) would be used in commissioning, then downgraded or if in later years is unsaleable, destroyed.

5.2.12.2 Option 2: Stockpiling of technical-grade HFC-134a, for later conversion to

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[19] Good Manufacturing Practice (GMP, also referred to as 'cGMP' or 'current Good Manufacturing Practice') is the aspect of quality assurance that ensures that medicinal products are consistently produced and controlled to the quality standards appropriate to their intended use and as required by the product specification. GMP guidance is provided by the World Health Organisation (https://www.who.int/teams/health-product-policy-and-standards/standards-and-specifications/gmp). More than 100 countries have incorporated the WHO GMP provisions into their national medicines laws, and many more countries have adopted its provisions and approach in defining their own national GMP requirements.

[20] Note: 75,000-100,000 pMDIs per metric tonne HFC propellant.

pharmaceutical-grade, for just-in-time supply

This concept is discussed in the context of HFC-134a, although HFC-227ea could be treated in an analogous manner.

This approach involves building a substantial bulk stock of technical-grade HFC-134a, using several large, grounded stock tanks, possibly on more than one distinct site. This would be most probably in the country that the main pharmaceutical HFC-134a purifier is located (UK). This stock would then be used post-closure of the technical-grade HFC-134a 'feed' plants. The stock facility would probably be operated by a specialist storage company, and the stock would be owned by one or more pharmaceutical companies, possibly operating as a consortium. All costs (construction and operation) would be to their account.

This option has some positive features, notably the ability to keep the medical purifier running for a limited period after the technical feed plants have been taken offline. Also, the storage facilities would be constructed to a lower 'technical-grade' standard. Shelf life of the pharmaceutical-grade HFCs made by processing this stock would only start from the time of conversion to pharmaceutical-grade HFCs; therefore, the quality concerns relating to stockpiling finished pharmaceutical-grade HFC would be avoided.

However, there are also a significant number of challenges with this approach:

- It is unlikely that such a specialist operator would be able to construct and commission such a facility in the time remaining, even assuming that funding was already in place. MCTOC is currently unaware of any significant discussions in this area.
- The matter of quota, for the manufacture and holding of the technical-grade and then the later supply of the converted pharmaceutical-grade to other countries, would need to be considered. Suitable steps would also need to be taken by the involved companies and countries to facilitate import and export and to render such transactions viable and permitted. This is not currently feasible in several countries.
- Negotiating and making the arrangements that would be required to form such a "feedstock owners' consortium" would be complex and time consuming. Funds could not be committed to start construction work prior to the full resolution of the previous point 2, and the full establishment of any consortium. MCTOC is currently unaware of any significant discussions in this area.
- Waste HFC-134a side stream in the purification process. The impurities in the technical-grade are concentrated up into a side stream representing approximately 15% of the original technical-grade fed to the purification plant. Traditionally this side stream would be sold for use in a suitable industrial application which could accept these impurity levels. However, this may not be possible in later years due to contraction of the industrial HFC-134a market, resulting in a destruction requirement and cost.

5.3 Response to Decision XXXIV/5: Identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options for enhancing such monitoring

Decision XXXIV/5: Identification of gaps in the global coverage of atmospheric monitoring of controlled substances and options for enhancing such monitoring:

To request the TEAP to prepare a report for the forty-fifth meeting of the Open-ended Working Group on:

a) Chemical pathways in which substantial emissions of controlled substances are likely
b) Best practices available to control these emissions
c) Gaps in understanding the sources of emissions referred to in point (a) above.

5.3.1 Chemical pathways in which substantial emissions of controlled substances are likely

MCTOC has assigned chemical pathways into associated global production bands and emission rates for relevant controlled substance for each chemical pathway. In assigning each chemical pathway to its appropriate global production band, MCTOC has used the production and feedstock data reported by parties under Article 7. In assigning the controlled substance to emission rate bands for each chemical pathway, MCTOC has used a combination of actual emissions data from plants where available, knowledge of likely reactions, including common side reactions in the various processes, and generic most likely emission rates previously reported in the 2022 MCTOC Assessment Report to infer mean emission rates of controlled substances for each chemical pathway (see Annex 3).

In order to cover a range of chemicals pathways identified as being capable of releasing controlled substances, two approaches have been adopted to identify likely mean emissions rates: for chemical pathways where sufficient data is available a direct estimate of likely emission rates can be made; and for other chemical pathways where sufficient data is not available, the most likely mean emission rates for controlled substances from the 2022 MCTOC Assessment Report have been applied and/or extrapolated from other known data.

This approach enabled an assessment of which chemical pathways are likely able to produce "*substantial emissions*" of controlled substances, which are those having a sufficiently high combination of likely emission rate and annual global production. Only chemical pathways with the necessary combination of high potential emissions rates and high global production are considered to meet the threshold of "*substantial emissions*" in decision XXXIV/5.

The output of this assessment is summarised in the matrix in Figure 5.3 and in Table 5.5, with the chemical pathway reference numbers in the Figure 5.3 matrix referring to the numbers in column 1 of Table 5.5. The light blue shaded region in the matrix is assessed as meeting a reasonable criterion for *chemical pathways in which substantial emissions of controlled substances are likely,* equating to greater than around 1,000 tonnes of controlled substance emitted per year. For this assessment, the light grey shaded region does not meet this criterion; hence the chemical pathways within this category are not described further in this report.

The use of production bands and emission rate bands is considered the most suitable approach, to identify substantial emissions of controlled substances that are likely for each chemical pathway based on the data available to MCTOC. This assessment might not align with emissions data reported by parties or atmospheric derived emissions data because the approach makes assumptions that necessitate the generalisation of a diverse range of actualities. There are gaps in current knowledge and understanding (see section 5.3.3).

Figure 5-3. Matrix to show chemical pathways in which substantial emissions of controlled substances are likely based on reported global production versus mean emission rate of controlled substance

		Global production				
		<1000 tonnes of product per year	1,000–10,000 tonnes of product per year	10,000–100,000 tonnes of product per year	100,000–1 million tonnes of product per year	>1 million tonnes of product per year
Mean emission rate of controlled substance from production	1–10 wt% 10–100 kg of emission per tonne of production			2, 3, 8, 9, 13, 15, 19, 22, 23, 24	1, 5, 11, 16, 17, 18, 20, 21	6, 14
	0.1–1 wt% 1–10 kg of emission per tonne of production				4, 7, 10, 12	
	0.01–0.1 wt% 0.1–1 kg of emission per tonne of production					
	0.001–0.01 wt% 10–100 grams of emission per tonne of production					
	<0.001 wt% <10 grams of emission per tonne of production	<10 kg per year				

Note: The numbers in Figure 5.3 matrix refer to the reference numbers in Table 5.5 below

Table 5-5. Reference table for the matrix for Chemical pathways in which substantial emissions of controlled substances are likely (Figure 5.3)

Reference number	Controlled substance emitted	Chemical pathway	Reason for presence of controlled substance	Estimated global production tonnage band for each chemical pathway (tonnes per year)	Estimated mean emission per tonne of production globally (weight %)
1	CFC-113	Perchloroethylene to CFC-113	Product	100,000–1 million	1–10
2	CFC-113a	CFC-113 to CFC-113a	Product	10,000–100,000	1–10
3	CFC-114	Perchloroethylene to CFC-114	Product	10,000–100,000	1–10
4	CFC-115	Perchloroethylene to HFC-125	By-product	100,000–1 million	0.1 -1
5	CTC	Methyl chloride to dichloromethane to chloroform to CTC	Product/By-product	100,000–1 million	1–10
6	HCFC-22	Chloroform to HCFC-22	Product	>1 million	1–10
7	HCFC-22	HCFC-22 to TFE/HFP by pyrolysis	Feedstock	100,000–1 million	0.1–1
8	HCFC-124	Perchloroethylene to HCFC-124	Product	10,000–100,000	1–10
9	HCFC-141b	1,1,1-Trichloroethane or vinylidene chloride (VDC) to HCFC-141b	Product	10,000–100,000	1–10
10	HCFC-141b	1,1,1-Trichloroethane or VDC to HCFC-141b	Co-product	100,000–1 million	0.1–1
11	HCFC-142b	1,1,1-Trichloroethane or VDC to HCFC-142b	Product	100,000–1 million	1–10
12	HCFC-142b	HCFC-142b to VDF to PVDF	Feedstock	100,000–1 million	0.1–1
13	HCFC-142b	HFC-152a to HCFC-142b	Product	10,000–100,000	1–10

Reference number	Controlled substance emitted	Chemical pathway	Reason for presence of controlled substance	Estimated global production tonnage band for each chemical pathway (tonnes per year)	Estimated mean emission per tonne of production globally (weight %)
14	HFC-23	Chloroform to HCFC-22	By-product	>1 million	1–10
15	HFC-23	Chloroform to HCFC-22 to TFE/HFP to HFC-227ea	By-product in HCFC-22 production step	10,000–100,000	1–10
16	HFC-32	Dichloromethane to HFC-32	Product	100,000–1 million	1–10
17	HFC-134a	Trichloroethylene to HFC-134a	Product	100,000–1 million	1–10
18	HFC-125	Perchloroethylene to HFC-125	Product	100,000–1 million	1–10
19	HFC-143a	1,1,1-Trichloroethane or VDC to HFC-143a	Product/Co-product	10,000–100,000	1–10
20	HFC-152a	Vinyl chloride to HFC-152a	Product	100,000–1 million	1–10
21	HFC-152a	Acetylene to HFC-152a	Product	100,000–1 million	1–10
22	HFC-245fa	Vinyl chloride and CTC to HFC-245fa	Product	10,000–100,000	1–10
23	HFC-227ea	HCFC-22 to HFP to HFC-227ea	Product	10,000–100,000	1–10
24	1,1,1-Trichloroethane	1,1-Dichloroethane to 1,1,1-trichloroethylene	Product	10,000–100,000	1–10

Note: For many of these controlled substances, their use is often dispersive and hence the emissions from the production process are expected to be significantly lower than the emissions from their use and EOL handling.

5.3.1.1 Conclusion

The conclusion of this assessment is that most production processes will only have substantial quantities of emissions of controlled substances when they are producing controlled substances or using them as feedstocks. Any other controlled substances involved in the process will only be produced and then released in much smaller quantities, which may be negligible, e.g., due to the presence of trace quantities of precursors as impurities in the feedstocks or as intermediates generated and consumed along the chemical pathway. There are a few exceptions noted below where unwanted by-products or intermediates could be emitted in significant quantities in some chemical pathways:

- Where the by-product is on the main reaction pathway, e.g., the production of HFC-23 is one fluorination step further on the chloroform to HCFC-22 pathway and CTC is one chlorination step further on the methyl chloride to dichloromethane to chloroform pathway.
  - HFC-23 by-production from the chloroform to HCFC-22 pathway is well understood. It is ranked at both the top of the global production and the top of the controlled substance emission bands. The mean emission rate is expected to decrease as more of the HFC-23 is captured and destroyed, in compliance with Article 2J of the Kigali Amendment.
  - CTC production from the methyl chloride, dichloromethane, chloroform pathway is also a large volume production route. However, although CTC is a valuable product, expected average mean emission rate is ~2 wt% across the industry.
- The existence of other non-trivial side reactions can lead to mean emission rates of around 0.01–0.1 wt% of other controlled substances from the production process, e.g., the formation of HFC-23 in HFC-32, and HFC-23 in HCFC-22 pyrolysis to TFE/HFP (tetrafluoroethylene/ hexafluoropropene). Considering the production quantities, these emission rates result in emissions on the boundary of the "*substantial emissions*" criteria used in this assessment. CFC-115 produced by a non-trivial side reaction during HFC-125 production is estimated to lead to mean emission rates in the 0.1–1 wt% band. Considering the production quantities, this estimated emission rate results in likely CFC-115 emissions meeting the "*substantial emissions*" criteria used in this assessment.

5.3.2 Best practices available to control emissions

Best practices available to control emissions include optimising plant design, equipment, operation, maintenance; instrumentation and monitoring of process and emissions; training and instruction for plant operators; periodic mass balancing; technologies for destruction or for separation and chemical transformation to treat unwanted co-products or by-products and abate their emissions; and regulatory controls to provide the economic framework to ensure any or all of the above emissions mitigation measures are implemented by operators, and to require emissions and other reporting.

To elaborate MCTOC's response to decision XXXIV/5, paragraph b, reproduced below is section 2.5 from the 2022 MCTOC Assessment Report on Production emissions and their mitigation.

An emission is usually considered to be the release of a substance into the environment; although often used to describe gas releases to the atmosphere, they can also include substances released in solids or liquids that later transition to the atmosphere. For example, the HFC-23 emission from an HCFC-22 process may include both direct emissions of HFC-23 from a vent and HFC-23 degassed to atmosphere during subsequent treatment of the aqueous effluent.

In some processes, substances can be dissolved or entrained in some of the co-products and can then be released to the environment in the location where these co-products are subsequently stored and used, which is often remote from the plant that produced them. For example, HFC-23 can be dissolved or entrained in the co-produced hydrochloric acid on an HCFC-22 process. The dissolved or entrained HFC-23 is then degassed to atmosphere from locations where the hydrochloric acid is subsequently stored and used. This can result in a wide dispersal of the eventual HFC-23 transitions to atmosphere and an apparent proliferation of secondary HFC-23 emission sources. It should be noted that this is not additional by-production of HFC-23 from either the HCFC-22 process or at the point of emission. The quantity of HFC-23 released in these dispersed emissions can vary widely as the quantity involved is dependent on several factors involved in the design and operation of the producing plant. These dispersed emissions are expected to account for <1% by weight of the total HFC-23 by-production of the HCFC-22 process. These dispersed emissions are typically unmitigated at point of release.

Emissions can be of products, co-products , intermediates, feedstock, or by-products; which of these are being emitted will have an important bearing on how the operation mitigates those emissions.

5.3.2.1 Emission of products, co-products, intermediates, and feedstocks

Emissions of products, co-products, intermediates, and feedstocks from processes are economically undesirable and the operators of the process will seek to minimise them. To achieve this the process will usually be designed, operated, monitored, and controlled to optimise feedstock to product ratios, and hence minimise product, co-product, intermediate and feedstock emissions within the limits of the plant design capability.

Most processes will employ a range of elements of good practice for minimising emissions of feedstocks, intermediates, and products, such as:

- Operating instructions documenting how to consistently achieve the desired optimum operation
- Training
- Instrumentation to allow suitable monitoring and control of the process
- Routine sampling and analysis of raw material, product and solid and liquid effluent and vent streams
- Routinely recording, trending, and reviewing relative feedstock consumption and product production ratios
- Periodic plant mass balancing
- Plant tours
- Maintenance procedures including routine leak checking
- Consideration of inherent emissions when selecting equipment, e.g., seal-less pumps
- Consideration of the materials of construction.

The operator may even, in some cases, alter the physical design of the process to reduce these emissions if there is a suitable case to do so.

5.3.2.2 Emissions of unwanted by-products

Emissions of unwanted by-products, and to a lesser extent low value co-products, is a different consideration. For financial reasons, a process will typically seek to minimise the formation of unwanted by-products because by doing so it will typically maximise its desired product to feedstock conversion ratios. Nevertheless, in some cases an increase in the rate of production of the desired product at the expense of a higher by-product production rate may be economically attractive. There would usually be a need to include additional equipment (such as destruction or separation and chemical transformation technologies), with further operating and maintenance costs to the process to mitigate these unwanted by-product emissions. However, the lack of a clear environmental, safety or economic drivers has often meant that, once produced, these unwanted by-products are emitted unabated.

