# MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

## REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

# MAY 2024

### VOLUME 1: PROGRESS REPORT

UN environment programme

**Montreal Protocol on Substances that Deplete the Ozone Layer**

**United Nations Environment Programme (UNEP)**
**Report of the Technology and Economic Assessment Panel**

**May 2024**

# VOLUME 1: PROGRESS REPORT

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# Foreword

## The 2024 TEAP Report

The 2024 TEAP Report consists of three volumes:

***Volume 1:*** *TEAP 2024 Progress Report covering the following:*

- ***Sector updates (Decisions IV/13 and XI/17)***
- ***TEAP procedures, organisational matters and matrix (Decisions XXXI/8)***
- ***Dec XXXV/6: Updated information on very short-lived substances***
- ***Dec XXXV/8: Feedstock uses***
- ***Dec XXXV/9: Abating emissions of carbon tetrachloride***
- ***Dec XXXV/10: Energy efficiency***
- ***Dec XXVIII/2, par. 5: Technical review of alternatives to hydrofluorocarbons***

***Volume 2:*** *Evaluation of 2024 critical use nominations for methyl bromide and related issues - Interim Report – May 2024*

***Volume 3:*** *Decision XXXV/11: Life-cycle refrigerant management*

This is Volume 1

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# 1 Introduction

This is volume 1 of 3 of the 2024 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 following decisions are also addressed in the corresponding chapters and/or sections of this report:

- Decision XXXV/6: Updated information on very short-lived substances
- Decision XXXV/8: Feedstock uses
- Decision XXXV/9: Abating emissions of carbon tetrachloride
- Decision XXXV/10: Energy efficiency
- Decision XXVIII/2, paragraph 5: Technical review of alternatives to hydrofluorocarbons

This report also contains the TEAP and TOC membership lists, as of 30 April 2024, 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 Force. TEAP held a face-to-face meeting, 29 April – May 3, 2024, in Rome. We want to express our sincere appreciation to the Ozone Secretariat for its continuing support and assistance with the organisation of 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*

The FTOC progress report is contained in Chapter 2 of this report.

Insulation demand and subsequent foam blowing agent (FBA) demand continues to increase to reduce energy demand and for other uses. Regulations are driving transitions away from high global warming potential (high-GWP) hydrofluorocarbons (HFCs) in non-Article 5 (non-A5) parties, and hydrochlorofluorocarbons (HCFCs) in Article 5 (A5) parties, with emphasis on avoiding adoption of high-GWP HFCs where possible.

Shortages of fluorinated and non-fluorinated (e.g., pentanes) lower GWP FBAs have improved in both A5 and non-A5 parties. As a result of the previous shortages, there had been a significant increase in the use of higher GWP HFCs blends in some A5 parties and a reversion to HFCs in some non-A5 parties, where lower GWP alternatives are not available.

The transition away from ozone-depleting FBAs and/or high-GWP HFC 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. Significant resources are spent by foam manufacturers in optimising the characteristics and costs of new FBAs and foam systems through optimising blends with new additives. The new FBA additives or co-blowing agents have different toxicity and thermal properties that can result in handling challenges and lower thermal performance of insulation.

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*

The FSTOC progress report is contained in Chapter 3 of this report.

The FSTOC is not aware of any new alternatives to halons, HCFCs or high-GWP HFCs under development since the last published progress report. Furthermore, the FSTOC understands the low-GWP blend in-kind total-flooding Halon 1301 replacement agent that was in the process of being commercialised is no longer being developed, owing to commercial and/or per- and polyfluoroalkyl substances (PFAS) considerations.

FSTOC is not aware of any shortage of Halons 1211 or 2402. For Halon 1301, the global availability continues to be a concern of the FSTOC. Discussions with industry stakeholders frequently indicate the mistaken belief that the Montreal Protocol bans the use of halons globally. The FSTOC is continually reinforcing the message that only production and consumption of newly manufactured halons for fire suppression are banned. Additionally, it has been reported to the FSTOC that misapplication and/or local regulations can prohibit or hinder the transboundary shipment of recovered/recycled/reclaimed Halon 1301. These misunderstandings can be linked to a “loss of institutional memory” that the FSTOC has been highlighting for several years which needs to be addressed.

In some instances, this misunderstanding and misapplication of the intent of the Protocol, may be leading to the destruction of halons (especially Halon 1301). The deliberate destruction of Halon 1301 for carbon credits by commercial entities and/or governments, if it becomes a widespread practice, has the potential to significantly reduce the amount of the available Halon 1301, thereby bringing the run-out date closer to 2030.

In light of the above, parties may wish to consider means of strengthening or reinforcing the correct intention of the Montreal Protocol by:

- Reinforcing the message that it is only production and consumption of newly manufactured halons that was banned and not the use of halons;
- Facilitating the transboundary shipments of recovered halons for recycling/reclamation in another party that has those capabilities; and
- Discouraging parties from destroying halons unless they cannot be reclaimed to an acceptable purity.

The following factors could affect the run-out date:

- The continued uncertainty surrounding the PFAS regulations is delaying or even stopping development of, or transition to, lower GWP alternatives to halons or high-GWP HFCs. Delaying transition to alternatives will prolong reliance on Halon 1301 to support enduring uses, for example, civil aviation, nuclear power plants and the oil and gas sector. This in turn would lead to an earlier runout date. This may also affect parties’ compliance to the Kigali Amendment, if transition to lower GWP fire suppressants is an important part of their strategy.
- As global emissions continue to deplete the available Halon 1301 bank (that is, Halon 1301 being used in non-enduring uses, such as computer room, ships, etc.), the relative proportions of the bank that is unavailable (the proportion of the bank that is deployed in or supporting enduring uses, e.g., oil & gas, military, nuclear power plants, etc.) inevitably becomes larger. Logically, in the future, the available bank will be depleted to zero, and even though the

unavailable bank (supporting enduring uses) will have significant reserves of Halon 1301, it is likely that there will be requests for Essential Use Nominations.

- As reported in the TEAP 2023 Progress Report, the unexplained temporary increases in emissions of Halon 1301 derived from atmospheric measurements continue to concern the FSTOC. The FSTOC has tried, but has been unsuccessful, in linking these unexplained temporary increases in emissions to the fire suppression bank or use. Since it is known that Halon 1301 is produced as a feedstock for Fipronil and some pharmaceuticals, the FSTOC is hypothesising that these unexplained temporary increases in emissions in Halon 1301 are somehow related to its feedstock production and use. Additional information is provided in Annex 1. The FSTOC seeks more information on emissions from production and use of Halon 1301 for feedstock.

Parties may wish to consider providing information on emissions from production and feedstock use of Halon 1301 to the Ozone Secretariat for confidential use by the TEAP in its assessment.

### *1.1.3 MBTOC*

The MBTOC progress report is contained in Chapter 4 of this report.

The phase out of over 60,000 tonnes of non-quarantine and pre-shipment (non-QPS) use of methyl bromide (MB) marks a very significant milestone for the Montreal Protocol as MB was once considered to be an essential fumigant for controlling soil borne diseases and pests impacting production of high value horticultural crops and for controlling pests attacking stored commodities and structures.

The reduction in this anthropogenic MB use to date is also a great outcome for ozone layer recovery as MB is short lived in the atmosphere (0.7 years) and the benefit of any reduction is very quickly felt in the atmosphere.

The phaseout has been underpinned more recently by the large reduction in critical use nomination (CUN) requests for MB declining from requests for 18,600 tonnes in 2005 to just 3 tonnes for 2025. However, concern exists that a significant amount of MB is still being used for non-QPS uses either via diversion from current production for QPS purposes or through incorrect classification of uses as QPS.

As approximately 9,000 tonnes of MB is annually used for QPS uses, the MBTOC report focuses on use of MB for QPS applications currently exempted from phaseout guidelines under the Montreal Protocol. It concentrates on the feasible alternatives for replacing this use, including challenges hindering the adoption of such alternatives.

Global MB **production** for QPS uses has decreased slightly in recent years, from 10,400 tonnes in 2021 to 8,865 tonnes in 2022. While most parties show downward trends, India exhibits a continuing rise in MB production.

Global MB **consumption** for QPS uses has reportedly declined in 2022, reaching 7,526.2 tonnes down from 10,395 tonnes in 2021, although large fluctuations are common with QPS data reported in the past.

When considered over a longer term (i.e., the past 7 years (2016-2022)), there is a surplus of MB produced for QPS compared to that reported for consumption by a total of 3,620 tonnes.

Noted findings in changes in consumption of MB for QPS include: a significant increase in Uruguay; a dramatic drop in New Zealand; unclear reporting from OIRSA (the International Regional Organism for Animal and Plant Health) member parties in Central America.

A lack of sector breakdown for QPS uses makes it difficult for MBTOC to assess the suitability of alternatives for such uses. In particular the correct classification of uses as pre-shipment (i.e., cosmopolitan pests) or quarantine uses (exotic pests) is a key issue for determining the suitability of an alternative.

As evidence demonstrates that alternatives exist for most pre-shipment uses, parties may wish to consider a revision of the QPS category to only allow consideration of the use of MB for quarantine purposes (i.e., against a quarantine pest) only.

The MBTOC report also provides updates on new registrations of effective alternatives to MB for some QPS applications in a range of parties, as well as research and development of promising alternatives like ethane dinitrile (EDN), hydrogen cyanide (HCN), ethyl formate (eFume), methyl iodide and technologies not requiring registration such as microwave technology for soils. Registration of EDN, a key alternative to replace QPS MB use for timber treatments, has been achieved in many parties.

MB has been recommended for listing under Annex III of the Rotterdam Convention, subjecting it to the Prior Informed Consent (PIC) procedure. If approved, this will add another layer of control over international trade of MB. A final decision will be made in 2025.

The report further analyses the changing scene for existing alternatives: controlled atmosphere treatments are emerging for control of the Khapra beetle; the European Union (EU) has stricter regulations on sulfuryl fluoride use and is now requiring measures to minimise release of emitted gas using recapture or other methods; Japan is considering expanding registration of methyl iodide for other products traded for QPS.

### *1.1.4 MCTOC*

The MCTOC progress report is contained in Chapter 5 of this report and also includes sections responding to the following: 1) Decision XXXV/6 on very short-lived substances, 2) Decision XXXV/8 on feedstocks, and 3) Decision XXXV/9 on abating emissions of carbon tetrachloride.

#### 1.1.4.1 Response to Decision XXXV/6 on very short-lived substances

Section 5.2 of this report provides a response to Decision XXXV/6 on very short-lived substances (VSLS), which includes updated information on VSLS, their ozone-depletion potential (ODP) and impact on the stratospheric ozone layer, and information on alternatives to VSLS in the main applications for which they are currently used. The report has been prepared by MCTOC and the TEAP, in cooperation with the Scientific Assessment Panel (SAP) as appropriate.

VSLS are not controlled under the Montreal Protocol. Therefore, parties to the Montreal Protocol are not required to submit data on production and use of VSLS to the Ozone Secretariat. Information provided in this progress report is based upon information obtained from industry experts and from publicly available government and industry data.

Many substances not controlled under the Montreal Protocol being evaluated by atmospheric scientists are chlorinated hydrocarbons with a very low, but non-zero, ODP. Collectively they are known as very short-lived substances (VSLS, chlorinated VSLS or Cl-VSLS) because of their atmospheric lifetimes of less than 6 months. Further detail on five VSLS that are very high-volume chemical products is provided for dichloromethane (DCM), trichloromethane (chloroform, CFM), 1,2-dichloroethane (ethylene dichloride, EDC), trichloroethylene (TCE), and perchloroethylene (PCE).

Each of these chemicals is used as feedstock, and some also have considerable emissive solvent use.

Feedstock usage of both EDC and CFM is more than 90% for each, although CFM has continued use as a process agent solvent in the pharmaceutical industry. EDC's main feedstock application is the production of vinyl chloride monomer to polyvinyl chloride (PVC), the third largest of the global plastics production. EDC can also be used as a feedstock for both TCE and PCE manufacture. DCM is predominantly used as a solvent, and TCE/PCE are partly used as solvents.

In feedstock applications, there is some limited regional downward impact on TCE (for HFC-134a) and PCE (for HFC-125, HFC-134a) in non-A5 parties due to Kigali Amendment measures for production and consumption of controlled HFCs. The effect is limited because the production of controlled fluorocarbons in non-A5 parties contributes a small percentage of the global production of fluorocarbons, which has overall increased since 2020.

In some regions, solvent applications of VSLS have shown some small growth in 2021 and 2022 versus 2020, which was heavily COVID-influenced.

#### 1.1.4.2 Response to Decision XXXV/8 on feedstock uses

Section 5.3 of this report provides a response to Decision XXXV/8 on feedstock uses, which includes an update on the emissions of controlled substances from feedstock production, as by-products and from feedstock use that has been carried out by MCTOC and the TEAP, in cooperation with the SAP as appropriate. This update can be summarised as follows:

- Data reported by parties to the Ozone Secretariat on production and import of controlled ODS used as feedstock for the years up to and including 2022 was provided to the MCTOC. In 2021, a total of 15 parties had reported use of ODS as feedstock; in 2022, 15 parties reported feedstock use of ODS, while ten of these parties also produced ODS for feedstock uses.

  In 2022, total production and import reported for feedstock uses of ODS was 1,943,134 metric tonnes, a significant increase compared to 2021 (2021: 1,755,171 tonnes), and an Increase of 66% over the last ten years. Comparing 2022 with 2021 and 2020, the most notable difference is the increase in Annex C1 (HCFCs). The 2022 reported total production and import of ODS for feedstock use in tonnes represents 685,204 ODP tonnes. The overall increase in ODS feedstock uses over the last 10 years has been mostly due to the increase in feedstock uses of Annex C1 (HCFCs), particularly HCFC-22, while increasing market demand of HFOs is driving a more recent increase in carbon tetrachloride (CTC) feedstock use.

  The proportions of the largest ODS feedstocks in 2022 were similar to 2021: HCFC-22 (50% of the total mass quantity, an increase from 48% in 2021), CTC (18%), and HCFC-142b (12%). HCFC-22 is, by a considerable margin, the largest feedstock used, with 968,775 tonnes reported in 2022, compared to 847,248 tonnes in 2021.

  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 has increased in recent years, due to growing demand for lower GWP hydrochlorofluoro-olefins/hydrofluoro-olefins (HCFO/HFOs) and perchloroethylene (PCE). In addition, there has been a marked increase in reported feedstock use of HCFC-244 and HCFC-21, which are both used as feedstocks for different routes to manufacture HFO-1234yf.

- A comparison was undertaken of estimates of annual global emissions of controlled substances by species based on bottom-up calculations, where such bottom-up calculations could reasonably be made with the data currently available, and global emissions estimated by the SAP on the basis of atmospheric observations at remote sites. Substances selected for comparison of emissions estimates are 1,1,1-trichloroethane, CFC-114 and CFC-114a, CFC-113 and CFC-113a, HCFC-124, HCFC-133a and CFC-115 by-product.

  For several substances considered, including 1,1,1-trichloroethane (methyl chloroform) and CFC-113, there was reasonable agreement between the bottom-up calculations and the estimates made by the SAP, although, according to SAP, the top-down emission estimates for CFC-113 may also have some small contribution from CFC-113a, which is not yet fully characterised. While for some other substances, such as CFC-114 and HCFC-133a, there were definite differences between the bottom-up calculations and the estimates made by the SAP on a global scale, in some cases, such as HCFC-124 and HCFC-133a, reasons for these differences could be proposed. However, for at least one substance, Halon 1301 ($CF_3Br$), a representative bottom-up calculation was not considered possible with the data currently available to TEAP. The situation with Halon 1301 emissions from feedstock use is further discussed in the FSTOC chapter of this report.

- Existing information on alternatives to ODS feedstock was reviewed, updated and expanded to include HFC feedstocks. Additional information on technical feasibility, economic viability, safety and sustainability is provided for large scale (>100,000 tonnes per year) feedstock uses.

  The list of alternatives to ODS and HFC feedstocks has not changed significantly from previous reports. The on-going use of a range of ODS and HFC feedstocks even where alternative feedstocks are technically feasible and economically viable suggest that there is currently an insufficient incentive for industry to move to non ODS or HFC feedstocks for many applications. Not all ODS and HFC feedstocks have viable non-ODS or non-HFC alternatives.

#### 1.1.4.3 Response to Decision XXXV/9 on abating emissions of CTC

Section 5.4 of this report provides a response to Decision XXXV/9 on abating emissions of carbon tetrachloride (CTC), which includes updated information on emissions of CTC by source categories and updated information on alternatives for CTC as feedstock applications. The report has been prepared by MCTOC and the TEAP, in cooperation with the SAP as appropriate.

The 2022 MCTOC Assessment Report assessed CTC production in 2020, which was reported as 289 ktonnes globally, a decline from the 2019 high of 317 ktonnes. In 2022, production increased to 358 ktonnes, an 11.9% increase from 2021 production of 320 ktonnes.

Most of the CTC production growth is from consumption in the HFC and HFO/HCFO sector. The demand for the major CTC-based products HFO-1234yf, HFO-1234ze, and HCFO-1233zd has been predictably increasing due to the Kigali-driven phase-down of HFCs in non-Article 5 parties and in regions where they are regulated.

Based on Article 7 reported data of 358 ktonnes of CTC production for 2022, MCTOC estimates that 15.0 ktonnes (8.6–27.8 ktonnes, or 4.2% of total CTC production) of anthropogenic CTC emissions arise globally from CTC production, handling, supply chain, and use. A further 5.0 ktonnes (2.5–7.5 ktonnes) of CTC emissions are estimated from anthropogenic non-chloromethanes production, notably the vinyl chain, which is currently the subject of further scientific investigation. In addition, 7.5 ktonnes (5–10 ktonnes) are estimated from anthropogenic legacy CTC emissions (historic landfill, industrial sites, and contaminated soil). Based on new information, an additional 2 ktonnes (1.0–3.0 ktonnes) of anthropogenic CTC emissions are estimated to arise from unknown industry sources not yet fully characterised.