If there are no financial incentives, regulatory controls may be needed to ensure that the emissions of unwanted by-products produced by the process are minimised. Various techniques are possible to treat unwanted by-products to minimise their emission. These techniques are typically end-of-pipe processes that destroy or convert the unwanted by-products to environmentally acceptable substances; e.g., conversion of the HCl and HF to hydrochloric and hydrofluoric acids or salts such as NaF and NaCl using aqueous scrubbing systems; or the thermal oxidation of HCFCs to water, CO_2, HCl and HF and the subsequent conversion of the HCl and HF to salts such as CaF_2 and $CaCl_2$ or in some cases the absorption of certain organic species on an absorbent (e.g., activated carbon) prior to appropriate disposal or regeneration of the absorbent.

5.3.2.3 Emissions monitoring

The determination of emission rates by process operators can be complex often requiring the monitoring of the flow and composition of numerous process streams. The physical and chemical characterises of these streams may also present significant challenges to achieve a sufficiently reliable and accurate set of data. In additional it is difficult to obtain a complete coverage of all emission as, for example, fugitive (unintended) emission points (e.g., leaks from pipework, flanges or fittings) are not suitable for continuous measurement and usually must be estimated/determined by mass balancing the flows into and out of the process.

The ability of processes to monitor, and the accuracy of the determination of, their substance emissions rates will vary. Some modern suitably designed, operated and highly instrumented processes may have continuous flow and frequent composition monitoring of all relevant flows into and out of the plant and be able to consistently balance the inputs and outputs, including emissions, from the plant to a reasonably high degree of accuracy, less well instrumented and monitored plants, maybe only covering the major raw material, product and vent steams, are still likely to mass balance their process but will only be able to do so to a lower accuracy and will be less able to determine the chemical species and route of any emissions.

Factors that affect the amount of instrumentation and the accuracy of the determination of emissions are numerous and include, for example:

- The age and design of the plant
- The presence (where in the process, for how long, with which other substances and in what physical state) of the chemical species being emitted
- The suitability of the measurement technique for the parameter to be measured
- The degree of accuracy and frequency of measurements of the flows and compositions of the various feedstocks, products, and emission points
- The number of possible (normal, emergency and fugitive) emission points to be monitored
- The percentage of the emission points monitored
- The regulatory requirements to measure and document emissions
- The perceived economic value and hence resources expended by the operator to estimate, control, minimise, and mitigate emissions.

In general, the more resource and importance an operator places on determining emissions and the higher the completeness, reliability and accuracy of the data obtained from the plant, the more accurate the mass balance and hence the more accurate the determination of the emissions.

5.3.2.4 Emission reporting

Many national regulations require the operators of chemical processes to report the level of emissions from the production of a range of substances including many controlled substances. Many of these reports are publicly available although it is often difficult to derive an accurate emission factor as a percentage of the product produced as typically only incomplete data on production rates is publicly available.

There is also a requirement to report a basket of HFCs to the UNFCCC[21]; these emissions cover a different scope and often a different calculation methodology to the paragraph above as they include an estimation of emissions whilst in use and at end of life.

5.3.3 Gaps in understanding the sources of emissions from chemical pathways with substantial emissions

There are many gaps in understanding the sources of emissions from chemical pathways with substantial emissions. The main reasons are the existing gaps in publicly available data, some of which may be unavailable due to commercial confidentiality. Estimations of mean emission rates of controlled substances and annual global production have a high degree of uncertainty because of gaps in the available public and/or non-commercially sensitive data.

Gaps in understanding include the following:

- The exact global capacity and production by chemical pathway are not accurately known and may be unavailable due to commercial-in-confidence reasons. Production and feedstock quantities are available for controlled substances under Article 7 reporting; however, quantities may not be available for chemical pathways producing or using non-controlled substances that might otherwise emit controlled substances.
- For most production facilities, actual emissions and locations across the globe are not reported by parties.
- Average global generation and mean emission rates of controlled substances by different chemical pathways are not accurately known. Emission rates are likely to vary over time for an individual process, and from process to process, as they are impacted by a range of factors, including the chemical pathway used, feedstock impurities, feedstock feed ratios, operating conditions in the reactor, recycles back to the reactor, catalyst condition and composition, operation of mitigation and destruction steps, use of continuous, discontinuous, and emergency release points, etc. These variations increase uncertainty when predicting a mean emission rate.
    - Side reactions vary by plant, process, and operation, even in the same chemical pathway, and cannot be accurately predicted.
    - Trace impurities vary by plant, process, and operation so are less likely to be analysed or reported, are not accurately known, and cannot be accurately predicted. These trace impurities are unlikely to influence the current assessment due to the significance level chosen. However, if smaller global emission rates, e.g., <100 tonnes per year per chemical pathway, are of interest then omissions in process plant analysis and reporting may be relevant.
    - Emission abatement controls, including treatment and destruction technologies, vary by plant, process, and operation, and are not accurately known for most production facilities.

[21] For example, UNFCCC, National Inventory Submissions 2021 | UNFCCC

- Additional processes/chemical pathways from which controlled substances are potentially generated and emitted that are not yet identified.

While sources of emissions and the emission rates are likely to be reasonable estimates, this means that the sources of emissions and emission rates may change, e.g., emission rates move up or down a band if or when more data becomes available.

5.4 Response to Decision XXXIV/6: Ongoing emissions of carbon tetrachloride

Decision XXXIV/6, Ongoing emissions of CTC states

1. To invite parties that have production of carbon tetrachloride, as well as by-production, or use of CTC as a feedstock for other substances or as a process agent, to provide to the Ozone Secretariat on a voluntary basis, by 1 February 2023, information on the national procedures and frameworks in place for the management of such activities in their respective countries;
2. To request the Secretariat to share with the TEAP the information received in accordance with paragraph 1 of the present decision;
3. To request the TEAP to review the information received and to present this information in its 2023 progress report for consideration by the Open-ended Working Group at its forty-fifth meeting.

In response to Decision XXXIV/6: On-going emissions of CTC, information was submitted by and received from 5 parties: China, the European Union, Japan, United Kingdom, and the United States.

Different approaches were taken by submitting parties to the information provided, with different aspects of the different frameworks highlighted in different ways. Some submissions were detailed, while some submissions summarised requirements.

MCTOC presents information provided by parties as a generic summary from across the submissions, identifying the similar elements of national procedures and frameworks that have been established by this sample of parties.

- Parties providing submissions have implemented controls for CTC that address activities associated with production, import, export, use, and sale.
- While production, import and use of CTC has been banned in alignment with the Montreal Protocol phase-out schedule, derogations exist to allow permitted uses, including for feedstock, process agent, and laboratory and analytical uses.
- Licences can be required for import or export, with quota limits applied to imported and exported quantities for permitted uses. Licences specify the use and maximum amounts allowed for a period.
- Registration of operators can be required for importers, exporters, and sales, with operator requirements around quotas, permitted uses etc.
- Registration can be required for permitted feedstock, laboratory and analytical, and process agent uses.
- Recording and reporting can be required for import, export, use, sale, or destruction. This includes data reporting on amounts for production, sales, disposal, purchase, use and storage.
- Labelling can be required for storage and transported containers.
- There are requirements for use, e.g., controls on feedstock uses so permitted CTC is only used for that purpose, and emissions of CTC.
- Emissions controls are intended to prevent and minimise CTC emissions, including to the

extent practicable, from permitted uses, e.g., for CTC production, inevitable by-production, inadvertent by-production, feedstock use, or CTC process agent use. Standards can require the maximum degree of emission reduction, as determined by the regulating authority, e.g., for major sources or area sources of pollutant emissions.

- Some parties describe a life-cycle management approach to address potential emissions during plant construction planning, through online real-time monitoring of CTC production, destruction, data reporting and verification processes, video inspection, and unannounced on-site inspections.
- Through permit applications and approvals, which define legal responsibilities for operators, facilities can be required to install modern pollution control equipment, or best available techniques, as determined by the regulatory authority, during construction, when undertaking works that could impact emissions, or during operation.
- Some parties publish aggregated reported data relating to CTC quantities manufactured, imported, processed, used, or emitted. Some parties included aggregated reported CTC emission data in their submissions.
- Some parties have implemented controls related to CTC as a hazardous air pollutant.
- Penalties apply to breaches of legislative and regulatory requirements.
- In some parties, there are monitoring stations for long-term atmospheric measurements of CTC, from which CTC emissions are derived, interpreted and published.

Below is a non-exhaustive list of national procedures and frameworks included in submissions (with links where provided):

China— Regulation on the Administration of Ozone Depleting Substances, that requires enterprises that produce, sell, or use CTC to report data on CTC production, sales, disposal, purchase, use, and storage. The Ministry of Ecology and Environment (MEE) has established: policies for construction projects for CTC production, requiring that "*Construction, reconstruction or expansion projects with CTC as by-product shall build ancillary facilities to dispose of CTC*"; online monitoring of CTC production that monitors the by-production, disposal, sales and inventory of CTC for all enterprises with CTC as by-product in real-time and stores the data in a national monitoring platform; annual registration of CTC sales enterprises, the list of which is made publicly available; annual quotas for CTC used as laboratory analysis agents and process agents; annual registration for CTC feedstock use enterprises, the list of which is made publicly available, that requires CTC to be used within the registered purposes; joint action and cooperation with local government authorities.

European Union— EU Regulations are directly applicable laws, creating rights and obligations for individuals, organisation and the Member States. Directives are only binding for Member States, setting policy objectives that need be transposed in their national legislation to create legal effects for individuals. *Regulation (EC) No 1907/2006* (18 December 2006) establishes Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), including restrictions under Annex XVII entry 3 (https://echa.europa.eu/documents/10162/6e698812-f218-5f39-aff3-e46a1555a67d). Sector specific legislation controls use and emissions, such as: *Regulation (EC) No 1005/2009* (16 September 2009) on substances that deplete the ozone layer (i.e., the ODS Regulation, currently under revision); Commission Implementing Decision 2014/8/EU (10 October 2013), amending Decision 2010/372/EU on the use of controlled substances as process agents under Article 8(4) of *Regulation (EC) No 1005/2009*; Directive 2010/75/EU (24 November 2010) on industrial emissions (integrated pollution prevention and control) (i.e., industrial emission directive or IED); *Regulation (EC) No 166/2006* (18 January 2006) establishing the European Pollutant Release and Transfer Register (EPRTR) (currently under revision), under which CTC emissions are reported; Directive 2012/18/EU (4 July 2012) on the control of major-accident hazards involving dangerous substances (i.e., the Seveso-III directive); Directive 2008/50/EC (21 May 2008) on ambient air quality and cleaner air for Europe (i.e., the Air Quality directive); Directive 2000/60/EC (23 October 2000) establishing a framework for Community action in the field of water policy (i.e., the Water Framework Directive). European Chemicals Agency (ECHA) provides a non-exhaustive list of EU legislation that explicitly refers to CTC (https://echa.europa.eu/legislation-obligation/-/obligations/100.000.239). Best available technique reference documents for relevant CTC industrial operations are available at links for Production of Chlor-alkali and Common Waste Gas Management and Treatment Systems in the Chemical Sector. The European Environment Agency (EEA) operates an online questionnaire for the reporting of ODS in the EU. The EU submission includes national legislation and regulation implemented in the Members States with activities relevant to CTC for Czech Republic, France, Germany, Spain, the Netherlands. Member States legislative and regulatory frameworks include, among other things, permitting, authorisations, reporting requirements, air quality objectives, emission limits, waste management procedures.

United Kingdom— *Ozone Depleting Substances Regulation*, with guidance provided for users, producers, and traders https://www.gov.uk/government/collections/ozone-depleting-substances-guidance-for-users-producers-and-traders. Long-term CTC emissions data is published at https://www.gov.uk/government/publications/uk-greenhouse-gas-emissions-monitoring-and-verification.

United States— Section 604 of the *Clean Air Act* (CAA) establishes the mandatory phase-out of Class I and Class II ozone-depleting substances, where CTC is a Class I ODS phased out in 1996 with limited exception for feedstock and process agent use; and associated regulations found at 40 CFR Part 82, https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-82/subpart-A. National Emission Standards for Hazardous Air Pollutants (NESHAPs) implemented under CAA, Section 112(d), and associated regulations found at 40 Code of Federal Regulations (CFR) Part 61: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-61?toc=1. New Source Review Permitting for facility operators and installation of emission control equipment, required under Part D of the CCA and associated regulations found at 40 CFR 52.21; information is available at https://www.epa.gov/nsr. Section 313 of *Emergency Planning and Community Right to Know Act* (EPCRA) requires annual reporting from certain facilities that manufacture, process, or otherwise use above threshold quantities a of chemicals listed in the Toxic Release Inventory, including CTC; reporting regulated under 40 CFR 372.65 and available publicly at https://www.epa.gov/toxics-release-inventory-tri-program. The Chemical Data Reporting Rule, issued under the *Toxic Substances Control Act,* requires reporting of exposure-related information, available at https://ww.epa.gov/chemical-data-reporting.

For further detailed information, please contact the parties that provided these submissions.

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

6.1 Introduction

The 2022 RTOC Assessment Report was only released at the end of February 2023 and contained the latest updates of all refrigeration, air conditioning, and heat pump (RACHP) technologies. No new information is available since publication of that report, so RTOC provides no further updates in this report.

After completing the 2022 RTOC Assessment Report, co-chairs started the process of nominating new members to the RTOC for the 2023-2026 quadrennium considering the commitments and the challenges RTOC will be asked to address. It was decided that all the appointments would be for a 2-year period to ensure on-going balance and sufficient expertise during the quadrennium.

The evolution in RTOC membership for the next quadrennium is presented in the list reported in the Annex 4. The list is still provisional due to the fact that the formal procedure of appointment (both for re-appointments and new appointments) has not been completed yet.

6.2 Updates to 2022 Assessment

Work on 2022 RTOC Assessment Report lasted up to the end of February 2023 and the report is updated to that deadline. No compelling new information on technology was received after the end February 2023.

Decision XXXIV/3 "Enabling enhanced access and facilitating the transition to energy-efficient and low- or zero-global-warming-potential technologies" was adopted by parties. The decision specifically requests TEAP to "*Integrate updates on energy efficiency while phasing down HFCs in the refrigeration, air-conditioning and heat pump sectors in its progress and quadrennial assessment reports from 2023 onwards*". In response, TEAP established an Energy Efficiency Working Group (EEWG) within the RTOC including 15 members of RTOC to provide information to parties on energy efficiency during HFC phase-down. The EEWG working group was supplemented with the addition of a co-Chair of TEAP and a co-Chair of FTOC to address cross-cutting issues while membership recruitment and appointment was on-going (as outlined above). The report responding to Decision XXXIV/3 is in the Supplement to the TEAP 2023 Progress Report.

7 Per- and poly-fluoroalkyl substances: Emerging policies and sector information

Following discussions at its meeting, and considering information available from its TOCs, TEAP has prepared the following chapter which outlines potential technical and economic issues that could arise from emerging policies and industry considerations related to per- and poly-fluoroalkyl substances (PFAS).

7.1 Emerging policies related to per- and poly-fluoroalkyl substances

7.1.1 Regulatory developments

The TEAP and its TOCs 2022 Assessment Reports outlined the increasing focus on the use, emissions, and environmental and health effects of PFAS.