MCTOC is unaware of alternatives to CTC or alternative processes that would not disturb the vital isomer distribution of the major HFOs and HCFOs, and would welcome information on technical feasibility, economic viability, safety and on such alternatives from parties that have carried out such analyses.

#### 1.1.4.4 Updates on metered dose inhalers and other aerosols

Section 5.9 of this report provides updates on metered dose inhalers and other aerosols. 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 chronic obstructive pulmonary disease (COPD).

The development of lower-GWP pMDIs is progressing, though a range of potential challenges are emerging that could risk the consistent supply of affordable medicines. These challenges were discussed in the 2022 MCTOC Assessment Report and 2023 TEAP Progress Report, with further updates given here.

MCTOC understands that there may be ten or more companies globally with active programmes to develop pMDIs containing lower GWP propellants involving two lower GWP propellants (HFC-152a GWP-100 164 (AR6), 124 (AR4); and HFO-1234ze(E) GWP-100 1.37 (AR6)). Generic pMDI manufacturers are also developing lower GWP pMDIs, including in A5 parties. Development is a complex process involving new ways of manufacturing, new clinical trials, and new regulatory approvals.

Three manufacturers have registered clinical studies for three inhalers, involving the two lower GWP propellants and two classes of therapy. These are due to complete in 2025. Allowing time for the subsequent regulatory submissions and approvals, the first lower GWP pMDIs may not reach the market until 2026. Many classes of inhaled therapies have yet to enter clinical trials. The European Medicines Agency has issued guidance on the transition to new propellants, but in other markets, such as the United States, no formal guidance is available.

The 2024 update to EU F-gas regulations accelerates the phase-down of HFCs currently in use in pMDIs; HFC-152a is also scheduled to be phased out by 2050 (unless exemptions for critical use are added). European Chemicals Agency (ECHA) draft regulations for the control of PFAS would, in their current form, ban the use of HFC-134a, HFC-227ea, and HFO-12Ie(E). It is likely that the price of bulk HFC propellant currently used in pMDI will increase as quotas for non-pharmaceutical uses tighten. There has already been a significant increase in the price of HFC-227ea, and it is likely that HFC-134a will follow when the next major drop in HFC production for non-A5 parties comes into effect in 2025. This may make some HFC pMDIs less attractive to manufacture from a commercial standpoint.

Although the Kigali Amendment allows A5 parties longer to phase down HFCs, global legislation and corporate policies of major pharmaceutical companies may accelerate the introduction of lower GWP pMDIs in A5 parties well before their scheduled phase down timeline. Pharmaceutical companies may market their lower GWP pMDIs globally at the earliest opportunity, rather than latest. This could potentially mean lower GWP pMDIs are available in Article 5 parties from 2026 onwards. The reduction in use of HFCs in Europe/United States may lead to security of supply and commercial pricing concerns for A5 parties, including India.

The price of some new lower GWP pMDIs will increase as a result of the capital investment, research and development, and increased cost of propellants and valves. It is not clear that there is sufficient manufacturing capacity in the industry for DPIs to make up any shortfall in supply if current pMDI products are withdrawn from the market.

Some international and national respiratory guidelines recommend considering environmental impact as part of inhaler choice and combination inhalers for asthma and COPD treatment. Prioritising combination inhalers could reduce the total number of inhalers needed, and potentially increase uptake of DPIs in some parties. Many patients, especially in low- and middle-income parties, have very limited access to affordable inhalers.

The non-pMDI aerosol market continues to evolve with improvements in aerosol valve technology allowing for effective use of some non-HFC propellants (such as nitrogen and compressed air) in more applications. Liquified petroleum gas (LPG) and dimethyl ether propellants dominate in Europe and Asia.

In the United States, HFC-134a has almost disappeared in aerosol production (less than 1000 tonnes) with the exception of a handful of specialised exempt products (excluding pMDIs). HFO-1234ze has been the primary replacement for HFC-134a; there is modest but constant growth in this propellant category. HFC-152a continues to be the most commonly used propellant in personal care, usually blended with the LPG propellant to control cost and vapour pressure.

### *1.1.5 RTOC*

The RTOC progress report is contained in Chapter 6 of this report.

In residential, commercial, and industrial refrigeration applications, refrigerant options with GWP <30 and <150 and corresponding technologies are known and available.

The air-conditioning and heat pump applications have good technology options with refrigerant GWP <700, but the options with GWP <30 are limited and hurdles (safety and performance) for their widescale adoption persist.

Accessibility to some new refrigerants and technologies is a challenge in several A5 and even some non-A5 parties.

Safety standards for all applications continue to be updated and improved with increased charge size of flammable refrigerant allowed. Awareness, education, training and certification for the safe use of flammable refrigerants continues to be important and requires additional support and attention for greater adoption of the new refrigerants.

Technologies to improve energy efficiency (EE) are well known in all applications, but technical challenges remain to balance the GWP and safety needs while increasing EE, especially in air-conditioning and heat pump applications.

Globally, the lack of clarity around potential PFAS regulations has caused some uncertainty around refrigerant and equipment choices in several applications; this may slow progress towards Kigali Amendment compliance.

## 1.2 Response to decision XXVIII/2 paragraph 5 on technical review of alternatives to HFCs

### *1.2.1 Overview*

Chapter 8 of this report contains the response to Decision XXVIII/2, Decision related to the amendment to phasedown hydrofluorocarbons, which included a request to the TEAP under paragraph 5 "*to conduct a technology review four or five years before 2028 to consider a compliance deferral of two years from the freeze date of 2028 for Article 5, group 2, parties to address growth above a certain threshold in relevant sectors*."

To respond to this request in **paragraph 5** of the decision, TEAP built upon its previous report prepared in 2022 responding to **paragraph 4 of the same decision**. Paragraph 4 of Decision XXVIII/2 requested TEAP "to conduct periodic reviews of alternatives, using the criteria set out in paragraph 1 (a) of decision XXVI/9, in 2022 and every five years thereafter, and to provide technological and economic assessments of the latest available and emerging alternatives to hydrofluorocarbons." The criteria referred to in the decision included whether alternatives were commercially available; technically proven; environmentally sound; economically viable and cost effective; safe to use in areas with high urban densities considering flammability and toxicity issues; easy to service and maintain; and with a description of the potential limitations of their use.

Information on alternatives to HFCs, contained in the September 2022 "*Volume 5: Decision XXVIII/2 TEAP Working Group Report: Information on Alternatives to HFCs*", was based on the understanding and information available to the relevant TOCs at the time of preparation of the TOCs 2022 Assessment Reports, as part of the TEAP 2022 quadrennial assessment report.

The September 2022 TEAP report focused on the global status of alternatives for HFCs in the following sectors: foams; fire suppression; medical and chemical uses; refrigeration, air conditioning and heat pumps (RACHP).

This 2024 technical review focuses on the status of alternatives in the same sectors as 2022, but now considering relevance to A5, Group 2 (G2) parties, as requested by the decision, and to the extent that updated information was available to the TEAP. The main focus was updates to the RACHP sector, as information on other sectors was essentially unchanged from the 2022 review.

The technical reviews of these sectors based on updates since the September 2022 report are summarised in the sections below. TEAP did not attempt to assess whether the alternatives will enable G2 parties to achieve specific reductions in HFC consumption by a certain date because such an assessment depends on other factors that are not related to the technical criteria TEAP was requested to assess. In addition, TEAP did not attempt to assess the relative ability of G2 parties to comply with the controls measures to phase down HFCs as adopted by parties at the 28$^{th}$ MOP in 2016. TEAP provides its technical review and defers to parties to consider, or not, any changes to phasedown schedules.

This technical review considers the status of progress in uptake of lower GWP refrigerants by A5 parties (including G2 parties), and the development of standards for refrigerants and for refrigeration and air conditioning equipment since the parties adopted Decision XXVIII/2 in 2016. Annex 3 provides information on technology conversion, with examples of relevant demonstration and investment projects approved since 2016 by the Multilateral Fund (MLF) for G2 parties. Annex 4 lists activities included in the 2024-2026 MLF Business Plan for G2 parties.

### *1.2.2 Refrigeration and air conditioning*

Information on alternatives in the RACHP sector remains essentially the same as reported in TEAP's September 2022 report. The previous technical review focused on the status of RACHP alternatives for HFCs globally. Considering the criteria for its technical review of the RACHP sector, TEAP noted the only distinguishing criterion for accessibility in G2 parties is whether refrigerants are technically proven. TEAP reviewed and reconstructed the tables from the September 2022 report for RACHP applications by listing the applications for each category of products and addressing the alternatives that are technically proven and globally available. The information is then presented by listing the accessibility of alternatives to G2 parties as well as the degree of accessibility in terms of limited use, growing use, or widespread use.

### *1.2.3 Foams*

Information on alternatives in the foams sector remains essentially the same as reported in TEAP's September 2022 report. HFC alternatives are already in use today with most providing necessary technical benefits to the foams end-product. Some characteristics are specific to the FBA, including commercial availability; environmental soundness, or economic viability and cost effectiveness, and safe for use in areas with high urban densities (considering flammability and toxicity issues, including risk evaluation). However, the technical performance of FBAs is specific to the end-use. Some specific concerns are identified with safety of FBAs in certain situations with specific foam types.

### *1.2.4 Fire suppression*

Information on alternatives for fire suppression remains essentially the same as reported in TEAP's September 2022 report. In that report, TEAP provided information where alternatives to HFCs are available for fire protection applications in the following sectors of use: civil aviation; military ground vehicles, naval, and aviation applications; oil and gas; general industrial fire protection, and merchant shipping. TEAP noted that the evolution of alternatives has proceeded along the path of selection of chemicals with the most similar characteristics to halons followed by research and development including testing, certification, toxicity and safety analyses, standards development, and commercialisation. Several HFCs were developed through to commercialisation (note: both the agent and hardware must successfully pass all testing and certifications).

The technical review shows that G2 parties face the same concerns to the use of lower GWP alternatives for fire suppression that also apply to Group 1 (G1) parties. Updated information to that contained in the 2022 report is provided for two alternatives: FK-5-1-12 and water mist.

### *1.2.5 Medical and chemical uses*

Information on alternatives for medical and chemical uses remains essentially the same as reported in TEAP's September 2022 report. The technical review shows that G2 parties face the same specific concerns on the use of lower GWP alternatives for medical and chemical uses that also apply to G1 parties.

### *1.2.6 Information on standards, technical regulations, and codes*

Industry standards, technical regulations (e.g., Globally Harmonised System of Classification and Labelling of Chemicals) and building codes have been updated to reflect industry research and mitigation for new refrigerants since 2016. Over the last 15 years, extensive research has confirmed the availability of lower GWP alternatives to HFCs in the different applications and the accessibility of parties to these alternatives. As the industry moves from conventional high GWP toward lower GWP products, this transition is being reflected in, for example, refrigerant safety classification, equipment design, and installation and applied system requirements. Lower GWP refrigerants typically have a higher level of flammability, therefore, equipment and installation standards need to be updated to adequately incorporate these changes. Updated standards have been adopted in several parties. Examples of relevant RACHP international and regional standards is provided in Annex 2.

### *1.2.7 Information on relevant MLF activities related to the Kigali Amendment*

Information relevant to activities of G2 parties since 2016 under the MLF is provided in this section for the consideration of parties. Since 2016, several relevant technology conversion and demonstration projects were approved by the MLF, implemented or are under implementation by G2 parties. This information is discussed and summarised in Annex 3. Information is also provided and summarised in Annex 4 on relevant, planned activities for G2 parties included in the Adjusted Consolidated Business Plan for the MLF 2024-2026.

### *1.2.8 HFC consumption data reported by some G2 parties*

Three G2 parties (India, Oman, and Pakistan) have reported HFC consumption from as early as 2019, and information is provided for the consideration of parties. It is noted that for G2 parties, the HFC baseline period is 2024-2026.

## 1.3 Organisational and other matters

In Chapter 9 of this report, TEAP provides information on its continued adherence to its Terms of Reference (TOR) related to nominations and appointments of experts to the TEAP, its TOCs and Temporary Subsidiary Bodies (TSBs) as well as organisational matters and ongoing planning considerations related to the Panel's work for parties. The current memberships of TEAP and its TOCs, matrix of needed expertise, and standardised nomination form are found in Annexes 5-7, respectively. To support parties' consideration of the workload of the TEAP in considering new requests, planned TEAP responses to decisions to date for 2024-2026 are provided in Annex 8.

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

## 2.1 Major issues influencing the global foams market

Regulations are driving transitions away from high-GWP HFCs in non-A5 parties, and HCFCs in A5 parties, with emphasis on avoiding adoption of high-GWP HFCs where possible.

Shortages of fluorinated and non-fluorinated (e.g., pentanes) lower GWP FBAs have improved in both A5 and non-A5 parties. As a result of the previous shortages, there had been a significant increase in the use of higher GWP HFCs blends in some A5 parties and a reversion to HFCs in some non-A5 parties, where lower GWP alternatives are not available.

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

Significant resources are spent by foam manufacturers in optimising the characteristics and costs of new FBAs and foam systems through optimising blends with new additives. The new FBA additives or co-blowing agents have different toxicity and thermal properties that can result in handling challenges and lower thermal performance of insulation. It has been estimated that 80-84% of HCFC-141b in A5 parties will be replaced with non-fluorocarbon alternatives including water-blown foams.

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*

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 hydrocarbons (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 small and medium-sized enterprises (SMEs) consuming 1000 tonnes or more to self-formulate blends for their own systems especially in Asia.

By design of the phase-down of the supply of FBAs (production and consumption), 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 (which is banned in many non-A5 parties), has slowed the transition to lower GWP substances. However, HFC-365 manufacturing was shuttered in late 2023. Manufacturers that invested in developing formulations containing HFC-365 have had to invest in evaluating and selecting alternate FBAs and develop foams using replacements.

China's Ministry of Housing, Urban, and Rural Development (MoHURD) has streamlined the fire code for building insulation. A new building code, *General Code for Building Fire Prevention* (GB55037-2022), came into force on June 1, 2023, replacing relevant existing codes. The new code has, for the first time, adopted the concept of classifying composite insulation materials (instead of bare foam) according to their fire resistance.

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[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. During the last decade, major enterprises, mainly in the domestic/commercial refrigeration and continuous panel sectors have been successfully converted to HCs. National HCFC Phaseout Management Plan (HPMP) projects continue to focus on implementation at SMEs, examining a wide range of non-HC pure and blended blowing agents (e.g., low volumes of HFOs, $CO_2$ (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.

Determining FBA in pre-blended polyols:

- Pre-blended polyol Safety Data Sheets (SDSs) and Certificates of Analysis can be used to identify the foam blowing agent in the polyol blend.
- SDS Section 3 "Composition" shows the specific foam blowing agent and the percentage in the composition.
- SDS Section 9 "Physical and Chemical Properties" also shows lower viscosity. (We will either add a standard viscosity to compare to or remove this example.)
- The Certificate of Analysis (COA) paperwork shows the foam blowing agent and composition.

In India, approximately 70% of companies are using non-ODS/lower-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 Southeast Asia, SME companies in the marine sector are using non-ODS/lower-GWP technologies containing higher dosage of water than conventional HCFC-141b systems. Additional water reduces FBA cost but can also increase friability than HCFC-141b foams. The polyurethane formulation is optimised commonly through changing the polyol choice (such as the addition of low functionality polyol), catalyst package, and the use of plasticizer or flame retardant to reduce friability (improve adhesive properties). Additional chemicals (e.g., maleate) may be added to optimise blends containing large quantities of water.).

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[3]. 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

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

[3] There are now some commercially available appliances using new technologies (e.g., vacuum panels) for insulation without foams.

blowing agents to support CE marking[4] and the Declaration of Performance[5] 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 parties, unsaturated HCFCs and HFCs are defined as volatile organic compounds (VOC) and require environmental permits for use. Other EU parties 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 EE.

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.

In the United States, a 150 GWP limit was set for most, if not all, FBAs effective January 2025 and January 2028 under the American Innovation and Manufacturing (AIM) Act 2023 Technology Transition Rule.

## 2.2 Foam blowing agent selection

Manufacturers of HFO/HCFOs have increased capacity of some of the HFOs/HCFOs to meet the demand for lower GWP blowing agents that is expected to result from the implementation of lower 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 lower 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. Foam manufacturers efforts to reduce costs with new FBAs and co-blowing agents with HFO/HCFOs to reduce costs in both A5 and non-A5 parties. As an example, the MLF published outcomes from a demonstration project at foam system houses[6] to formulate pre-blended polyols for spray polyurethane foam applications using a lower 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 foam co-blowing agent and 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

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[4] The CE marking (an acronym for the French "Conformite Europeenne") certifies that a product has met EU health, safety, and environmental requirements, which ensure consumer safety.

[5] A Declaration of Performance (DoP) describes the construction product's characteristics, such as the extent to which it is airtight or fire resistant. Most construction products on the European market are required to have a DoP.

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

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.

1.2- trans-dichloroethylene (DCE) continues to be used as a co-blowing agent worldwide, for use with HFCs, HFOs/HCFOs, with a new tradename now available in southeast Asia. DCE use may have increased in use as a co-blowing agent to reduce FBA cost.