PFAS have been defined differently by national and sub-national jurisdictions. Definitions of PFAS incorporated into potential future regulations may or may not include Montreal Protocol controlled substances and their substitutes, as well as their breakdown products, such as trifluoroacetic acid and its salts (TFA). This is creating uncertainty for industry regarding the long-term availability of certain alternatives to ODS and HFCs. Some companies and other stakeholders have reported that they are delaying decisions on the selection of alternatives and the associated investments, due to concerns about whether some or all those fluorinated alternatives might become unavailable as a result of future regulations. The uncertainty for industry raised even with proposed regulations could have unintended impacts, i.e., delaying the phase-out of ODS and phase-down of high GWP HFCs.

The Organisation for Economic Co-operation and Development (OECD) definition of PFAS encompasses a wide range of chemicals from gases to liquids to solid polymers. A number of fluorinated chemicals within this definition are controlled substances under the Montreal Protocol and/or are used as alternatives to controlled substances.

PFAS are defined, by the OECD as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group ($–CF_3$) or a perfluorinated methylene group ($–CF_2–$) is a PFAS. This definition includes TFA and commercially used HFCs and HFOs but excludes several fluorinated gases such as HFC-32, HFC-23, CF_3I, HFC-152a, and HCFC-22.

A proposal for the restriction of around 10,000 PFAS has been published by the European Chemicals Agency (ECHA) under the REACH regulation that applies in the European Economic Area. Authorities in Denmark, Germany, the Netherlands, Norway and Sweden prepared and submitted the proposal to ECHA on 13 January 2023. ECHA's scientific committees have commenced evaluating the proposal according to the risks to people and the environment and the impacts on society with an initial 6-month public consultation process that started in March 2023. The draft regulatory timetable could include subsequent additional consultation and regulatory process steps, with a draft completion date for the regulatory process proposed in 2025.

Under the current proposal, PFAS, as defined, would not be manufactured, used or placed on the market as substances on their own, or in another substance, or in a mixture, or in an article, above certain concentration levels, with these restrictions applying 18 months after entry into force, with the earliest date assumed to be 2025. Two options are considered: one with no derogations and the other with derogations, including time-limited use-specific derogations (5 and 12 years), after which the restrictions apply to that use. The proposal is subject to public consultation and regulatory process steps, and so the final restriction may be different.

Several uses relevant to the Montreal Protocol are derogated or potentially derogated from the proposed restrictions after entry into force for periods of 5 or 12 years, including refrigeration, air conditioning, foam insulation, fire protection, technical aerosols, laboratory and analytical uses, precision cleaning, and semiconductor manufacturing.

The proposed restrictions, which ban manufacture, use, or placing on the market, include pMDI propellants defined as PFAS (i.e., HFC-134a, HFC-227ea, HFO-1234ze(E)). Under the current proposal, the restrictions would apply to pMDIs 18 months after entry into force, as early as 2025. The proposal derogates fluoropolymer coatings used in pMDIs until 13.5 years after entry into force.

The Stockholm Convention on Persistent Organic Pollutants aims to eliminate or restrict the production and use of persistent organic pollutants (POPs). Some jurisdictions, e.g., China and Japan, restrict certain PFAS that are specifically listed under the Stockholm Convention, i.e., perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA), and perfluorohexane sulfonate (PFHxS). Other PFAS are not restricted in China and Japan.

In 2021, in North America, Canada published a notice of intent to address the broad class of 4700 PFAS chemicals[22], and the United States (U.S.) Environmental Protection Agency (EPA) published the "PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024" in 2021[23]. U.S. EPA is using a working definition of PFAS as chemicals that structurally contain the unit R-(CF_2)-C(F)(R′)R″ where both the CF_2 and CF moieties saturated carbons and none of the R groups (R, R′ or R″) can be hydrogen. This is a narrower PFAS working definition than the EU REACH proposal. The EPA program excludes most, if not all, HFCs, HFOs, and specifically TFA from the working PFAS definition.

At the subnational level in the United States, some States are considering or enacting policies requiring reporting and bans on PFAS chemicals with a definition and scope that is broad enough to include substances controlled under the Montreal Protocol. This may result in unique requirements that may also be potentially different from national regulations.

- The State of Maine has enacted legislation[24] banning the use of all PFAS chemicals, defined as containing a single fully fluorinated carbon, which includes commercially used HFCs and HFOs (excluding several fluorinated gases such as HFC-32, HFC-23, CF_3I, HFC-152a, HCFC-22), and TFA, by 2030 unless a “currently unavoidable use” exemption is approved. The Maine Department of Environmental Protection has proposed a regulation to implement the mandate, which also includes a reporting requirement for all PFAS chemicals entering the state in bulk or incorporated into products, including aerosols, foams, and refrigerating equipment by January 1, 2023. The state has provided extensions to the reporting requirements for approximately 2,500 companies and has proposed a process for exempting “currently unavoidable uses.” There is proposed legislation that would extend the reporting deadline until 2025. Other proposed legislation for discussion in committees in the next months may further modify state requirements, including the definition. Notwithstanding the extensions granted and possible exemptions and modifications, the Maine mandate is currently in effect.

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[22] Canada Gazette, Part I: Vol. 155 No. 17 – April 24, 2021 available at: https://www.canada.ca/en/health-canada/services/chemical-substances/other-chemical-substances-interest/per-polyfluoroalkyl-substances.html

[23] U.S EPA Strategic Roadmap: EPA’s Commitments to Action, 2021 – 2024 available at: https://www.epa.gov/pfas/pfas-strategic-roadmap-epas-commitments-action-2021-2024.

[24] July 2021, Public Law c. 477, An Act to Stop Perfluoroalkyl and Polyfluoroalkyl Substances Pollution available at: https://www.maine.gov/dep/spills/topics/pfas/PFAS-products/#:~:text=A%20retailer%20may%20not%20sell,products%20containing%20intentionally%20added%20PFAS.

- The States of Minnesota and New Jersey have proposed nearly identical legislation to the state of Maine; but no other states currently have proposed or enacted PFAS legislation impacting substances controlled by the Montreal Protocol. Other states have enacted or are considering legislation banning the use of PFAS chemicals in cosmetics, children's toys, turf, clothing, food packaging, and other specific uses, where there is high potential for exposure to PFAS chemicals. These uses do not include products using chemicals controlled under the Montreal Protocol.

In the context of these ongoing national and subnational actions related to PFAS, which may or may not restrict products using chemicals controlled under the Montreal Protocol, TEAP is providing additional information related to current considerations within some exemplar sectors of use.

7.1.2 Fire suppression

Major halon alternatives in fire suppression are fluoroketone (FK)-5-1-12, and 3,3,3-trifluro-2-bromo-propene (2-BTP), HFC-236fa and HFC-227ea. Under the broader definitions of PFAS such as in the proposed EU REACH restriction and as currently used by the US State of Maine, fire suppression agents in use as halon alternatives such as HFC (except for HFC-23), and the low-GWP alternatives 2-BTP, FK-5-1-12 are all proposed to be classified as PFAS. In contrast, current fire suppression agents, such as ozone-depleting halons and high-GWP HFC-23 that are being phased out under the Montreal Protocol, would not be considered PFAS.

As an example of implications is halon 1211. As there are quantities of halon 1211 still installed on aircraft and as recycling companies continue to report availability of recovered/recycled/reclaimed halon 1211, there is now considerable uncertainty about how much halon 1211 will be available to supply ongoing civil aviation needs. There has not been much concern about halon 1211 supply because the main continuing civil aviation use is being phased-out by the low GWP 2-BTP. Significant concern is now being raised by the civil aviation industry in coordination with the International Civil Aviation Organization (ICAO) that the transition to 2-BTP is being paused while the industry determines if 2-BTP will be viable in the long term. This will affect the on-going availability of recycled halon 1211 in two ways: firstly, not transitioning to 2-BTP in newly produced aircraft will deplete the halon 1211 bank faster; secondly, ceasing retrofit of existing halon 1211 will reduce the amount available to recycling organisations to supply civil aviation. FSTOC has not performed any "run-out" analyses for halon 1211 as has been done for halon 1301, and therefore it is not known if civil aviation will need additional production of halon 1211.

A second example of implications is the uncertainty being introduced by classifying the low-GWP fire suppressant FK-5-1-12 as a PFAS. Several FSTOC members have reported that at least several, and possibly more, Kigali Implementation Plans (KIPs) under development may be relying on the transition from HFC-227ea to FK-5-1-12 as part of their strategy to meet their Kigali obligations.

A third example of implications is the potential for continued use of halons or an increase in the use of HFC-23 in fire protection as these are not considered PFAS. As reported in the FSTOC 2022 Assessment report, there continue to be some uses that can only be met through the use of the original halon or a high GWP HFC. These include some nuclear power plant, military, and oil and gas applications. The additional uncertainly surrounding the high GWP HFCs, except for HFC-23, being also now potentially classified as PFAS, is causing some enduring users of halon 1301 to consider continuing their use in lieu of transitioning to alternatives or transitioning to HFC-23 (GWP 14,800) instead of HFC-227ea (GWP 3,220) or HFC-125 (GWP 3,500)

Although the EU REACH proposal provides for a 12-year derogation for fire suppression, to allow time for the development of non-PFAS alternatives, as reported in the 2005 IPCC/TEAP Special Report, the path to market for new fire extinguishing agents and systems is laborious (Wickham, 2002) and typically takes significantly longer than 10 years to identify and implement a new fire suppressant. The process involves various authorities and organizations, including health and environmental authorities, standard-making organizations and certification bodies, both nationally and internationally. This lengthy and expensive process is often repeated country-by-country to meet different national standards to ensure both fire protection performance and environmental safety. Countries and regions with high levels of regulatory supervision tend to avoid unapproved products, while others have experienced difficulties with agents of questionable safety and effectiveness. The most recent fire suppressant proposed, an HCFO, received US EPA SNAP listing in 2016, several years after development began, and is not yet commercialized some 10 years later. It is now being considered as a blend with FK-5-1-12 but as both could be classified as PFAS, its future is affected in the same way as other PFAS. Furthermore, all known candidate clean agent chemical groups have already been researched, such that discovering alternatives that are zero ODP, low GWP, and non-PFAS is highly unlikely. Based on these factors, there is little to no financial incentive for companies to invest in the research and development of potential new fire suppression agents. As there are no new candidate fire suppressants available for consideration that are not PFAS under these broad definitions, it is anticipated that the only options that will be available after the 12-year derogation are the same ones available today.

7.1.3 Foams

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 proposed regulations. While the current PFAS Restriction proposal in the EU contains the provision for time-limited derogations for some uses, thermal insulation foams are not currently included. However, consideration is being given to a potential time-limited derogation for the use of fluorinated blowing agents in PU Spray Foams, where the choice of other alternatives is not so obvious on safety grounds. If mainstream uses of F-gases are limited in Europe, there could be broader implications for investment in HFOs and HCFOs going forward.

7.1.4 Propellants for aerosols and pMDIs, and other chemicals uses

Controlled substances and their technically and economically feasible alternatives that are used in aerosols, pMDIs, solvents, electronic manufacturing, and magnesium production, could be impacted by the broad-ranging definitions of PFAS, such as the OECD definition, and associated possible restrictions.

For example, propellants HFC-134a, HFC-227ea, and HFO-1234ze(E), currently under development, that are used, or are being invested in, for pMDIs could be impacted. This is leading to industry uncertainty, e.g., impacting multi-million dollar investments in drug development, and emerging industry concern about the uncertain future of existing products, manufacturing, and plans to transition to lower GWP alternatives. Industry is also concerned for the patients that rely on pMDIs for their asthma and chronic obstructive pulmonary disease treatment and about ensuring an uninterrupted global supply of essential medicine that is affordable and accessible.

Several industries with specialist uses are also concerned about potentially closing off options where there are currently few alternatives with more suitable properties, such as in electronics manufacturing, magnesium production, and precision cleaning for aerospace and military uses, where the remaining options could be continued use of, or a reversion to, substances with higher GWP.

7.1.5 Refrigeration, Air Conditioning and Heat Pumps (RACHP)

The proposed broad-range restrictions on PFAS chemicals would include the majority of fluorinated refrigerants used for refrigeration, air-conditioning and heat pump (RACHP) applications. The only commonly used HFC refrigerant that falls outside the PFAS definition is HFC-32. All other commonly used HFC and HFO refrigerants could be affected. This includes high GWP refrigerants such as HFC-134a, R-404A and R-410A and lower GWP alternatives including all HFOs and all HFC-HFO blends.

A broad-ranging PFAS restriction, if finalised, for the RACHP market would likely (a) slow the uptake of low GWP alternative refrigerants (which is crucial to meet HFC phase-down targets), (b) limit the energy efficiency of medium sized RACHP systems and (c) slow the roll-out of heat pumps (which are much needed to decarbonise heating). These three issues could likely lead to an increase in greenhouse gas emissions from the RACHP sector.

Most of the fluoropolymers used as flexible seals in compressors, valves and other RACHP components are defined as PFAS. It would be very challenging for the RACHP industry to redesign all these products with alternative sealing materials. Fluoropolymers are widely used because they provide high integrity seals in the arduous temperature and pressure conditions found inside RACHP systems – most other flexible products cannot achieve this.

7.2 Announcement by manufacturer to cease production of chemicals falling under PFAS definition

One long-time manufacturer[25] of several alternatives has announced that due to the rapidly evolving regulatory and business landscape it intends to cease production of chemicals falling under the PFAS definition by the end of 2025. Some of these chemicals are currently used as alternatives to controlled substances in end uses including solvent applications, semiconductor and electronics manufacturing, and magnesium production. For example, this company produces several HFOs that are used as alternatives to ODSs and HFCs in solvent applications (e.g., for precision cleaning in critical military and aerospace applications) and as heat transfer fluids in semiconductor operations. Additionally, a fluoroketone supplied by that manufacturer is used as an alternative to HFC-134a in magnesium production cover gas mixtures.

These alternatives have been supporting the transition away from ODS and HFCs under the Montreal Protocol and its Kigali Amendment. Based on this announcement, the supply of, and choices available for, alternatives to controlled substances for a range of industries and applications may be reduced or eliminated (where the company is the sole supplier of these chemicals globally), depending upon production from other suppliers. This will likely impact, technically and/or economically, industries using these alternatives, with the potential to delay transition to lower GWP options in some applications.

[25] https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025

8 Decision XXXIV/11: Composition, balance and workload of the Technology and Economic Assessment Panel and its technical options committees

8.1 Mandate and organisation of work

Following discussions on proposals put forward by TEAP during the 44th OEWG on the current and future tasks and workload of TEAP and its TOCs, the parties approved Decision XXXIV/11 at the ensuing MOP-34, in reference to the composition, balance and workload of the panel and its technical committees. The Decision reads:

Acknowledging the important role of the Technology and Economic Assessment Panel and its technical options committees and temporary subsidiary bodies in the provision of independent technical and scientific assessments, which have assisted the parties in arriving at well-informed decisions,

Recalling decision XXIV/8, in which the parties set out the terms of reference, a code of conduct, and disclosure and conflict of interest guidelines for the Panel and its technical options committees and temporary subsidiary bodies,

Recalling also decision XXVIII/1, by which parties adopted the Kigali Amendment to the Montreal Protocol, and decision XXVIII/2, which set out elements associated with the Kigali Amendment,

1. To request the Technology and Economic Assessment Panel, including through consultation by the co-chairs of the technical options committees with their members, to provide more information on existing challenges and potential options for the future configuration and function of its technical options committees, for consideration by the Open-ended Working Group of the Parties to the Montreal Protocol at its forty-fifth meeting, taking into account:

a) Discussions and questions raised by parties at the forty-fourth meeting of the Open-ended Working Group and the Thirty-Fourth Meeting of the Parties concerning the Panel's recommendations in its 2022 progress report;

b) The fact that the vast majority of HFC uses are in the refrigeration, air-conditioning and heat-pump sector;

c) Expertise required to provide technical and cost-related information to the parties, including in the context of implementation of the Kigali Amendment;

d) Guidance provided in its terms of reference;

e) The need to ensure continued collaboration and coordination across the technical options committees;

2. To rename the Halons Technical Options Committee the Fire Suppression Technical Options Committee.

8.2 Organization of work

In response to Decision XXXIV/11, TEAP assigned a working group amongst its members, including one representative from each TOC and one senior expert, to address the decision. Work was conducted initially by electronic communication, discussed face-to-face during the TEAP meeting, 23-27 April 2023, and finalised on-line in the weeks following the TEAP meeting.