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[7]) is being promoted, as an 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[8] blowing agents requires approximately18 to 36 months for capital investment and product qualification based on the specific end use (e.g., walls, roofs, structural support, transportation, cold storage). Flammable blowing agent use is also impacted by local and regional air quality regulations on volatile organic compounds. It was also noted that at least one non-flammable, mid-range (750 GWP) blend, containing HFC-134a, is currently under consideration for use.

An alternative FBA with lower GWP is commercially available (HFO 1234ze), which \reportedly provides better thermal performance <28 mW/mK (milliwatts per meter-Kelvin). This performance is achieved with additional cost, which can be minimised with blends with less expensive material but with higher GWP or with flammable alternatives**.**

In China, there are 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.

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

[8] 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

# 3 Fire Suppression TOC (FSTOC) Progress Report

The FSTOC met 28 February to 1 March, 2024, in Bangkok, Thailand. The meeting was attended in person by 16 members from the following parties: Bangladesh, Brazil, China, India, Italy, Japan, Kuwait, Sweden, the United Kingdom, and the United States.

## 3.1 Alternatives

The FSTOC is not aware of any new alternatives to halons, HCFCs or high-GWP HFCs under development since the last progress report. Furthermore, the FSTOC understands the lower GWP blend in-kind total-flooding Halon 1301 replacement agent that was in the process of being commercialised is no longer being developed, owing to commercial and/or PFAS considerations.

## 3.2 PFAS regulations

Many parties have been, or plan to transition from high-GWP HFCs (particularly HFC-227ea and HFC-125) to the lower GWP FK-5-1-12 for fire protection applications. This includes parties intending to meet their Kigali Amendment obligations. The proposed PFAS regulations, and their uncertainty, have caused many of the parties to pause these transitions or transition plans. Refer also to the Chapter 7 of this report on PFAS.

## 3.3 HFC regulations

HFC regulations are increasing in number, complexity and/or restrictions.

The reason for the Kigali Amendment phasedown schedules rather than phaseout was to allow uses to be preserved where alternatives are not readily available. The phasedown of production was not expected to negatively affect the fire suppression sector as quickly as it has. Furthermore, it was not expected to negatively impact uses where there are NO other alternatives other than going back to halons. It was reasoned that the use of HFCs in fire protection is extremely small in comparison to other uses, the emissions are low, and sales of HFCs for fire protection applications in most non-A5 parties were either declining or flat. In contrast, for example, what we have seen in the United States is that there has already been significant increase in the cost of newly produced HFCs. Responsible users in the fire sector have significantly reduced emissions while refining the applications to targeted, appropriate uses.

A continuing concern of the FSTOC is that there are some fire suppression applications in enduring uses where the only alternatives to Halon 1301 are high-GWP HFCs. In the United States, commercial considerations have led to the production of high-GWP HFCs being phased down or phased out early, and the $CO_2$-equivaent allocation being used for lower GWP HFCs used in other (non-fire) sectors. Should this trend be followed globally, there is a concern that these fire suppression applications may need to revert back to halons, as the only option, because the only "safety valve" remaining is an Essential Use Nomination under the Montreal Protocol. It is known that Halon 1301 is manufactured for feedstock use, implying there is capacity to manufacture the agent for fire suppression uses also, under an Essential Use Exemption.

There have been some recent developments in banking of HFCs:

- FM-200R™ (Recycled): FM200R is a Tradename for reclaimed HFC-227ea that can be used for refill and "first fill" of system cylinders, *i.e.,* it is now viewed as equivalent to newly produced agent. The FSTOC views this as a significant step towards HFC banking, as it reduces reliance on newly produced HFC-227ea and provides additional economic incentive to recover and reclaim this agent. This could serve as an example for other high-GWP HFCs in the fire suppression and other sectors.

- Additionally, testing and certification associations such as FM Global and UL Solutions are developing criteria for implementing reclaimed agent. This will further facilitate recovery, recycling, reclamation and banking for continued responsible use of high-GWP HFCs for fire suppression.

Parties may wish to consider the negative impacts pending or potential PFAS restrictions are having on the ability to achieve the overall goal of ozone and climate protection while maintaining life safety.

## 3.4 Civil Aviation

One aircraft manufacturer and fire suppression system provider continues to evaluate $CF_3I$ as a halon 1301 alternative for engine/auxiliary power unit (APU) fire extinguishing applications. U.S. Federal Aviation Administration (FAA) Minimum Performance Standard (MPS) testing was completed last year. Another aircraft manufacturer and fire suppression system provider is testing the finely-divided sodium bicarbonate solid aerosol. MPS testing of this agent is on-going at the time of writing this report.

In the cargo compartment fire suppression application, one aircraft manufacturer and fire suppression system provider while still evaluating the 50/50 blend of 2-BTP and $CO_2$, has slowed this activity, mainly owing to concerns surrounding the uncertainty of the proposed PFAS regulations. It should be noted that this blend of 2-BTP and $CO_2$ is toxic at its design concentration. While cargo compartments are classified as unoccupied areas, animals are allowed to be transported in cargo bays and may be put at an increased risk with this blend. The aircraft manufacturer evaluated this blend in the cargo compartment during flight tests of its demonstrator aircraft. The outcome of these tests has not been made public.

A fifth fire threat is being added to the MPS, in part to address the hazard of inadvertent shipping of lithium-ion batteries in aircraft cargo compartments. Testing of the blend of 2-BTP and $CO_2$ against this new fire threat has been completed and the results are viewed as successful. The timescale for approval of the updated MPS is not known at this time.

In regard to portable extinguishers, the transition from Halon 1211 to 2-BTP is now well underway, with many operators on course to complete this by the EU retrofit date of December 2025.

## 3.5 Regulations Update – European Union

On 20 February 2024, the new regulations (EU) 2024/573[9] on fluorinated gases (F-gas Regulation)[10], and (EU) 2024/590[11] on ozone-depleting substances (ODS Regulation) have been published in the Official Journal of the European Union, and both entered into force on 11 March 2024.

### *3.5.1 F-gases*

Under the new F-gas Regulation, the consumption of HFCs will be completely phased out by 2050. Both production and consumption will be phased down on the basis of a tight schedule with a progressive quota allocation. Furthermore, the text introduces a full ban on placing products and

[9] https://eur-lex.europa.eu/eli/reg/2024/573/oj

[10] This link is to guidance on the EU's F-gas Regulation and its legal framework: https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-rules_en

[11] https://eur-lex.europa.eu/eli/reg/2024/590/oj

equipment containing HFCs on the market for several categories for which it is technologically and economically feasible to switch to F-gas alternatives; fire protection equipment that contain or rely on other fluorinated greenhouse gases listed in Annex I, except when required to meet safety requirements at the site of operation, shall be prohibited from 1 January 2025. Guidelines for the interpreting "meeting safety requirements at the site of operation" are not available at this time and some parties have expressed concern on how to proceed.

In addition to the above placing on the market prohibitions, the import, use or export of non-refillable containers for fluorinated greenhouse gases listed in Annex I (HFCs, PFCs, and other (per)fluorinated compounds and fluorinated nitriles) is also prohibited.

The impacts and effects of the regulation will be periodically reviewed by the European Commission.

#### *3.5.2 Ozone depleting substances*

The new ODS Regulation bans ODS for almost all uses, with strictly limited exemptions that include: i) the use of ODS as feedstock to produce other substances; ii) the use of ODS under strict conditions as process agents; iii) in essential laboratory and analytical uses; and iv) for fire protection systems and fire extinguishers containing halons applied for critical uses in special applications such as military equipment and aircraft.

The European Commission may grant time-limited derogations from the end dates (retrofit) or cut-off dates (no longer allowed in new designs) set out in Annex V for specific cases where it is demonstrated in the derogation request that no technically and economically feasible alternative is available for that particular application.

The European Parliament and the Council of the EU incorporated into the new rule text the advice of the FSTOC (referred to in the Regulation by the committee former name "HTOC" for the Halons Technical Options Committee) indicating that non-virgin halon stocks for critical uses might not be sufficient to meet the needs at a global level from 2030 onwards; for this reason to avoid having to produce new halons to meet future needs, it is important to take measures to increase the availability, and provide for adequate monitoring, of stocks of halon recovered from equipment (bullet point 13), Regulation (EU) 2024/590.

### 3.6 Halon destruction

In the United States, there have now been multiple projects that have destroyed halons to obtain carbon offset credits that can be used on the voluntary carbon market. These projects were performed under the American Carbon Registry (ACR) Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removal from the Destruction of Ozone Depleting Substances and High-GWP Foam[12]. This methodology allows for the destruction of Halon 1211 and Halon 1301 from the United States and Canada.

There are two major factors fuelling these halon destruction projects. First, large corporations that are seeking high quality carbon offset credits are willing to pay more to purchase halon for destruction than the current market price of Halon 1301 for supporting enduring users. Second, industries with enduring halon uses (for example, aviation and oil and gas industries) that were purchasing halons beyond their current needs to build a future supply have largely stopped this practice, leading to a short-term "oversupply" of recycled halon on the market. Recyclers that may have been reluctant in

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[12] This ACR methodology is available at: https://acrcarbon.org/methodology/destruction-of-ozone-depleting-substances-and-high-gwp-foam/.

the past to sell halon for destruction are now finding that it may be the only outlet to sell some of their current supply.

Currently, it appears that the destruction of halons for carbon credits is limited to the United States. The EU recently prohibited the destruction of halons "unless there is documented evidence that the purity of the recovered or recycled substance does not technically allow its reclamation and subsequent re-use" as part of its revised ODS regulations. Due to the circumstances outlined above, the FSTOC expects that halon destruction projects will continue and possibly increase in the United States. Should this practice spread to other parties, it has the potential to significantly reduce the size of the available Halon 1301 supply, thereby bringing the run-out date closer to 2030, which was estimated by the FSTOC in its 2022 Assessment Report.

### 3.7 Emissions of Halon 1301

As the FSTOC has been suggesting for many years in many different forums, stakeholders supporting enduring uses of Halon 1301 may want to consider purchasing their expected future supply needs now while the agent is available rather than waiting, only to find it is not available to purchase when they need it. Parties to the Montreal Protocol have been kept informed of these potential impacts to future halon supplies by the FSTOC, and in "Decision XXIX/8: Future availability of halons and their alternatives", paragraph 3, they encouraged "parties to refrain from destroying uncontaminated recovered, recycled or reclaimed halons before they have considered their national and the global long-term future needs for halons, and to consider retaining uncontaminated recovered, recycled or reclaimed halons for anticipated future needs in a manner that employs best practices for storage and maintenance, in order to minimise emissions." Parties may wish to consider ways to strengthen this message given the increase reported in large-scale Halon 1301 destruction.

As reported in the TEAP 2023 Progress Report, the unexplained temporary increases in emissions of Halon 1301 derived from atmospheric measurements continue to concern the FSTOC. The FSTOC has tried, but has been unsuccessful, in linking these unexplained temporary increases in emissions to the fire suppression bank or use. If these additional emissions were from the bank, the cumulative total would make the resulting bank smaller, and the available bank much smaller. Additionally, if the bank was subsequently smaller, one would expect the emissions to also be smaller, which is not what the data show. The FSTOC therefore considers that these additional emissions are not from the bank, but from another source.

Since it is known that Halon 1301 is produced as a feedstock for Fipronil and some pharmaceuticals, the FSTOC is hypothesising that these unexplained temporary increases in emissions in halon 1301 are somehow related to its feedstock production and use. Recently the FSTOC has been made aware that production of halons (believed to be substantially or exclusively $CF_3Br$ or Halon 1301) for feedstock has been published by the Ozone Secretariat under Article 7 reporting[13].

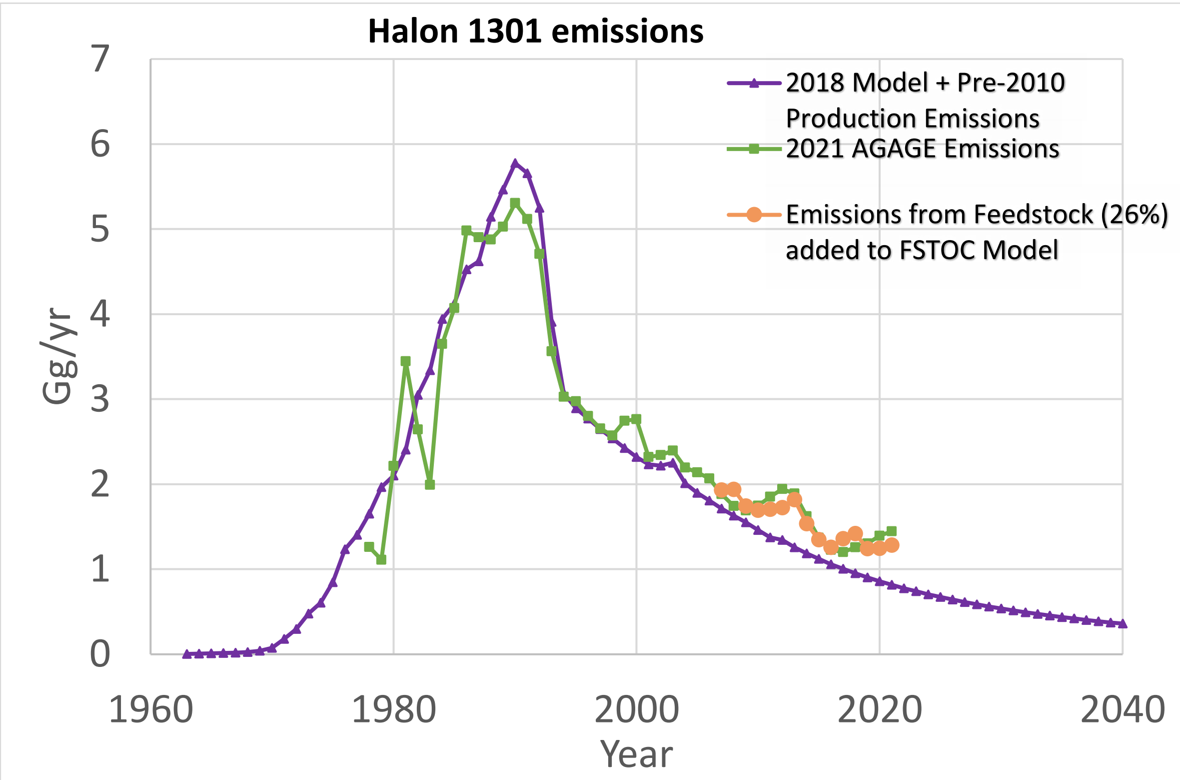
[13] Information provided by parties in accordance with Articles 7 and 9 of the Montreal Protocol on Substances that Deplete the Ozone Layer: https://ozone.unep.org/system/files/documents/MOP-35-6_IMPCOM-71-2E.pdf.

**Table 3-1 Production of halons for feedstock**

| Year | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| Number of Parties Reporting | 2 | 3 | 3 | 3 | 4 | 4 | 3 | 3 |
| Annex II (Halons)/ Tonnes | 855 | 1,202 | 758 | 900 | 1,270 | 1,471 | 2,163 | 1,342 |
| **Year** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | |
| Number of Parties Reporting | 2 | 2 | 4 | 4 | 4 | 4 | 4 | |
| Annex II (Halons)/ Tonnes | 871 | 753 | 1,360 | 1,805 | 1,306 | 1,486 | 1,796 | |

The FSTOC applied the range of emissions factors provided by the MCTOC. Even at the high end of the range, although the resultant emissions were much smaller than those derived from atmospheric concentrations, the pattern looked very similar. The FSTOC then applied higher emissions factors to the feedstock production and found that at 26% the match was remarkable. For further information refer to Annex 1.

**Figure 3-1 Emissions of Halon 1301 derived from atmospheric measurements, compared with the FSTOC model, combined with emissions from feedstock production**




The FSTOC is aware that an emission rate of 26% is unusually high and seeks more information on emissions from production and use of halon 1301 for feedstock from relevant parties.

Parties may wish to consider providing information on emissions from production and feedstock use of halon 1301 to the Ozone Secretariat for confidential use by the TEAP in its assessment.

# 4 Methyl Bromide TOC (MBTOC) Progress Report

## 4.1 Executive summary

The phase out of over 60,000 tonnes of non-QPS use of MB marks a very significant milestone for the Montreal Protocol as MB was once considered to be an essential fumigant for controlling soil borne diseases and pests impacting production of high value horticultural crops and for controlling pests attacking stored commodities and structures.

The reduction in this anthropogenic MB use to date is also a great outcome for ozone layer recovery as MB is short lived in the atmosphere (0.7 years) and the benefit of any reduction is very quickly felt in the atmosphere.

The phase out has been underpinned more recently by the large reduction in CUN requests for MB declining from requests for 18,600 tonnes in 2005 to just 3 tonnes for 2025. However, concern exists that a significant amount of MB is still being used for non-QPS uses either via diversion from current production for QPS purposes or through incorrect classification of uses as QPS.

As approximately 9,000 tonnes of MB is annually used for QPS uses, the MBTOC report focuses on MB use or QPS applications currently exempted from phase out guidelines under the Montreal Protocol. It concentrates on the feasible alternatives for replacing these uses, including challenges hindering the adoption of such alternatives.

Global MB **production** for QPS uses has decreased slightly in recent years, dropping from 10,400 tonnes in 2021 to 8,865 tonnes in 2022. While most parties show downward trends, India exhibits a continuing rise in MB production.

Global MB **consumption** for QPS uses has reportedly declined in 2022, reaching 7,526.2 tonnes down from 10,395 tonnes in 2021, although large fluctuations are common with QPS data reported in the past.

When considered over a longer term, i.e., the past 7 years (2016-2022), there is a cumulative surplus of MB produced for QPS compared to that reported for consumption by a total of 3,620 tonnes.