8.3 Questions from the parties (44th OEWG and 34th MOP)

At the 44th OEWG (July 2022), TEAP presented a proposal for restructuring its technical options committees. A summary of this presentation can be found in Annex III, Section C of the 44th OEWG report https://ozone.unep.org/system/files/documents/OEWG-44-4E.pdf paras 61 and 62. This issue was discussed under agenda item VIII and during bilateral and informal group meetings. The topic was then further discussed during the MOP-34 under agenda item XI. A contact group was formed for parties to further discuss how to strengthen the TEAP and its TOCs for the phase-down of HFCs and other future challenges related to the Montreal Protocol and the climate. The Ozone Secretariat recorded the questions and comments from the parties, which can be found at https://ozone.unep.org/meetings/thirty-fourth-meeting-parties/contact-groups/restructuring-teaptocs.

8.4 Expertise required for current and anticipated workload to provide technical and cost-related information to the parties, including in the context of implementation of the Kigali Amendment

The TEAP anticipates that the workload of TEAP and its TOCs will remain, at least, at the same high level it has had for the past several years.

In addition to yearly requests for technical and economic information of interest to the parties for a particular topic or activity, the TEAP and its TOCs have several standing requirements for annual, triennial, quadrennial and quintennial analyses and reports on ODS phase-out, HFC phase-down and alternatives, destruction technologies, process agents, *n*-propyl bromide, laboratory and analytical uses, replenishment, energy efficiency, cross panel issues, etc. The TEAP has in the past, and will continue in the future, to organise its activities to meet all of these current and emerging technical and economic assessment needs of the parties.

To maintain or enhance the information that TEAP and its TOCs provide to the parties, and as the TEAP has reported for many years, TOC co-chairs continually review their membership to ensure having the expertise necessary to provide parties with the latest technical and economic information in their sector, and to be able to respond to specific party requests. That will continue for the foreseeable future. Likewise, the TEAP also continually assesses its organisation and functioning to ensure an effective and efficient structure to respond to ongoing party requests and needs.

In 2022, TEAP made a proposal to reconfigure two of its TOCs with the intended outcome not only to continue to support the parties' needs efficiently and effectively, but also to facilitate greater collaboration and synergy across sectoral topics with commonalities, particularly across the RACHP and foam sectors. In response to the discussion of the parties during the 44th OEWG and the 34th MOP, and the direction given by parties in this decision, TEAP is now proposing a modified approach that is still aimed at ensuring an effective and efficient organisation to respond to ongoing party needs and requests. This has involved critically reviewing and renewing the organisation and membership of RTOC to provide broader and more varied expertise to address cross-cutting and emerging issues. This is an ongoing process. The TEAP will continue to monitor its configuration and functioning to maintain or enhance its ability to respond to the parties while achieving synergies between its TOCs in addressing cross-cutting and emerging issues including energy efficiency and flammability/safety.

Currently, the TEAP and its TOCs have the following positions it would like to fill, keeping in mind gender and geographic balance but also understanding the need for technical and economic information to the parties. The full matrix of needed expertise for TEAP, which includes Senior Experts, is in Annex 5 of this report.

Table 8-1. Matrix of needed expertise on TOCs

Body	Required Expertise	A5/ Non-A5
Foams TOC	Experts in extruded polystyrene production in India and China	A5
	Polyurethane system house technical experts (especially from small and medium enterprises)	A5 from southern Africa, the Middle East, Southeast Asia, or Mexico
	Foam chemistry experts and expertise in building science related to the cross cutting issue of energy efficiency	A5 or non-A5
Fire Suppression TOC	Use of HFCs and Alternatives	South America, Middle East and Africa (2)
	Halon use in merchant shipping and recovery from shipbreaking	A5
Methyl Bromide TOC	QPS uses of MB and their alternatives particularly SE Asia	A5
	Alternatives to QPS uses of MB adopted in Europe	Non-A5
	Members with expertise in disinfestation of agricultural produce and bilateral trade agreements and links to the Technical Panel on Phytosanitary treatments Committee (TPPT) and the International Plant Protection Convention.	Non-A5 or A5
	Nursery industries, especially issues affecting the strawberry runner industries globally	A5 or non-A5
Medical and Chemical TOC	Aerosols	China, Indonesia, Latin America
	Semiconductor/electronics manufacturing and use	East Asia and non-A5
	End-of-life management Non-refillable and refillable containers, storage	A5 A5 and non-A5
Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC)	After 17 new members were appointed to cover the expected scope for the next Assessment term, no required expertise is needed at present. Following the outcomes of the discussion of the TOCs TOR for the next Assessment Report, new expertise may be needed and will be appropriately addressed.	

8.5 Ensuring continued collaboration and coordination across technical options committees

In light of recent proposals and discussions, and in response to Decision XXXIV/11, TEAP re-considered options of combining TOCs, dividing TOCs, creating new TOCs, and of maintaining the status quo.

The TEAP is proposing to maintain the structure of its current five TOCs aligned along the Montreal Protocol sectors: Flexible and Rigid Foams (FTOC), Fire Suppression (FSTOC), Methyl Bromide (MBTOC), Medical and Chemicals (MCTOC) and Refrigeration, Air-conditioning and Heat Pumps (RTOC), at this time. TEAP deems that positions the TEAP, its TOCs and the Montreal Protocol for continued coverage of the key sectors under the ODS phase-out and HFC phase-down.

The TEAP understands that the uses/subsectors in RACHP addressed by the RTOC account for the majority of HFCs and their alternatives on a sheer mass or volume basis, as stated in paragraph 1(b) of this decision. TEAP recognises the importance of the RTOC being positioned to fully address the different sectoral uses while also addressing cross-cutting and emerging issues for parties. TEAP is also mindful that there remain important technical challenges and risks posed within the other sectors that need to continue to be fully taken into account in the composition of the TEAP and its TOCs. While these other sectors are smaller in the consumed amount of ODS or HFCs, they are nonetheless not trivial and are important to the functioning, health, or safety of society; asthma patients need their inhalers, civil aircraft and server farms need their fire suppressants, buildings and appliances need their foams to reduce energy consumption, agriculture needs its pesticides for safe import and export of foodstuffs and handling of exotic (quarantine) pests, and so forth. TEAP and its TOCs also need to maintain their expertise in production, feedstocks, banks, and emissions (from all sources) to address the needs of parties. To fully support the parties, TEAP also needs to be ready to address any potential critical use or essential use nominations from these sectors. The Montreal Protocol has been successful in managing such challenges and the risks posed to society while protecting the ozone layer and climate.

All TOCs have reviewed, are reviewing, and continue to review their required membership for the future and have made, are making, and continue to adjust accordingly. This allows for renewal of new expertise where required. TEAP provides its further considerations on the workload and configuration of its TOCs in the following sections.

8.6 Further considerations on the workload and configuration of TEAP TOCs

8.6.1 Flexible and Rigid Foams Technical Options Committee (FTOC)

FTOC members currently have required expertise in: producing and handling foam blowing agents; foam formulation; foam production (PU, XPS, Phenolic, 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.

FTOC is seeking additional experts to provide expertise in A5 extruded polystyrene production in India and China replacing experts that left the FTOC. FTOC also seeks polyurethane system house technical experts from southern Africa, the Middle East, Southeast Asia, or Mexico (especially from small and medium enterprises) as they seem to continue to face challenges in the transition from HCFC-141b. FTOC also seeks additional foam chemistry experts globally and expertise in building science related to the cross-cutting issue of energy efficiency from A5 or non-A5 parties.

For the immediate future, no change in current composition is anticipated for the FTOC. The current organisation of FTOC includes 20 members consisting of two co-chairs, 7 A5 members and 13 non-A5 members. FTOC continues to work to improve its geographical as well as gender balance among its expert members.

8.6.2 Fire Suppression Technical Options Committee (FSTOC)

The parties renamed the Halons TOC as the Fire Suppression TOC in 2022 in recognition that the committee had an increased scope beyond halons. This includes assessing current and potential HFC alternatives needed to implement the Kigali Amendment and potential ramifications of the increased reliance on flammable refrigerants. The committee considers that it has sufficient expertise in the area of refrigerant flammability and no additional members will need to be recruited for now.

The FSTOC maintains expertise in the following five main areas:

1. A fundamental scientific understanding of fire chemistry and the process of combustion and fire extinguishment, flammability characteristics, 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 enduring 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 off high-GWP HFCs.

5. In addition, the FSTOC 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 FSTOC 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 FSTOC also maintains expertise in banking and recycling of halons, HCFCs, high GWP HFCs and their alternatives and on halon recovery (amounts, quantity and quality) from active and historic shipbreaking activities. From a regional standpoint, the FSTOC 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 (China, India and World Bank expertise on halon production phase-out in China).

The FSTOC currently has 17 members including three cochairs (two from non-A5 parties and one from a former County with Economy in Transition (CEIT)). In 2023, a former member from a non-A5 party retired and a new A5 party member has been added for a total of six A5 members, all males. There are four females of the eight non-A5 members, excluding the co-chairs).

As noted in the matrix of expertise needed in the TEAP 2022 Progress Report, the FSTOC is continuing to look for additional experts to promote A5/non-A5 and regional balance while also being mindful of gender balance. Considering the above discussion, as the HFC phase-down commences in A5 parties, the committee envisions expanding its A5 membership to increase representation of HFC and alternatives use in the currently under-represented areas or regions, namely South America, Middle East and Africa (2). In addition, the committee is looking to increase its knowledge in shipbreaking activities as this could remain an important source of recycled halon 1301. In recognition of the TEAP Terms of Reference, ideally, the committee would increase its A5 membership from 6 to 11 keeping in mind the goal of gender and geographic balance to give a total membership of 18 members, 3 co-chairs with a total of 50% A5 participation.

8.6.3 Methyl Bromide Technical Options Committee (MBTOC)

MBTOC provides parties to the Montreal Protocol with information on alternatives which could be used to replace methyl bromide used as a fumigant to kill pests, diseases and weeds affecting agricultural products and commodities, and other structures and artefacts. It also assesses CUNs submitted by parties, plus QPS uses and alternatives which affect global trade and biosecurity. It provides parties with information on emissions of MB from the variety of uses, the registration of MB and its alternatives around the world. It documents health effects of MB, assesses destruction technologies for MB, and various other issues as requested by the parties over time. MBTOC also provides updates on developments related to research, evaluation, and availability of MB alternatives and on MB consumption and production trends in all parties. Importantly for QPS use, it also provides an important role in identifying the main categories of use and where alternatives are most needed.

MBTOC currently consists of 17 experts with expertise in the control of diseases and pests which affect commodities in international trade or movement and production within countries. It has two co-chairs, one A5 and one non-A5 and one economist. Members also have specialist expertise with knowledge of management of incursions from exotic outbreaks of quarantine pests and all members have relevance to quarantine and pre-shipment uses of MB. MBTOC members are active as researchers, academic professionals, technical consultants, commercial fumigators, trainers and speakers in countries and regions around the globe, who keep permanently abreast of new developments and trends to control pests and plant diseases. Through its wealth of expertise, MBTOC has contributed significantly to the present virtually complete phase-out of global MB consumption for controlled uses.

As clarity of definitions evolve around QPS uses of MB, MBTOC stands ready to assist parties on this issue, and the impact of any further controls on MB, bearing in mind that QPS use of MB is one of the key non-controlled uses for an ODS. MBTOC will, where relevant, continue to provide updated information on alternatives to the parties. It also has expertise available to assess other issues affecting sustainability of alternatives and the impact of other ODS on agricultural production if required. MBTOC is aware of the need of strengthening its geographical and gender balance ensuring the best expertise as required for the appropriate completion of its tasks to support the parties.

8.6.4 Medical and Chemical Options Committee (MCTOC)

The MCTOC reports to the Montreal Protocol on production, by-production, and feedstock uses of controlled substances, solvent and process agent applications, electronics manufacturing, magnesium production, laboratory and analytical uses, end-of-life management, disposal and destruction of controlled substances, aerosols, and pressurised metered dose inhalers (pMDIs) and their alternatives.

In May 2023, MCTOC has 3 co-chairs (from Australia, China, Japan), 36 members, and 2 consulting experts. At the end of 2022, MCTOC had 15 members whose terms of appointment ended; by May 2023, 11 of those have been reappointed as members for additional terms of up to 4 years. Two members with sterilants expertise retired at the end of 2022.

To address the wide range of topics and reporting tasks, members include experts in asthma and chronic obstructive pulmonary disease and their treatment, pharmaceutical manufacturing and markets, aerosols manufacturing and markets, chemicals manufacturing and markets, laboratory and analytical procedures, end-of-life management, banks, disposal, and destruction. Members have academic, research, clinical, regulatory, laboratory, industrial, business, consulting, and commercial experience.

Co-chairs of MCTOC continue to review and renew its membership and to consider its configuration, gender and geographic balance, to ensure it can address current and future challenges of the Montreal Protocol in medical/aerosols and chemical sectors. The broad range of topics and applications that are addressed by MCTOC requires flexible management and a large membership to ensure adequate sectoral coverage. This leads to a heavy administrative and sectoral workload for MCTOC co-chairs and members in providing coverage and in addressing each application and issue in the detail required for reports. This continues to be challenging with such a broad range of topics, and leads to a heavy workload, especially for quadrennial assessments.

To assist with management, MCTOC operates in sub-groups, when appropriate, divided into Chemicals and Medical/Aerosols. Within those two broad sub-groups, smaller working groups operate to discuss topics and draft text, as needed. For the assessment report this included separate sub-groups within Chemicals for production, solvents and process agents, electronics manufacturing and magnesium production, end-of-life/destruction, laboratory and analytical uses, and within Medical/Aerosols for each of pMDIs, sterilants, and aerosols. This led to challenging timetabling of online meetings for co-chairs and cross-cutting expert members, with up to four 1-2-hour meetings timetabled per week during some busy periods. This put pressure on individuals, particularly co-chairs, in balancing their professional and personal lives with their volunteer MCTOC commitments.

Acknowledging current and emerging interests of parties to the Montreal Protocol, MCTOC continues to expand its expertise in HFCs used in semiconductor and electronics manufacturing and end-of-life management, disposal, and destruction of controlled substances. To respond to emerging issues in the transition to low GWP pMDIs, MCTOC is seeking additional expertise in pMDIs. MCTOC is also seeking to expand expertise in aerosols to address geographic balance.

MCTOC seeks new members to strengthen expertise in the following identified key knowledge areas: aerosols (China, Indonesia, Latin America); electronics manufacturing and use (including East Asia); end-of-life management (A5 party) and non-refillable and refillable containers and storage; metered dose inhalers (India, Japan, United States).