Noted findings in changes in consumption of MB for QPS include: a significant increase in Uruguay; a dramatic drop in New Zealand; unclear reporting from OIRSA member parties in Central America

A lack of sector breakdown for QPS uses makes it difficult for MBTOC to assess the suitability of alternatives for such uses. The correct classification of uses as pre shipment (i.e. cosmopolitan pests, present in both the exporting and importing parties) or quarantine uses (exotic pests, not present in the importing country) is a key issue for determining the suitability of an alternative.

As evidence demonstrates that alternatives exist for most pre-shipment uses, parties may wish to consider a revision of the categorisation of QPS to only allow consideration of the use of MB for controlling quarantine pests.

The MBTOC report also provides updates on new registrations in a range of parties of effective alternatives to MB for some QPS applications, as well as research and development of promising alternatives like ethane dinitrile (EDN), hydrogen cyanide (HCN), ethyl formate (eFume), methyl iodide and technologies not requiring registration such as microwave technology for soils. Registration of EDN, a key alternative to replace MB for timber treatments, has been achieved in many parties.

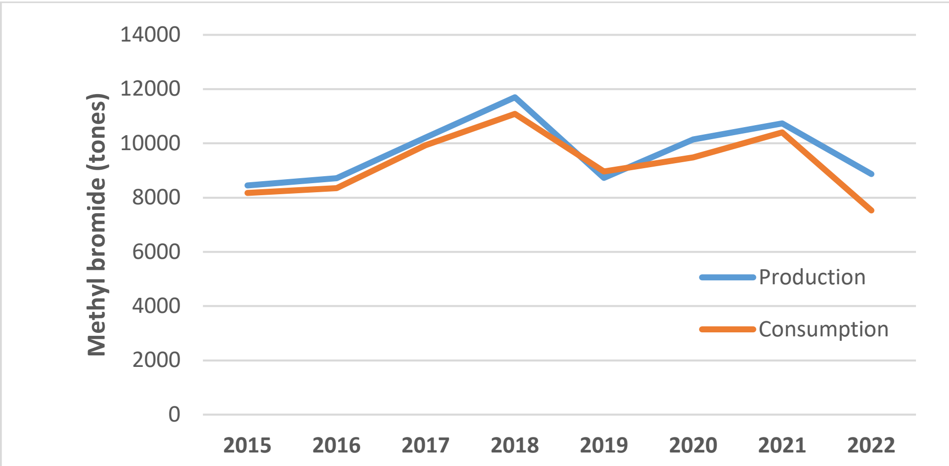
MB has been recommended for listing under Annex III of the Rotterdam Convention, subjecting it to the Prior Informed Consent (PIC) procedure. If approved, this will add another layer of control over international trade of MB. A final decision will be made in 2025.

The report further analyses the changing scene for existing alternatives: controlled atmosphere treatments are emerging for control of the Khapra Beetle; the EU has stricter regulations on SF use and is now requiring measures to minimise release of emitted gas using recapture and others; Japan is considering expanding registration of methyl iodide for other products traded for QPS.

### 4.2 Methyl bromide production and consumption for QPS applications

The reported global production of MB for QPS in 2022 was 8,865 tonnes, down from 10,400 tonnes in 2021 (Figure 4-1). There is a cumulative surplus of 3,620 tonnes over the past 7 years of MB produced for QPS purposes when comparing reported production versus reported consumption.

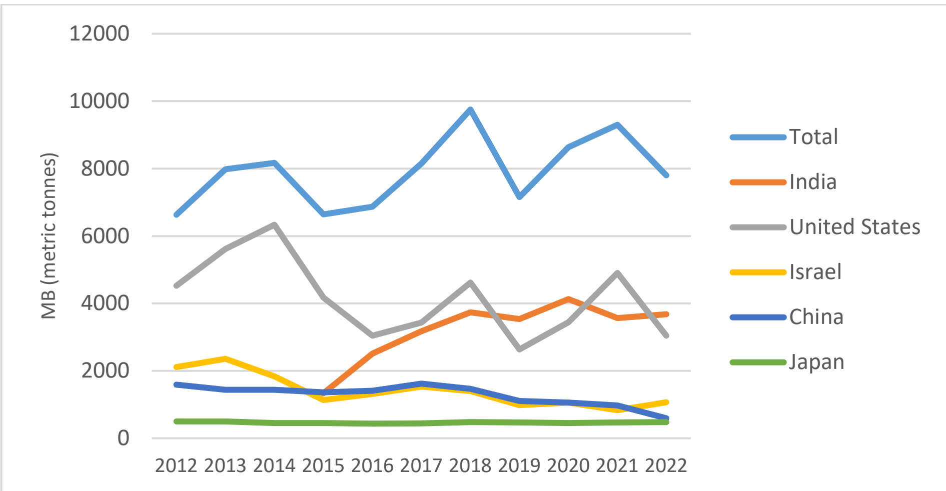
**Figure 4-1 Production vs. consumption of MB for QPS-uses 2015-2022 (tonnes)**




Source: Ozone Secretariat Data Access Centre, accessed March 2024

Production currently occurs in five parties only – China, Israel, India, Japan and the US as shown in Figure 4-2 below. Whilst the United States, China, and Israel show slightly downward production trends, India continues an upward tendency. Together, India and the United States account for 76% of global production, reported at 8,865 tonnes for 2022.

**Figure 4-2 MB production for QPS-uses by party 2012-2022**

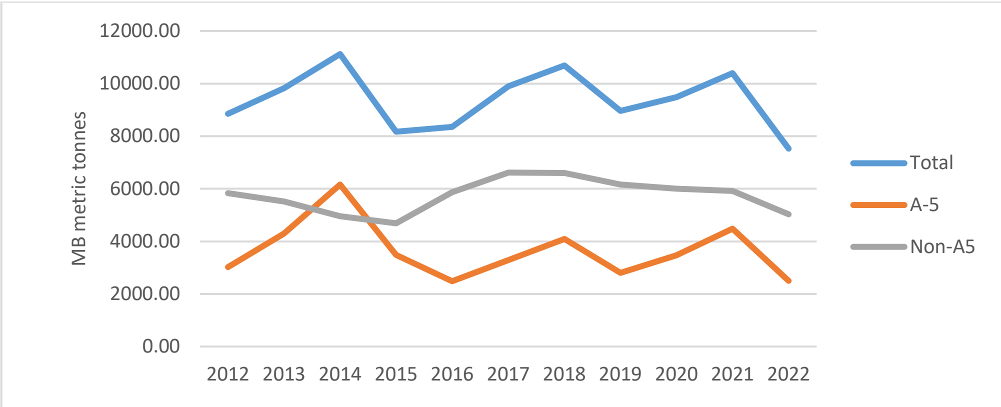



Source: Ozone Secretariat Data Access Centre, accessed March 2024

Global reported QPS **consumption** in 2022 was 7,526.2 tonnes, down from 10,395 tonnes reported in 2021. This number however could be up to 500 tons higher since as at the date of producing this report some key parties (e.g., Republic of Korea, Guatemala) had not submitted consumption information for 2022.

Reported consumption over the past decade continues to show variations between years as noted in previous MBTOC reports (see for example MBTOC 2022 Assessment Report). Non-A5 parties accounted for 67% of global consumption in 2022 but nevertheless show a downward trend as shown in Figure 4-3 below.

**Figure 4-3 QPS-consumption A5/non-A5 2012-2022**




Source: Ozone Secretariat Data Access Centre, accessed March 2024

A more detailed analysis of the consumption data reported under Article 7 reveals:

- Uruguay has become the largest user of MB for QPS in South America, increasing from an average of 25.4 tonnes reported for the period 2013-2018 to 112 tonnes between 2020 and 2022 on average. In 2022, Uruguayan consumption was almost equivalent to that of Argentina, Brazil and Chile combined. MBTOC has received information that this steep increase is related to increased export of timber and wood products from Uruguay (and Argentina) to India, where the latter required MB treatment before the goods are shipped.
- New Zealand reported a very sharp drop in its consumption, decreasing from 857.2 tonnes to just 6.15 tonnes in 2022. This is due to an uneven reporting between, reduced log exports, new EPA regulations (such as ship hold ban), increased alternatives such as debarking and phosphine. Actual consumption is likely to be slightly higher than reported in 2023.
- OIRSA (the International Regional Organism for Animal and Plant Health) is a Central American organisation providing quarantine services for its nine member countries, including methyl bromide imports. MBTOC is not clear as to how OIRSA member countries report their individual MB-consumption. High figures from El Salvador (where OIRSA headquarters are located) would suggest that consumption of the individual members is aggregated and reported jointly, however some members like Mexico, Guatemala, Honduras, Nicaragua, and Costa Rica report individually, while others like Panama and Belize do not report any consumption.
- The United States is the only country which classifies preplant soil use as QPS. In 2009 up to 1476 tonnes of MB were reported (TEAP, 2009) as being used for nursery uses under QPS, but the use appears to have decreased. Based upon the 2022 California Pesticide Use Report (CDPR, 2021), 348 tonnes was reported in California alone for preplant soil fumigation. Overall, in California, a total of 727 tonnes of MB were reported for all uses, which is down from 765 tonnes in 2020 and a significant drop from 1822 tonnes in 2012. After preplant soil use, the largest amount of MB for QPS use in California is 244 tonnes for outdoor plants (i.e.

treatment of soil for transplants and use for containers) followed by 18.2 tonnes for strawberries. Specific amounts of MB application outside of California are not available but MB used in the production of bare-root pine seedlings has reported to decrease by 17% between 1980 to 2012 (Southern IPM Center, 2022). Although many nurseries that produce bare-root pine seedlings in the southern United States have evaluated alternative fumigants, only 16% have switched to them.