8.6.5 Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC)

The RTOC assesses refrigerant options mainly for vapor compression cycles used for stationary refrigeration, transport refrigeration, space cooling and heating, industrial applications, and mobile air conditioning. In addition, RTOC responsibilities have expanded to encompass not-in-kind refrigeration and heating technologies, servicing and refrigerant management, and energy efficiency.

The global demand for these applications is high, and growing fast, because these applications address essential human needs such as food, health and comfort. They can be found across multiple sectors globally, reflecting their versatility and usefulness.

Many of the refrigerants currently used in RACHP applications are controlled substances under the Montreal Protocol, i.e., HCFCs and HFCs. However, there is a current trend in using synthetic refrigerants, HFOs, and the so-called “natural refrigerants,” namely ammonia, carbon dioxide and hydrocarbons (HCs) in some applications. The use of alternative refrigerants is typically a balance between environmental issues, suitability for the targeted use, availability, cost of the refrigerant and associated equipment and service, energy efficiency rating, safety/flammability, and ease of use.

At the end of 2022, the term of all RTOC members terms expired, thus, as soon as the work on RTOC 2022 Assessment Report was completed, co-chairs started working for a membership evolution that took into account the emerging needs of the Montreal Protocol, expertise needed, regional balance, and gender balance. The results achieved so far are detailed at the end of this present section. The resulting appointments considered two main areas: cold chain for the conservation of food and vaccines (CC, short for Cold Chain), and space heating and cooling via heat pumps and air conditioning equipment and systems (AC, short for Air Conditioning).

While there are two main application categories (CC and AC), there are some additional important RACHP applications and cross cutting issues that need to be considered that also support RTOC to continue functioning as a single body:

a) the applications are based on the same technology (vapor compression cycle) and require the same theoretical competences and skills;

b) the refrigerants (working fluids) used in the diverse RACHP applications are the same and share the same local and global environmental issues;

c) energy efficiency is an issue that encompasses all the applications, and can be tackled with the same type of arrangements, with the same goal of reducing greenhouse gas emissions;

d) issues to be faced when the applications are to be installed in particular environments (e.g., high ambient temperature locations) are the same;

e) some applications do not naturally fit into these applications, e.g., industrial refrigeration for non-food sectors (e.g. oil and gas), organic Rankine cycles, etc.;

f) servicing requires the same competencies and skills, and the same technician can service adequately both CC and AC applications; modelling for refrigerant bank estimates and emissions should be done for both CC and AC.

Based on all of these considerations, including the discussions and questions from the parties, TEAP is now proposing to continue to maintain a single RTOC to address all of the current and future RACHP issues. Maintaining one RTOC will not be without some challenges, but it is considered the best path forward at this time. In this sense, it is important to note the following:

a) The typical industry arrangement is to have companies that design, produce and install systems for the cold chain separate from the companies that design, produce and install systems for space cooling and heating.

b) The decarbonization of the energy final uses is progressing with the substitution of gas/oil boilers for space heating in favour of heat pumps, which will increase the demand for refrigerants (most of the current options are controlled substances under the Montreal Protocol), creating new market opportunities for the companies so far addressing specifically the space cooling market,

c) Highly skilled designers and engineering companies are increasingly specialising in one sector of activity (CC or AC) only.

d) Even if they are based on the same physical theory, equipment and systems designed and built for the CC often have many differences from equipment and systems built for the AC.

Drawing upon the lessons learned from other TOCs in periods of high workload, e.g., MBTOC with a large number of CUNs, and in addressing multiple sectors or subsectors, e.g., MCTOC, and considering the discussions within TEAP for RTOC re-organisation, the RTOC will continue to be a single body be primarily organised around its two main areas — Cold Chain and Space Heating and Cooling — as implementation of Kigali Amendment proceeds. The entire RTOC will meet as a single body in the same location but will hold separate breakout working groups focused on the Cold Chain and Space Heating and Cooling. RTOC will produce a single consensus report. The cochairs will manage the work across cross-cutting issues. From a workload and management standpoint, it is proposed that the RTOC have one additional co-chair, for a total of four, two from A5 and two from non-A5 parties. The proposal for scope and organisation can be articulated as follows:

a) One additional co-chair, proposed from a non-A5 party, for a total of four, taking into consideration the TEAP TOR requirements of expertise and experience relevant to managing a TOC, while accounting for gender and geographic balance. Two co-chairs would coordinate the activities of the CC sub-group and the other two would coordinate the activities of AC sub-group.

b) The 4 co-chairs would work together for the coordination of, and across, all RTOC activities.

c) For CC working group: the refrigeration applications including cold chain for food and vaccines, domestic refrigeration, commercial refrigeration, transport refrigeration (road, rail, sea and air), industrial food and medical refrigeration.

d) For AC working group: all the technologies devoted to maintaining comfort conditions in inhabited spaces, both in winter and in summer (building and mobile, also considering the thermal management of electrical vehicles), and also the technologies for the climatization of industrial process and special applications (such as for micro-electronics industry, clean rooms, etc.).

e) The cross-cutting issues (refrigerants, energy efficiency, servicing, industrial refrigeration, heat engines, and modelling) will be treated together by the experts of the full RTOC, per the consensus direction of the four co-chairs.

f) Considering that many cross-cutting issues are shared with FTOC (e.g., energy efficiency, minimisation of cooling and heating loads in buildings and cold chambers, etc.), RTOC co-chairs will work closely with FTOC co-chairs to maintain consistency between FTOC and RTOC outputs. When appropriate, FTOC and RTOC experts will coordinate to give consistent answers to common technical issues.

At the beginning of 2023, the RTOC co-chairs started working to nominate members to address emerging and current issues in the Montreal Protocol and the 2023-2026 quadrennium, taking composition and work balance into consideration. This is summarised as follows.

a) To address the additional scope related to the current and future challenges, new expertise was sought in the following fields:
   - Energy aspects related to RACHP applications,
   - Systems view of the RACHP applications,
   - Building energy simulation,
   - Economic aspects and modelling of RACHP sectors.

b) A recruitment campaign was then started to address expertise needed, geographical balance, and gender balance. The nominations for the new RTOC membership includes: 26 reappointed members from the previous term of appointments; and 17 new members. These members include 21 members from A5 parties and 13 females, to achieve the needed expertise, and geographical and gender balance.

c) This size of the committee (around 20 members for the CC subgroup and around 20 members for the AC subgroup) is deemed appropriate to address the current and future challenges that RTOC will be asked to address in the near future.

9 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

9.1 Introduction

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 publicise 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 4 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 party's experts to consider nominating. Nominations to a TSB (including TSB co-chairs) can be made by the TEAP co-chairs" (TOR 2.2.2).

9.2 Nominations and appointment process

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 6), that may include a curriculum vitae, and which is also available on the Ozone Secretariat's website[26]. 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 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."

9.3 Needed expertise on the TEAP

Section 2.1.1 of the TEAP Terms of Reference (TOR) states the following:

The membership size of the TEAP should be about 18-22 members, including 2 or 3 co-chairs to allow it to function effectively. It should include the co-chairs of the TOCs; there should be two co-

[26] https://ozone.unep.org/science/assessment/teap

chairs per TOC and 2-4 Senior Experts for specific expertise not covered by the TEAP co-chairs or TOC co-chairs, considering gender and geographical balance.

At the end of 2023, the terms will end for some TEAP members including two co-chairs each for MCTOC and RTOC and all Senior Experts (see Annex 4).

As indicated in the TEAP TOR, the Senior Experts to the TEAP fulfil an important role by providing specific expertise not covered by the other members (TEAP or TOC co-chairs). TEAP has identified its current needed expertise for Senior Experts in the matrix contained in Annex 5 of this report and provided below:

Body	**Required Expertise**	**A5/ Non-A5**
Senior Experts	Experts with extensive experience on TEAP technical and economic assessments, especially sector transitions and challenges in A5 parties; extensive knowledge and experience of Multilateral Fund (MLF) decisions, guidelines, operations, and related funding to meet financial needs of A5 parties under the ODS phase-out and HFC phase-down. Expert in the analysis and assessment (including modelling) of factors, including energy efficiency and regional economics, for forecasting the market penetration and potential future disposition of HCFCs, HFCs, and alternatives	A5 or non-A5

Currently, TEAP has four Senior Experts whose terms end in 2023. Based on the needed expertise, as indicated above, and taking into account gender and geographical balance as required by the TOR as well as continuity to its work, TEAP is recommending reappointment of the current Senior Experts for four-year terms.

Annex 1: List of pests that have been successfully controlled with EDN

Type	Family	Scientific name	Common name
Insect	Bostrichidae	*Rhyzopertha dominica*	Lesser grain borer
Insect	Cerambycidae	*Anoplophora glabripennis*	Asian long-horned beetle
Insect	Cerambycidae	*Arhopalus ferus*	Burnt pine longhorn beetle
Insect	Cerambycidae	*Hylotrupes bajulus*	House longhorn beetle
Insect	Cerambycidae	*Monochamus alternatus*	Japanese pine sawyer
Insect	Cerambycidae	*Tetropium fuscum*	Brown spruce longhorn beetle
Insect	Curculionidae	*Crypahalus fulvus*	Minute pine bark beetle
Insect	Curculionidae	*Dryocoetes autographus*	Hairy spruce bark beetle
Insect	Curculionidae	*Dryocoetes hectographus*	-
Insect	Curculionidae	*Hylastes ater*	Black pine bark beetle
Insect	Curculionidae	*Hylurgops palliatus*	Lesser spruce shoot beetle
Insect	Curculionidae	*Hylurgus ligniperda*	Golden-haired bark beetle
Insect	Curculionidae	*Ipstypographus*	European spruce bark beetle
Insect	Curculionidae	*Pityogenes chalcographus*	Spruce wood engrave
Insect	Curculionidae	*Polygraphus poligraphus*	-
Insect	Curculionidae	*Tomicus piniperda*	Common pine shoot beetle
Insect	Dermestidae	*Trogoderma variabile*	Warehouse beetle
Insect	Dryophthoridae	*Sitophilus granarius*	Wheat weevil
Insect	Dryophthoridae	*Sitophilus oryzae*	Rice weevil
Insect	Erebidae	*Hyphantria cunea*	Fall webworm
Insect	Kalotermitidae	*Cryptotermes brevis*	West Indian drywood termite
Insect	Ptinidae	*Lasioderma serricorne*	Cigarette beetle
Insect	Rhinotermitidae	*Reticulitermes speratus*	Japanese termite
Insect	Siricidae	*Sirex noctilio*	Sirexwoodwasp
Insect	Siricidae	*Sirex juvenus*	Steel-blue woodwasp
Insect	Siricidae	*Urocerus gigas*	Giant woodwasp
Insect	Tenebrionidae	*Tribolium castaneum*	Red flour beetle
Insect	Tenebrionidae	*Tribolium confusum*	Confused flour beetle
Nematode	Heteroderidae	*Meloidogyne incognita*	Southern root-knit nematode
Nematode	Hoplolaimidae	*Hoplolaimus galeatus*	Lance nematode
Nematode	Hoplolaimidae	*Helicotylenchus spp.*	Spiral nematodes
Nematode	Parasitaphelenchidae	*Bursaphelenchus xylophilus*	Pine wood nematode
Nematode	Pratylenchidae	*Pratylenchus spp.*	Lesion nematodes
Nematode	Rhabditidae	*Cruznema tripartitum*	-
Nematode	Rhabditidae	*Oscheius sp.*	-
Nematode	Rhabditidae	*Rhabditis sp.*	-
Fungi	Bionectriaceae	*Geosmithia morbida*	Thousand cankers black walnut disease
Fungi	Bondarzewiaceae	*Heterobasidion annosum*	-
Fungi	Fagaceae	*Ceratocystis fagacearum*	Oak wilt
Fungi	Peronosporaceae	*Phytophthora ramorum*	Sudden oak death

Annex 2: Alternative treatments approved for compliance with ISPM-28 standards

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 01	Radiation treatment (RAT)	*Anastrephaludens* *Tephritidae : Diptera* Mexican fruit fly ANSTLU	All fruits and vegetables, that are hosts of *Anastrepha ludens*	Minimum absorbed dose of 70 Gy to prevent the emergence of adults of *Anastrepha ludens*.	99.9968%
PT 02	Radiation treatment (RAT)	*Anastrephaobliqua* *Tephritidae : Diptera* Antillean fruit fly ANSTOB	All fruits and vegetables that are hosts of *Anastrepha obliqua*	Minimum absorbed dose of 70 Gy to prevent the emergence of adults of *Anastrepha obliqua*.	99.9968%
PT 03	Radiation treatment (RAT)	*Anastrephaserpentina* *Tephritidae : Diptera* sapodilla fruit fly ANSTSE	All fruits and vegetables that are hosts of *Anastrepha serpentina*	Minimum absorbed dose of 100 Gy to prevent the emergence of adults of *Anastrepha serpentina*.	99.9972%
PT 04	Radiation treatment (RAT)	*Bactrocerajarvisi* *Tephritidae : Diptera* Jarvis's fruit fly BCTRJA	All fruits and vegetables that are hosts of *Bactrocera jarvisi*	Minimum absorbed dose of 100 Gy to prevent the emergence of adults of *Bactrocera jarvisi*.	99.9981%
PT 05	Radiation treatment (RAT)	*Bactroceratryoni* *Tephritidae : Diptera* Queensland fruit fly DACUTR	All fruits and vegetables that are hosts of *Bactrocera tryoni*	Minimum absorbed dose of 100 Gy to prevent the emergence of adults of *Bactrocera tryoni*.	99.9978%
PT 06	Radiation treatment (RAT)	*Cydiapomonella* *Tortricidae : Lepidoptera* Codling moth CARPPO	All fruits and vegetables that are hosts of *Cydia pomonella*	Minimum absorbed dose of 200 Gy to prevent the emergence of adults of *Cydia pomonella*.	99.9978%
PT 07	Radiation treatment (RAT)	*Tephritidae* *Insecta : Hexapoda* 1TEPHF	All fruits and vegetables that are hosts of fruit flies of the family *Tephritidae*	Minimum absorbed dose of 150 Gy to prevent the emergence of adults of fruit flies.	99.9968%
PT 08	Radiation treatment (RAT)	*Rhagoletispomonella* *Tephritidae : Diptera* Apple maggot fly RHAGPO	All fruits and vegetables that are hosts of *Rhagoletis pomonella*	Minimum absorbed dose of 60 Gy to prevent the development of phanerocephalic pupae of *Rhagoletis pomonella*.	99.9921%
PT 09	Radiation treatment (RAT)	*Conotrachelus nenuphar* Curculionidae : Coleoptera plum weevil CONHNE	All fruits and vegetables that are hosts of *Conotrachelus nenuphar*	Minimum absorbed dose of 92 Gy to prevent the reproduction in adults of *Conotrachelus nenuphar*.	99.9880%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 10	Radiation treatment (RAT)	*Grapholit amolesta Tortricidae :* Lepidoptera oriental fruit moth LASPMO	All fruits and vegetables that are hosts of *Grapholita molesta*	Minimum absorbed dose of 232 Gy to prevent the emergence of adults of *Grapholita molesta.*	99.9949%
PT 11	Radiation treatment (RAT)	*Grapholita molesta Tortricidae :* Lepidoptera oriental fruit moth LASPMO	All fruits and vegetables that are hosts of *Grapholita molesta* under hypoxia	Minimum absorbed dose of 232 Gy to prevent oviposition of *Grapholita molesta.*	99.9932%
PT 12	Radiation treatment (RAT)	*Cylas formicarius* Apionidae : Coleoptera sweet-potato weevil CYLAFO	All fruits and vegetables that are hosts of *Cylasformicarius*	Minimum absorbed dose of 165 Gy to prevent the development of F1 adults of *Cylas formicarius.*	99.9952%
PT 13	Radiation treatment (RAT)	*Euscepe spostfasciatus* Curculionidae : Coleoptera West Indian sweet-potato weevil EUSPPO	All fruits and vegetables that are hosts of *Euscepe spostfasciatus.*	Minimum absorbed dose of 150 Gy to prevent the development of F1 adults of *Euscepes postfasciatus.*	99.9950%
PT 14	Radiation treatment (RAT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	All fruits and vegetables that are hosts of *Ceratitis capitata.*	Minimum absorbed dose of 100 Gy to prevent the emergence of adults of *Ceratitis capitata.*	99.9970%
PT 15	Vapour Heat (TPT-VH)	Tephritidae : Diptera melon fly DACUCU	*Cucumis melo var. reticulatus* Cucurbitaceae : Cucurbitales netted melon CUMMR(netted melon)	Fruit core temperature raised to a minimum of 45 °C in a vapour heat chamber and maintained for 30 minutes in accordance with ISPM 28 PT 15.	99.9889%
PT 16	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	(Orange)	Maximum fruit core temperature kept at 3 °C or below for 16 continuous days.	99.9981%
PT 17	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Citrus reticulata x C. sinensis (tangor)*	Maximum fruit core temperature kept at 3 °C or below for 16 continuous days.	99.9986%
PT 18/1	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Citrus limon* Rutaceae : Sapindales lemon CIDLI(lemon)	Maximum fruit core temperature kept at 2 °C or below for 14 continuous days.	99.99%

ISPM 28 number	**Type of Treatment**	**Pest**	**Product Commodity**	**Schedule**	**Efficacy**
PT 18/2	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Citrus limon* Rutaceae : Sapindales lemon CIDLI(lemon)	Maximum fruit core temperature kept at 3 °C or below for 14 continuous days.	99.9872%
PT 19	Radiation treatment (RAT)	*Dysmicoccus neobrevipes* Pseudococcidae : Sternorrhyncha grey pineapple mealybug DYSMNE *Planococcus lilacinus* Pseudococcidae : Sternorrhyncha cacao mealybug PLANLI *Planococcus minor* *Pseudococcidae : Sternorrhyncha* *passion vine mealybug* *PLANMI*	All fruits and vegetables that are hosts of the above mealybugs	Minimum absorbed dose of 231 Gy to prevent the reproduction of adult females of *Dysmicoccus neobrevipes, Planococcus lilacinus* and *Planococcus minor.*	99.99023%
PT 20/1	Radiation treatment (RAT)	*Ostrinia nubilalis* Pyralidae : Lepidoptera European corn borer PYRUNU	All fruits and vegetables that are hosts of *Ostrinia nubilalis.*	Minimum absorbed dose of 289 Gy to prevent F1 development of *O. nubilalis.*	99.987%
PT 20/2	Radiation treatment (RAT)	*Ostrinia nubilalis* Pyralidae : Lepidoptera European corn borer PYRUNU	All fruits and vegetables that are hosts of *Ostrinia nubilalis.*	Minimum absorbed dose of 343 Gy to prevent F1 egg hatching of *O. nubilalis.*	99.9914%
PT 21	Vapour Heat (TPT-VH)	*Bactrocera melanota* Tephritidae : Diptera BCTRME *Bactrocera xanthodes* Tephritidae : Diptera BCTRXA	*Carica papaya* Caricaceae : Brassicales pawpaw CIAPA(papaya)	Fruit core temperature raised to a minimum of 47.5 °C in a forced hot air chamber and maintained for 20 minutes in accordance with ISPM 28 PT 21.	99.9914%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 22/1	Fumigation (CHT-FU)	Wood-borne life stages of insects, including *Anoplophora glabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopalus tristis* (Coleoptera: Cerambycidae)	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis).	Sulphuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 3200 g·h/m3 and minimum concentration of 93 g/m3 at ≥15 °C over 24 hours.	*Anoplophora glabripennis* (larvae and pupae) 99.99683% *Anobium punctatum* 99.7462% *Arhopalus tristis* 99%
PT 22/2	Fumigation (CHT-FU)	Wood-borne life stages of insects, including *Anoplophora glabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopalus tristis* (Coleoptera: Cerambycidae)	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis).	Sulphuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 2300 g·h/m3 and minimum concentration of 67 g/m3 at ≥20 °C over 24 hours.	*Anoplophora glabripennis* (larvae and pupae) 99.99683% *Anobium punctatum* 99.7462% *Arhopalus tristis* 99%
22/3	Fumigation (CHT-FU)	Wood-borne life stages of insects, including *Anoplophora glabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopa lustristis (Coleoptera: Cerambycidae)*	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis)	Sulphuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 1500 g·h/m3 and minimum concentration of 44 g/m3 at ≥25 °C over 24 hours.	*Anoplophora glabripennis* (larvae and pupae) 99.99683% *Anobium punctatum* 99.7462% *Arhopalus tristis 99%*
PT 22/4	Fumigation (CHT-FU)	Wood-borne life stages of insects, including *Anoplophor aglabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopa lustristis* (Coleoptera: Cerambycidae).	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis).	Sulfuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 1400 g·h/m3 and minimum concentration of 41 g/m3 at ≥30 °C over 24 hours.	*Anoplophora glabripennis* (larvae and pupae) 99.99683% *Anobium punctatum* 99.7462% *Arhopalus tristis* 99%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 23/1	Fumigation (CHT-FU)	Wood-borne life stages of *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae) and insects, including *Anoplophora glabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopa lustristis* (Coleoptera: Cerambycidae).	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis).	Sulphuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 3000 g·h/m3 and minimum concentration of 29 g/m3 at ≥20 °C over 48 hours.	*Bursaphelenchus xylophilus* to not less than 99.99683%
PT 23/2	Fumigation (CHT-FU)	Wood-borne life stages of *Bursaphelenchus xylophilus* (Nematoda: Aphelenchoididae) and insects, including *Anoplophora glabripennis* (Coleoptera: Cerambycidae), *Anobium punctatum* (Coleoptera: Anobiidae) and *Arhopa lustristis* (Coleoptera: Cerambycidae).	Debarked wood not exceeding 20 cm in cross-section at its smallest dimension and 75% moisture content (dry basis).	Sulphuryl fluoride fumigation to achieve a minimum concentration time product (CT) of 1400 g·h/m3 and minimum concentration of 41 g/m3 at ≥30 °C over 24 hours.	*Bursaphelenchus xylophilus* to not less than 99.99683%
PT 24/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus sinensis* Rutaceae : Sapindales sweet orange CIDSI	Maximum fruit core temperature kept at 2 °C or below for 16 continuous days.	99.9937%
PT 24/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus sinensis* Rutaceae : Sapindales sweet orange CIDSI	Maximum fruit core temperature kept at 2 °C or below for 18 continuous days.	99.999%
PT 24/3	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus sinensis* Rutaceae : Sapindales sweet orange CIDSI	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9989%
PT 25/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus reticulata x Citrus sinensis* (tangerine)	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9987%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 25/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus reticulata x Citrus sinensis* (tangerine)	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9987%
PT 26/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus limon* Rutaceae : Sapindales lemon CIDLI	Maximum fruit core temperature kept at 2 °C or below for 16 continuous days.	99.9975%
PT 26/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus limon* Rutaceae : Sapindales lemon CIDLI	Maximum fruit core temperature kept at 3 °C or below for 18 continuous days.	99.9973%
PT 27/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus paradisi* Rutaceae : Sapindales pomelo CIDPA (grapefruit)	Maximum fruit core temperature kept at 2 °C or below for 19 continuous days.	99.9917%
PT 27/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus paradisi* Rutaceae : Sapindales pomelo CIDPA	Maximum fruit core temperature kept at 3 °C or below for 23 continuous days.	99.9916%
PT 28	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus reticulata* Rutaceae : Sapindales clementine CIDRE	Maximum fruit core temperature kept at 2 °C or below for 23 continuous days.	99.9918%
PT 29	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Citrus clementina* Rutaceae : Sapindales clementine CIDCL	Maximum fruit core temperature kept at 2 °C or below for 16 continuous days.	99.9900%
PT 30	Vapour Heat (TPT-VH)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Mangifera indica* Anacardiaceae : Sapindales mango MNGIN	Fruit core temperature raised to a minimum of 46.5 °C in a vapour heat chamber and maintained for 10 minutes in accordance with ISPM 28 PT 30.	99.9968%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 31	Vapour Heat (TPT-VH)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Mangifera indica* Anacardiaceae : Sapindales mango MNGIN	Fruit core temperature raised to a minimum of 47 °C in a vapour heat chamber and maintained for 15 minutes in accordance with ISPM 28 PT 31.	99.9968%
PT32	Vapour Heat (TPT-VH)	*Bactrocera dorsalis* Tephritidae : Diptera oriental fruit fly DACUDO	*Carica papaya* Caricaceae : Brassicales pawpaw CIAPA	Fruit core temperature raised to a minimum of 46 °C in a vapour heat chamber and maintained for a minimum of 70 minutes in accordance with ISPM 28 PT 32.	99.9841%
PT 33	Radiation treatment (RAT)	*Bactrocera dorsalis* Tephritidae : Diptera oriental fruit fly DACUDO	*Carica papaya* Caricaceae : Brassicales pawpaw CIAPA All fruits and vegetables that are hosts of *Bactrocera dorsalis*	Minimum absorbed dose of 116 Gy to prevent the emergence of adults of Bactrocera dorsalis	99.9963%
PT 34/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus avium* Rosaceae : Rosales cherry PRNAV	Maximum fruit core temperature kept at 1 °C or below for 16 continuous days.	99.9979%
PT 34/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus salicina* Rosaceae : Rosales Chinese plum PRNSC	Maximum fruit core temperature kept at 1 °C or below for 16 continuous days.	99. 9984%
PT 34/3	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus persica* Rosaceae : Rosales peach PRNPS	Maximum fruit core temperature kept at 1 °C or below for 16 continuous days.	99.9983%
PT 34/4	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus avium* Rosaceae : Rosales cherry PRNAV	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9982%
PT 34/5	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus salicina* Rosaceae: Rosales Chinese plum PRNSC	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9978%

ISPM 28 number	Type of Treatment	Pest	Product Commodity	Schedule	Efficacy
PT 34/6	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Prunus persica* Rosaceae : Rosales peach PRNPS	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9986%
PT 35/1	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Prunus avium* Rosaceae: Rosales cherry PRNAV	Maximum fruit core temperature kept at 3 °C or below for 14 continuous days.	99.9928%
PT 35/2	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Prunus salicina* Rosaceae: Rosales Chinese plum PRNSC	Maximum fruit core temperature kept at 3 °C or below for 14 continuous days.	99.9966%
PT 35/3	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Prunus persica* Rosaceae: Rosales peach PRNPS	Maximum fruit core temperature kept at 3 °C or below for 14 continuous days.	99.9953%
PT 36/1	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Vitis vinifera* Vitaceae: Vitales common grapevine VITVI	Maximum fruit core temperature kept at 1 °C or below for 16 continuous days.	99.9987%
PT 36/2	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Vitis vinifera* Vitaceae: Vitales common grapevine VITVI	Maximum fruit core temperature kept at 2 °C or below for 18 continuous days.	99.9987%
PT 36/3	Cold Treatment (TPT-CT)	*Ceratitis capitata* Tephritidae : Diptera Mediterranean fruit fly CERTCA	*Vitis vinifera* Vitaceae: Vitales common grapevine VITVI	Maximum fruit core temperature kept at 3 °C or below for 20 continuous days.	99.9986%
PT 37/1	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Vitis vinifera* Vitaceae: Vitales common grapevine VITVI	Maximum fruit core temperature kept at 1 °C or below for 12 continuous days.	99.9964%
PT 37/2	Cold Treatment (TPT-CT)	*Bactrocera tryoni* Tephritidae : Diptera Queensland fruit fly DACUTR	*Vitis vinifera* Vitaceae: Vitales common grapevine VITVI	Maximum fruit core temperature kept at 3 °C or below for 14 continuous days.	99.9984%
PT 38	Radiation treatment (RAT)	*Carposina sasakii* Carposinidae : Lepidoptera peach fruit moth CARSSA	All fruits and vegetables that are hosts of *Carposina sasakii*	Minimum absorbed dose of 228 Gy to prevent the emergence of viable adults of *Carposina sasakii*.	99.9893%
PT 39	Radiation treatment (RAT)	*Anastrepha* Diptera : Insecta 1ANSTG	All fruits and vegetables that are hosts of *Anastrepha*	Minimum absorbed dose of 70 Gy to prevent the emergence of adults of *Anastrepha* spp.	99.9968%

Annex 3: Chemical pathways in which substantial emissions of controlled substances are likely

A3.1 Likely emission rates

Controlled substances can be emitted from processes where they are present as either a product, an intermediate, a feedstock, or an impurity. The 2022 MCTOC Assessment Report provides the following mean production emission rates[27]:

- Products (Table 2.6 and 2.8)
  - 2.4 wt% for modern-day, regulated manufacturing from production (by weight of production)
  - 4 wt% for 1960–1980s vintage, regulated manufacturing annual emissions from production (by weight of production).
- Feedstocks (Table 2.7)
  - 0.3–0.9 wt% for modern-day, regulated production for feedstock use (by weight of production)

Other possible emissions include intermediates and impurities. In practice intermediate emissions are typically seen at less than 0.1 wt%, non-isolated intermediates are often emitted at less than 0.01 wt%.

There are also several mechanisms that account for the by-production of controlled substances in other production processes (see section 2.3 of the 2022 MCTOC Assessment Report[28]) including:

- Over- or under-reaction en route to the intended product, e.g., HFC-23 is an over-fluorination of HCFC-22, or CTC is an over-chlorination of chloroform.
- Presence of impurities in the feedstocks being reacted to a by-product, e.g., the presence of CTC in chloroform used to produce HCFC-22 will typically result in the formation of CFC-11 and CFC-12, and CFC-13 formation is also possible.
- Side reactions where the feedstock follows a different reaction path than the one that is desired to make the product. For example, it is reported that:
  - when perchloroethylene is used to produce HFC-125, there are several side reactions that can result in the formation of a CFC, most likely CFC-115, but other less fluorinated CFCs, such as CFC-113 or CFC-114, may be formed.
  - CFC-13, HFC-23 and HFC-32 are produced in the pyrolysis of HCFC-22 when making TFE (tetrafluoroethylene).

The design intent of most plants is to minimise the by-production of these controlled substances as they tend to have a detrimental economic effect, because they:

- Consume feedstocks that cannot be sold as the final product.
- May require additional process steps to remove them from the final product and/or mitigate

[27] Mean emission rates are used because the assessment covers global production employing these chemical pathways. Individual process plants may operate either transiently or continuously at higher or lower emission rates. Process plant with effective destruction technology, e.g., thermal oxidation, may emit at significantly lower rates, whereas less optimised process plant may emit at significantly higher rates. Emissions rates used for this assessment are for production emissions only (for the chemical pathway), not the distribution and supply chain emissions.

[28] UNEP, 2022, *2022 MCTOC Assessment Report*, December 2022. Section 2.3.

the release of the by-product e.g., through thermal oxidation.

- In some cases, risk making the final product unsaleable.

Once formed unwanted by-products are likely to be emitted or destroyed (e.g., through thermal oxidation or incineration). Due to the additional expense of building and operating a process to collect and destroy these unwanted by-products regulation is often required to ensure effective mitigation.

The use of exceptionally impure feedstock (high in controlled substance precursors) or unusual process operating conditions, including during start up and shutdown and emergency relief, could emit elevated level of controlled substances however these elevated levels would typically be expected to be transient in nature as they are unlikely to be economically attractive to the operation of the process.

A3.2 Chemical pathway assessment process

1. *Listed likely controlled substance mean emission rates (as a fraction of the substance produced) by band for as many chemical pathways as we consider likely.*

Using a combination of actual emissions data from plants where available, knowledge of likely reactions, including common side reactions in the various processes, and generic most likely emission rates previously reported in the 2022 MCTOC Assessment Report, an estimate of mean emission rates per tonne of product for each controlled substance by chemical pathway was made according to the following 5 bands:

i. Mean emission rate per tonne of product 1–10 wt%, i.e., 10–100 kg of the controlled substance was emitted per tonne of product produced.[29]

ii. Mean emission rate per tonne of product 0.1–1 wt%, i.e., 1–10 kg of the controlled substance was emitted per tonne of product produced.

iii. Mean emission rate per tonne of product 0.01–0.1 wt%, i.e., 0.1–1 kg of the controlled substance was emitted per tonne of product produced.

iv. Mean emission rate per tonne of product 0.001–0.01 wt%, i.e., 10–100 grams of the controlled substance was emitted per tonne of product produced.

v. Mean emission rate per tonne of product <0.001 wt%, i.e., <10 grams of the controlled substance was emitted per tonne of product produced.

It should be noted that emission rates are likely to vary over time for an individual process, and from process to process, as they are impacted by a range of factors, including the chemical pathway used, feedstock impurities, feedstock feed ratios, operating conditions in the reactor, recycles back to the reactor, catalyst condition and composition, operation of mitigation and destruction steps, use of continuous, discontinuous, and emergency release points, etc. These variations increase uncertainty when predicting a mean emission rate.

Similarly, emission rates will also depend on the extent to which mitigation and destruction technologies are being employed by process plants across the globe to prevent the emission of the controlled substances generated. In many cases, this information is not publicly available or accessible.

It is suspected that not all, if any, process plants analyse and report all possible trace impurities that could be produced in their processes. These omissions are unlikely to influence the current assessment

[29] Emission rates at the top end this emission band would less likely be relevant to high quantity production.

due to the significance level chosen. However, if smaller global emission rates, e.g., <100 tonnes per year per chemical pathway, are of interest then these omissions in process plant analysis and reporting may be relevant.

2. *Assigned likely global production rates by band*

The current rates of production and feedstock use were estimated to provide a likely scale of emissions of the controlled substance. Production and feedstock quantities are available for controlled substances, but quantities are not available for chemical pathways producing or using non-controlled substances, e.g., for production of HFOs, or for reasons of commercial confidentiality. Exact production and feedstock quantities are not available for all different chemical pathways, so the production or feedstock consumption quantities were estimated and assigned to the relevant bands.

i. <1000 tonnes per year
ii. >1000 but less than 10,000 tonnes per year
iii. >10,000 but less than 100,000 tonnes per year
iv. >100,000 but less than 1 million tonnes per year
v. >1 million tonnes per year

3. *Plotted the substances by pathway on the matrix based on their likely emission rate band and global production band. Provide an accompanying table to outline, for clarity, the controlled substance released, the chemical pathway employed, and the likely emission rate per tonne and global production tonnage bands.*

4. *Included in the report the substances with "substantial" emissions by chemical pathway on the matrix and in the accompanying table, i.e., in the upper righthand corner of the matrix where emissions rates per tonne and global production rates are highest, these will include many products and feedstocks for large volume chemical processes.*

A.3.3 Application of the step-wise approach for this assessment

Example 1: HFC-32 production by dichloromethane pathway

- Most HFC-32 is generated by this route, so an estimate of HFC-32 global production by this pathway is in the 100,000 to 1 million tonnes per year band.
- Emissions of the product HFC-32 from a well-run, modern, highly regulated production plant, including storage and loading for transportation off-site, could average 2.5 wt%.[30]
- As HFC-32 is a product, mainly used in the RACHP industry, it is probable that most emissions will occur at point of use or end-of-life.
- Controlled substances generated from side reactions and feedstock impurities:
    - Average HFC-23 emissions based on data from a number of plants suggest that the average HFC-23 emission rate is likely to be in the 0.01–0.1 wt% band, with some plants in the 0.1–1 wt% band, and some likely to be in the <0.001 wt% emission band where thermal oxidation of vent streams is used.
    - HCFC-31 is an intermediate in HFC-32 production that is almost completely consumed in the process, therefore emissions are likely to be 0.001–0.01 wt%, although could be

[30] UNEP, 2022, *2022 MCTOC Assessment Report*, December 2022. Section 2.5.5.

higher or lower on different processes.

- Average HCFC-22 emissions, based on the assumptions that there is minimal chloroform in the dichloromethane feedstock and limited chlorination of dichloromethane to chloroform, suggest that the emission rate is likely to be in the 0.0001–0.001 wt% band as most HCFC-22 produced will be reacted to HFC-23.

This would put emission rates of HFC-32, HFC-23, HCFC-31, and HCFC-22 from HFC-32 production using the dichloromethane pathway in the follow boxes.

Table A3-1. HFC-32 production by dichloromethane pathway

		Global production				
		<1000 tonne of product per year	1,000–10,000 tonnes of product per year	10,000–100,000 tonnes of product per year	100,000–1 million tonnes of product per year	>1 million tonnes of product per year
Controlled substance emission rate from production	1–10 wt% 10–100 kg of emission per tonne of production				HFC-32	
	0.1–1 wt% 1–10 kg of emission per tonne of production					
	0.01–0.1 wt% 0.1–1 kg of emission per tonne of production				HFC-23	
	0.001–0.01 wt% 10–100 grams of emission per tonne of production				HCFC-31	
	<0.001 wt% <10 grams of emission per tonne of production				HCFC-22	

Note— Some HFC-23, HCFC-31, HCFC-22, and other controlled substances, may be contained in the product HFC-32, and therefore not released at the process plant but at the point that the HFC-32 is emitted during use or at end-of-life.

Example 2: HFC-125 production by perchloroethylene vapour phase pathway

- Most HFC-125 is generated by this route, so an estimate of HFC-125 global production by this pathway is in the 100,000 to 1 million tonnes per year band.
- Emissions of the product HFC-125 from a well-run, modern, highly regulated production plant including storage and loading for transportation off-site, could average 2.5 wt%.[31]
- As HFC-125 is a product, mainly used in the RACHP industry, it is probable that the majority of emissions will occur at point of use or end-of-life.
- Controlled substances generated from side reactions and feedstock impurities:
    - Average HFC-23 emissions based on data from a number of plants suggest that the HFC-23 emission rate is likely to be in the 0.001–0.01 wt% band, although individual plants may have higher or lower emission rates than this.
    - HCFC-122 and HCFC-123 are intermediates that are practically completely consumed in the process, with emissions likely to be 0.001–0.01 wt%, although individual plants may have higher or lower emission rates.
    - Average HCFC-124 generation is ~100 %, as it is an intermediate that is consumed in the process, with emissions likely to be 0.01–0.1 wt%, higher than HCFC-122 and HCFC-123 as HCFC-124 is involved in the final fluorination step to HFC-125.
    - Average CFC-115 generation and emissions based on plant data is expected to be in the 0.1–1 wt% band, although some plants may emit at over 1 wt% and some emit at <0.1 wt% if vent treatment is used.
    - Average other controlled substances emissions are likely to be <0.001 wt%.

This would put emission rates of HFC-125, HFC-23, HCFC-122, HCFC-123, HCFC-124, and CFC-115 from HFC-125 production using the perchloroethylene vapour phase pathway in the follow boxes.

[31] UNEP, 2022, *2022 MCTOC Assessment Report*, December 2022. Section 2.5.5.

Table A3-2. HFC-125 production by perchloroethylene vapour phase pathway

		Global production				
		<1000 tonne of product per year	1,000–10,000 tonnes of product per year	10,000–100,000 tonnes of product per year	100,000–1 million tonnes of product per year	>1 million tonnes of product per year
Controlled substance emission rate from production	1–10 wt% 10–100 kg of emission per tonne of production				HFC-125	
	0.1–1 wt% 1–10 kg of emission per tonne of production				CFC-115	
	0.01–0.1 wt% 0.1–1 kg of emission per tonne of production				HCFC-124 HFC-23	
	0.001–0.01 wt% 10–100 grams of emission per tonne of production				HCFC-122 HCFC-123	
	<0.001 wt% <10 grams of emission per tonne of production				Other controlled substances	

Note— Some CFC-115, HCFC-124, HFC-23, and other controlled substances, may be contained in the product HFC-125, and therefore not emitted at the process plant but at the point that the HFC-125 is emitted during use or end-of-life.

Example 3: HCFC-22 production by chloroform ($CHCl_3$) pathway

- Most HCFC-22 is generated by this route, so an estimate of HCFC-22 global production by this pathway is in the more than 1 million tonnes per year band.
- Emissions of the product HCFC-22 from a well-run, modern, highly regulated production plant, including storage and loading for transportation off-site, could average 2.5 wt%.[32]
- As HCFC-22 is a product mainly used as a feedstock, with some use in the RACHP industry, it is probable that the minority of emissions will occur at point of use or end-of-life.
- Controlled substances generated from side reactions and feedstock impurities:
    - Average HFC-23 emissions based on data from a number of plants suggest that the HFC-23 emission rate is likely to be in the >1 wt% band.
    - Average HCFC-21 generation is around 100 % as it is an intermediate that is practically completely consumed in the process, emissions are likely to be 0.01–0.001 wt%, this is in part due to the lower volatility of HCFC-21 compared with HCFC-22 and the standard design recycling HCFC-21 back to the reactor for fluorination to HCFC-22. HCFC-21 typically leaves as an impurity in the product HCFC-22, and some maybe dissolved in the aqueous scrubbing media. Individual plants may have higher or lower emission rates than this.
    - Average CFC-12 generation and emissions, based on the assumptions that there is minimal CTC in the feedstock and limited chlorination of $CHCl_3$ to CTC or $CHCl_2F$ to CCl_3F is likely in the reactor, suggest that the generation/emission rate is likely to be in the 0.001–0.01 wt% band. CFC-12 is measured in the product HCFC-22 at an average of less than 100 ppm by wt.
    - Other controlled substances are found on average at level of less than 10 ppm by weight of the HCFC-22 produced. They are typically found in the product HCFC-22 or main plant vent.

This would put emission rates of HCFC-22, HFC-23, HCFC-21, and HCFC-12 from HCFC-22 production using the chloroform pathway in the follow boxes.

[32] UNEP, 2022, *2022 MCTOC Assessment Report*, December 2022. Section 2.5.5.

Table A3.3 HCFC-22 production by chloroform liquid phase pathway

		Global production				
		<1000 tonne of product per year	1,000–10,000 tonnes of product per year	10,000–100,000 tonnes of product per year	100,000–1 million tonnes of product per year	>1 million tonnes of product per year
Controlled substance emission rate from production	1–10 wt% 10–100 kg of emission per tonne of production					HCFC-22 HFC-23
	0.1–1 wt% 1–10 kg of emission per tonne of production					
	0.01–0.1 wt% 0.1–1 kg of emission per tonne of production					
	0.001–0.01 wt% 10–100 grams of emission per tonne of production					CFC-12 HCFC-21
	<0.001 wt% <10 grams of emission per tonne of production					Other controlled substances

Note— Some CFC-12, HCFC-21, HFC-23, and other controlled substances, may be contained in the product HCFC-22, and therefore not emitted at the process plant but at the point that the HCFC-22 is emitted during use or end-of-life.

Annex 4: 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 31st December of the final year of appointment, up to four years.

A4.1 Technology and Economic Assessment Panel (TEAP) 2023

TEAP is presently composed of three co-chairs, the co-chairs of the Technical Options Committees and four senior experts as indicated in Table A4.1 below.

Table A4-1. TEAP Membership at May 2023

	Co-chairs	**Affiliation**	**Country**	**Appointed through**
1	Bella Maranion	U.S. Environmental Protection Agency	US	2024
2	Marta Pizano	Independent Expert	Colombia	2026
3	Ashley Woodcock	Manchester University NHS Foundation Trust	UK	2026
	Senior Experts	**Affiliation**	**Country**	**Appointed through**
4	Suely Machado Carvalho	Independent Expert	Brazil	2023*
5	Ray Gluckman	Gluckman Consulting	UK	2023*
6	Marco Gonzalez	Independent Expert	Costa Rica	2023*
7	Shiqiu Zhang	College of Environmental Sci. & Eng., Peking University	China	2023*
	TOC Chairs	**Affiliation**	**Country**	**Appointed through**
8	Omar Abdelaziz	The American University in Cairo	Egypt	2023*
9	Paulo Altoé	Independent Expert	Brazil	2024
10	Adam Chattaway	Collins Aerospace	UK	2024
11	Sergey Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2025
12	Kei-ichi Ohnishi	AGC, Inc.	Japan	2023*
13	Roberto Peixoto	Maua Institute (IMT), Sao Paulo	Brazil	2023*
14	Fabio Polonara	Universitá Politecnica delle Marche	Italy	2026
15	Ian Porter	La Trobe University	Australia	2025
16	Helen Tope	Planet Futures	Australia	2025
17	Daniel P. Verdonik	Jensen Hughes Inc	US	2024
18	Helen Walter-Terrinoni	Trane Technologies	US	2025
19	Jianjun Zhang	Zhejiang Chemical Industry Research Institute	PRC	2023*

** Indicates members whose terms expire at the end of 2023. See comments under TOC for consistency.*

A4.2 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 A4-2. FTOC Membership at May 2023

	Co-chairs	**Affiliation**	**Country**	**Appointed through**
1	Helen Walter-Terrinoni	Trane Technologies	US	2025
2	Paulo Altoé	Independent Expert	Brazil	2024
	Members	**Affiliation**	**Country**	**Appointed through**
3	Paul Ashford	Anthesis Group	UK	2023*
4	Kultida Charoensawad	Covestro	Thailand	2024
5	Roy Chowdhury	Foam Supplies	Australia	2025
6	Joseph Costa	Arkema	US	2026
7	Gwyn Davis	Kingspan Group	UK	2024
8	Gabrielle Dreyfus	IGSD	US	2025
9	Rick Duncan	Spray Polyurethane Association	US	2023*
10	Ilhan Karaağaç	Kingspan Group	Turkey	2024
11	Shpresa Kotaji	Huntsman Corporation	Belgium	2023*
12	Simon Lee	Independent Expert	US	2023*
13	Yehia Lotfi	Techno Cam	Egypt	2024
14	Smita Mohanty	LARM CIPET Bhubaneswar	India	2024
15	Miguel Quintero	Independent Expert	Colombia	2025
16	Sascha Rulhoff	H-C-S Group	Germany	2026
17	Enshan Sheng	Huntsman Corporation	China	2026
18	Koichi Wada	Japan Urethane Industry Institute	Japan	2024
19	Dave Williams	Independent Expert	US	2023*
20	Ernest Wysong	Natural Polymers LLC	US	2024

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

A4.3 TEAP Fire Suppression Technical Options Committee (FSTOC)

The parties renamed the Halons TOC as to the Fire Suppression TOC in 2022 in recognition that the committee had an increased scope beyond halons. This includes assessing current and potential HFC alternatives needed to implement the Kigali Amendment and potential ramifications of the increased reliance on flammable refrigerants.

Table A4-3. FSTOC Membership at May 2023

	Co-chairs	Affiliation	Country	Appointed through
1	Adam Chattaway	Collins Aerospace	UK	2024
2	Sergey N. Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2025
3	Daniel P. Verdonik	Jensen Hughes, Inc.	USA	2024
	Members	**Affiliation**	**Country**	**Appointed through**
4	Mohammed Jana Alam	Jahanabad Trading	Bangladesh	2024
5	Jamal Alfuzaie	Independent Expert	Kuwait	2026
6	Johan Åqvist	FMV	Sweden	2023*
7	Youri Auroque	European Aviation Safety Agency	France	2023*
8	Michelle M. Collins	Independent Expert - EECO International	USA	2026
9	Khaled Effat	Modern Systems Engineering	Egypt	2025
10	Laura Green	Hilcorp Alaska, LLC	USA	2024
11	Elvira Nigido	A-Gas Australia	Australia	2024
12	Emma Palumbo	Safety Hi-tech srl	Italy	2026
13	Erik Pedersen	Independent Expert	Denmark	2024
14	R.P. Singh	CFEES, DRDO	India	2024
15	Mitsuru Yagi	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan	2024
16	Xiaomeng Zhou	Civil Aviation University of China	China	2026
	Consulting Experts	**Affiliation**	**Country**	**One-year renewable terms**
1	Thomas Cortina	Halon Alternatives Research Corporation	USA	2023*
2	Carl Chapel	Hilcorp Alaska LLC	USA	2023*
3	Alan Edler	Johnson Controls	UK	2023*
4	Joshua R. Fritsch	United States Army	USA	2023*
5	Carlos Moacir Grandi	Independent Expert	Brazil	2023*
6	Matsuo Ishiyama	Nohmi Bosai Ltd & Fire and Environment Prot. Network	Japan	2023*
7	Nikolai Kopylov	Russian Res. Institute for Fire Protection	Russian Fed.	2023*
8	Steve McCormick	United States Army (alternate)	USA	2023*
9	Alexandra Mekjian	SK Aerosafety Group	USA	2023*
10	John G. Owens	3M Company	USA	2023*
11	John J. O'Sullivan	Bureau Veriitas	UK	2023*
12	Mark L. Robin	Chemours	USA	2023*
13	Joseph A. Senecal	FireMetrics LLC	USA	2023*
14	Sidney de Brito Teixeira	Embraer	Brazil	2023*

** Indicates members whose terms expire at the end of 2023*

A.4.4 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 soil-borne pests and pathogens attacking various crops where methyl bromide is used 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 A4-4. MBTOC Membership at May 2023

	Co-chairs	Affiliation	Country	Appointed through
1	Marta Pizano	Independent Expert	Colombia	2025
2	Ian Porter	La Trobe University	Australia	2025
	Members	**Affiliation**	**Country**	**Appointed through**
3	Jonathan Banks	Independent Expert	Australia	2024
4	Mohamed Besri	Institut Agronomique et Vétérinaire Hassan II	Morocco	2025
5	Fred Bergwerff	Oxylow BV	Netherlands	2025
6	Aocheng Cao	Chinese Academy of Agricultural Sciences	China	2026
7	Guillermo Castellá	Independent Expert	Uruguay	2024
8	Ayze Ozdem	Plant Protection Central Research Institute	Turkey	2026
9	Ken Glassey	MAFF – NZ	New Zealand	2026
10	Eduardo Gonzalez	Fumigator	Philippines	2026
11	Takashi Misumi	MAFF – Japan	Japan	2026
12	Christoph Reichmuth	Honorary Professor – Humboldt University	Germany	2026
13	Jordi Riudavets	IRTA – Department of Plant Protection	Spain	2024
14	Akio Tateya	Technical Adviser, Syngenta	Japan	2024
15	Alejandro Valeiro	Nat. Institute for Ag. Technology	Argentina	2026
16	Nick Vink	University of Stellenbosch	South Africa	2026
17	Tim Widmer	USDA	US	2023*

** Indicates members whose terms expire at the end of the 2023. See previous comments on status of expired memberships.*

A4.5 TEAP Medical and Chemicals Technical Options Committee (MCTOC)

The Medical and Chemicals Technical Options Committee brings together expertise in production, by-production, and feedstock uses of controlled substances, solvent and process agent applications, electronics manufacturing, magnesium production, laboratory and analytical uses, end-of-life management, disposal and destruction of controlled substances, metered dose inhalers and their alternatives, and aerosols. Members are experts in asthma and chronic obstructive pulmonary disease and their treatment, pharmaceutical manufacturing and markets, aerosols manufacturing and markets, chemicals manufacturing and markets, laboratory and analytical procedures, end-of-life management, banks, disposal and destruction. Members have academic, research, clinical, regulatory, laboratory, industrial, business, consulting, and commercial experience.

Table A4-5. MCTOC Membership as of May 2023

	Co-chairs	Affiliation	Country	Appointed through
1	Kei-ichi Ohnishi	Consultant to AGC Inc.	Japan	2023*
2	Helen Tope	Independent Consultant, Planet Futures	Australia	2025
3	Jianjun Zhang	Zhejiang Chemical Industry Research Institute	China	2023*
	Members	**Affiliation**	**Country**	
4	Emmanuel Addo-Yobo	Kwame Nkrumah University of Science and Technology	Ghana	2026
5	Fatima Al-Shatti	Consultant to the International Ozone Committee of the Kuwait Environmental Protection Authority	Kuwait	2026
6	Paul Atkins	Inhaled Delivery Solutions	USA	2026
7	William Auriemma	Diversified CPC International	USA	2025
8	Christian Sekomo Birame	University of Rwanda	Rwanda	2023*
9	Stephanie Bogle	U.S. Environmental Protection Agency	USA	2025
10	Steve Burns	AstraZeneca	UK	2025
11	Nick Campbell	Arkema	UK	2026
12	Andrea Casazza	Chiesi Farmaceutici	Italy	2024
13	Nee Sun (Robert) Choong Kwet Yive	University of Mauritius	Mauritius	2026
14	Rick Cooke	Man-West Environmental Group Ltd.	Canada	2025
15	Takeshi Eriguchi	AGC Inc.	Japan	2025
16	Maureen George	Columbia University School of Nursing	USA	2025
17	Jianxin Hu	College of Environmental Sciences & Engineering, Peking University	China	2026
18	Ryan Hulse	Honeywell	USA	2024
19	Fang Jin	Guangzhou Medical University	China	2024
20	Rabinder Kaul	SRF Limited	India	2023*
21	Andrew Lindley	Independent consultant to Koura and European Fluorocarbon Technical Committee (EFCTC)	UK	2024
22	B. Narsaiah	CSIR-Indian Institute of Chemical Technology (Retired)	India	2023*
23	Timothy J. Noakes	Koura	UK	2026
24	John G. Owens	3M	USA	2024
25	Irene Papst	HEAT GmbH, Germany	Austria	2025
26	Jose Pons Pons	Spray Quimica	Venezuela	2023*
27	John Pritchard	Independent Consultant, Inspiring Strategies	UK	2026
28	Rabbur Reza	Beximco Pharmaceuticals	Bangladesh	2026
29	David Sherry	Nolan Sherry & Associates Ltd.	UK	2023*
30	Peter Sleigh	Retired	UK	2023*
31	Jørgen Vestbo	Manchester University NHS Foundation Trust and Allergi- og Lungeklinikken, Vanløse	Denmark	2025
32	Kristine Whorlow	Non-Executive Director	Australia	2026
33	Alex Wilkinson	East and North Hertfordshire NHS Trust	UK	2025
34	Gerallt Williams	Aptar Pharma	UK	2024
35	Ashley Woodcock	Manchester University NHS Foundation Trust	UK	2023*
36	Arzu Yorgancıoğlu	Celal Bayar University Medical Faculty	Turkey	2025

37	Lifei Zhang	National Research Center for Environmental Analysis and Measurement	China	2026
	Consulting Experts	Affiliation	Country	**One-year renewable terms**
1	Javaid Khan	The Aga Khan University	Pakistan	
2	Robert Meyer	Consultant, Greenleaf Health	USA	

** Indicates members whose terms expire at the end of 2023.*

A4.6 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 A4-6: RTOC Membership at May 2022

	Co-chairs	**Affiliation**	**Party**	**Appointed through**
1	Omar Abdelaziz	American Univ. in Cairo	Egypt	2023*
2	Roberto Peixoto	Maua Institute (IMT)	Brazil	2023*
3	Fabio Polonara	UNIVPM	Italy	2026
	Members	**Affiliation**	**Party**	**Appointed through**
4	Ghina Annan	Stantec	Lebanon	2024
5	Jitendra Bhambure	Independent Expert	India	2024
6	Maria C. Britto Bacellar	Johnson Controls, JCI	Brazil	2024
7	Feng Cao	Xi'an Jiaotong University	China	2024
8	Ana Maria Carreño	CLASP	Colombia	2024
9	Radim Čermák	Thermo King	Czech Republic	2024
10	Yu Chen	TRANSICOLD	USA	2024
11	Daniel Colbourne	Re-phridge Consultancy	UK	2024
12	Sukumar Devotta	Independent Expert	India	2024
13	Hilde Dhont	Daikin Europe	Belgium	2024
14	Gabrielle Dreyfus	IGSD	USA	2024
15	Bassam Elassaad	Independent Expert	Lebanon	2024
16	Kylie Farrelley	Refrigerant Reclaim Australia	Australia	2024
17	Qiang Gao	Sanhua Group	China	2024
18	Ray Gluckman	Gluckman Consulting Ltd	UK	2024
19	Samir Hamed	Petra Industries	Jordan	2024
20	Herlin Herlianika	Independent Expert	Indonesia	2024
21	Michael Kauffeld	Karlsruhe Univ.of A.S.	Germany	2024
22	Mary Koban	AHRI	USA	2024
23	Juergen Kohler	University of Braunscheig	Germany	2024
24	Steve Kujak	TRANE	USA	2024
25	Lambert Kuijpers	A/gent b.v. Env. Cons.	Netherlands	2024
26	Richard Lawton	Cambridge CRT	UK	2024

27	Tingxun Li	Guangzhou Sun Yat Sen U.	China	2024
28	Carloandrea Malvicino	Stellantis	Italy	2024
29	Mary Najjuma	Independent Expert	Uganda	2024
30	Petter Nekså	SINTEF Energy Res.	Norway	2024
31	M. Alaa Olama	Olama Consultants	Egypt	2024
32	Mr.Tetsuji Okada	JRAIA	Japan	2024
33	Pallav Purohit	Int. Inst. for Appl. Syst. Analysis	India	2024
34	Madi Sakande	New Cold System	Burkina Faso	2024
35	Natarajan Rajendran	Emerson	USA	2024
36	Tao Ren	Qingdao Haier Air Con. Electronics	China	2024
37	Giorgio Rusignuolo	UTC Carrier	USA	2024
38	Leyla Sayin	Centre for Sustainable Cooling, University of Birmingham	Turkey	2024
39	Nihar Shah	Lawrence Berkeley National Laboratory	India	2024
40	Andrea Voigt	Danfoss	Germany	2024
41	Asbjørn L. Vonsild	Vonsild Consulting	Denmark	2024
42	Christian M. Wisniewski	US EPA	USA	2024
43	Samuel Yana Motta	ORNL	Peru	2024

** Indicates members whose terms expire at the end of 2023*

Annex 5: Matrix of needed expertise

As required by the TEAP TOR an update of the matrix of needed expertise on the TEAP and its TOCs is provided below valid as of May 2023.

To facilitate the submission of appropriate nominations by the parties, the TEAP TOR require the TEAP and its TOCs to draw up guidelines for the nomination of experts by the parties. Section 2.9 of the TOR states 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."

The matrix of needed expertise is the basis for facilitating the nomination by parties of appropriate experts to the TEAP and its TOCs and TSBs. Nominations are typically made through a simple communication to the TEAP or TOC or the Ozone Secretariat accompanied by the curriculum vitae of the nominee. In annex C to its report issued in May 2012 pursuant to decision XXIII/10, the TEAP had proposed a draft standardized nomination form for detailed information about a nominee, such as education and other qualifications, employment history, publications, awards, memberships, language knowledge and references. Consultation among the parties and TEAP and its TOCs and TSBs on potential nominations are helpful to ensure the appropriate experts are considered. In the case of nominations or renominations for membership in a committee, the committee co-chairs consult with the Panel co-chairs and the relevant national focal points. Nominations for committee membership and appointments to a committee can be made at any time. Section 3.5 of the TOR states that once appointed, "TEAP/TOCs/TSBs members function on a personal basis as experts, irrespective of the source of their nominations and accept no instruction from, nor function as representatives of Governments, industries, nongovernmental organizations (NGOs) or other organizations."

Ensuring appropriate and sufficient technical expertise is the priority consideration for the TEAP and its committees.

Body	Required Expertise	A5/ Non-A5
Foams TOC	Experts in extruded polystyrene production in India and China	A5
	Polyurethane system house technical experts (especially from small and medium enterprises)	A5 from southern Africa, the Middle East, Southeast Asia, or Mexico
	Foam chemistry experts and expertise in building science related to the cross=cutting issue of energy efficiency	A5 or non-A5
Fire Suppression TOC	Use of HFCs and Alternatives	South America, Middle East and Africa (2)

	Halon use in merchant shipping and recovery from shipbreaking	A5
Methyl Bromide TOC	QPS uses of MB and their alternatives particularly SE Asia	A5
	Alternatives to QPS uses of MB adopted in Europe	Non-A5
	Members with expertise in disinfestation of agricultural produce and bilateral trade agreements and links to the Technical Panel on Phytosanitary treatments Committee (TPPT) and the International Plant Protection Convention.	Non-A5 or A5
	Nursery industries, especially issues affecting the strawberry runner industries globally	A5 or non-A5
Medical and Chemical TOC	Aerosols	China, Indonesia, Latin America
	Semiconductor/electronics manufacturing and use	East Asia and non-A5
	End-of-life management Non-refillable and refillable containers, storage	A5 A5 and non-A5
Refrigeration, Air Conditioning and Heat Pumps TOC (RTOC)	After 17 new members were appointed to cover the expected scope for the next Assessment term, no required expertise is needed at present. Following the outcomes of the discussion of the TOCs TOR for the next Assessment Report, new expertise may be needed and will be appropriately addressed.	
Senior Experts	Experts with extensive experience on TEAP technical and economic assessments, especially sector transitions and challenges in A5 parties; extensive knowledge and experience of Multilateral Fund (MLF) decisions, guidelines, operations, and related funding to meet financial needs of A5 parties under the ODS phase-out and HFC phase-down. Expert in the analysis and assessment (including modelling) of factors, including energy efficiency and regional economics, for forecasting the market penetration and potential future disposition of HCFCs, HFCs, and alternatives	A5 or non-A5

Annex 6: Nomination Form

For reference the standard nomination form is set out at:

https://ozone.unep.org/sites/default/files/assessment_panels/teap-nomination-form-2022.docx.

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