## 4.3 Methyl bromide under the Rotterdam Convention

As reported earlier by MBTOC, in September 2022, the Chemical Review Committee (CRC) of the Rotterdam Convention recommended listing MB in Annex III of the Convention, which includes pesticides and industrial chemicals that have been banned or severely restricted for health or environmental reasons by at least two parties to the Convention (UNEP, 2022).

In October 2023 a draft decision guidance document was considered and approved by the CRC and will be forwarded for final decision at the $12^{th}$ MOP of the Convention in 2025 (UNEP, 2023).

If MB is listed in Annex III, parties exporting or importing this fumigant will need to follow the PIC procedure, which involves exchanging information to ensure informed decisions about trade (DAFF, 2024).

## 4.4 Pre-shipment versus quarantine

Differences between the MB applications for either quarantine or pre-shipment purposes have been the subject of several decisions of the Montreal Protocol (e.g., VI/12; VII/5; XI/12; XXIII/5). However, as noted by MBTOC in several of its reports, some parties still express confusion when making this differentiation. As the pre-shipment category is for non-quarantine pests for which more alternatives exist, parties may wish to consider refining the definition of QPS to Q only to avoid any confusion and urge parties to adopt alternatives for the pre-shipment category.

MBTOC recently provided detail in response to Decision XXXIV/10 but has also in the past provided detailed explanations and tools to help clarify these concepts and now provides the following statements to further complement that effort.

### *4.4.1 Classification of MB use under the 'Pre-shipment' category:*

MB use under the pre-shipment category is only for cosmopolitan, non-quarantine pests and only applies for treatments 21 days before shipping. It must have official documentation (pre-December 1996) for the use of MB.

This fumigation practice occurs because of pest infestation occurring during storage, particularly for high-value or historically pest-prone commodities like rice, cassava chips or coffee. Currently, with new developments in storage sanitation and pest control techniques and a lowering of the required efficacy rates (e.g., controlled atmospheres, hermetic storage, and carbon dioxide) there is a much wider range of alternatives now available for pre-shipment treatments. For this reason, data shows that most pre-shipment treatments have alternatives and do not need to use MB (Opit *et al*, 2011; Makinya *et al*, 2021; Nakamura *et al*, 2008; Bingham and Hagstrum, 2024). Technical data and other information indicate that MB can be replaced as a pre-shipment treatment for timber products. The majority of use reported as timber pre-shipment is likely to be misnamed and may actually be for quarantine use to meet importing parties' requirements. In one instance for example, one country providing data reported 96% of use was pre-shipment to treat phytosanitary certified export logs, when the country has a policy of only using MB for quarantine uses under official direction.

Since alternatives are generally available for pre-shipment applications and owing to the confusion of the uses which satisfy the pre-shipment category, parties are urged to consider removing it from the QPS definition and only allowing exemptions for quarantine pest situations.

#### *4.4.2. Classification of MB use under the 'Quarantine' category:*

MB use under the quarantine category must have an official certificate stating the use is against a quarantine pest.

Importing parties often require a phytosanitary certificate (PC) confirming that goods originating in the exporting country are free of quarantine pests. Fumigation with methyl bromide may be listed as an additional requirement on the PC, and a very high mortality rate (often Probit 9[14] or 99.997% mortality) must be achieved for acceptance of an alternative to MB for a quarantine pest. Owing to the amount of work required to demonstrate effectiveness of a new alternative, there is little incentive to adopt alternatives for quarantine treatments. This is a difficult situation for the Montreal Protocol because often MB does not meet the Probit 9 requirements either, but is the historical treatment used and adopted.

When quarantine pests are found on imported goods at the port of entry of a particular country, or when the imported commodity has a high risk of being infested or difficult to detect, the importing country may require fumigation with MB. Similar to export quarantine treatments, a high mortality rate is required from any alternative treatment being considered to replace MB, again offering minimal incentive to switch to any alternatives to MB. This is partly because methyl bromide has been the standard for quarantine treatment since the 1930s; however, technically and economically feasible alternatives exist and their adoption, thereby replacing MB, would be of immediate benefit to the ozone layer.

**Quarantine pests** are officially designated and regulated by the importing country. The International Plant Protection Convention (IPPC) defines "official control" within its ISPM 5 document (IPPC, 2018) which emphasizes the importance of enforcing regulations and procedures to control quarantine pests and regulated non-quarantine pests.

While recognising that interpretation of decisions is made by individual parties, MBTOC has used one interpretation to provide consistency in discussing aggregate quantities used for Q and PS and particular QPS uses.

The following table (Table 4-1) provides examples for the three categories - Q, PS and non-PS as used by MBTOC. This table may assist in identifying 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.

[14] Probit-9 mortality is a standard for treatment effectiveness that has its origin in fruit fly research and has been adopted by the United States Department of Agriculture for fruit flies and several other pests. Following this, the probit-9 standard has been adopted as a benchmark for many quarantine treatments worldwide. Source:

**Table 4-1 Example situations of MB classification under Quarantine, Pre-shipment on non-PS as used by MBTOC (see further details in the MBTOC 1998 Assessment Report)**

| Commodity Traded | | Q or non-Q Pest | Treatment prior to Export or in Import |
|---|---|---|---|
| Quarantine Use | | | |
| 1 | Packed commodities (e.g., Rice, spices and wooden crates) | Quarantine pest: e.g. Khapra beetle (*Trogoderma grannarium*) | Could be treated prior to export (e.g. Australia) or on interception on import (e.g. Japan) |
| 2 | Rice<br>or<br>Oranges | Restricted location of Quarantine pest, khapra beetle or *<br>fruit flies (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) |
| 3 | Houses and other structures | Localized quarantine pest - Dry wood termite *Cryptotermes* spp | Subject to official control |
| A. Pre-shipment treatment (within 21 days prior to export) | | | |
| 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 parties |
| 3 | Empty ship holds | After interception of cosmopolitan (common) grain pests by inspection authorities (e.g., Canada, United States) | Must have an official government regulation prior to Dec 1994 for non A5 and prior to Dec 1995 for A5 parties |
| 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 parties |
| 5 | Treatment of land prior to nursery product being moved to another region | No quarantine pest involved but may have regulated non quarantine pests. | May satisfy quarantine if party accepts and has known regulated non-quarantine pests |
| B. Examples - which Quarantine or Pre-shipment | | | |
| 1 | Cocoa beans (export) | No pests nominated; no official document required. | |
| 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)

## 4.5 Barriers or limitations to consider assisting adoption of alternatives to MB for QPS uses

Factors that can hamper the adoption of alternatives to MB for QPS uses can be summarised as follows:

- More specific efficacy data are needed: current efficacy requirements for quarantine treatments often only specify "control" without detailed levels of effectiveness. **Solution:** Efficacy levels only need to match the level of risk and volume of trade. Research funds should be available.
- Small volume use hurts adoption of alternatives: limited use of some alternatives for QPS applications makes them less economically attractive, commercially viable, and readily available. **Solution:** Governments can assist by being the registrant for quarantine uses or waving fees.
- Registration delays hinder alternatives: some alternative treatments are not yet registered in many parties. This registration process can be lengthy, expensive, and complex, which delays their adoption. **Solution:** Governments can assist by being the registrant for quarantine uses or waving fees.
- Approvals can be time-consuming: local permits, public approvals, and trade partner agreements are all necessary steps for using new treatments. These approvals can be time-consuming to obtain. **Solution**: Governments can assist by fast tracking quarantine treatment approvals.
- Consumer resistance slows adoption: hesitation to switch from established methods can slow the adoption of alternatives. Building confidence often requires trials, demonstrations, and information exchange on alternative options. **Solution:** Positive messaging by trusted sources such as government.
- Training is necessary: safe handling, residue management, application techniques and others are essential to ensure successful adoption of alternative treatments. **Solution:** Governments can assist by developing and providing training for alternative quarantine treatments.
- Residues and plant damage are ongoing concerns: treatment residues and potential phytotoxicity need to be addressed. **Solution:** Research funds should be made available.
- Consumer safety: adoption of new treatments needs to be accompanied with measures ensuring their safe application and handling. **Solution**: Research funds should be made available.
- Qualified and viable suppliers: treatment suppliers should be officially approved, and capable of offering feasible and effective treatments. **Solution:** Governments need a clear path for approval to promote alternative treatments.
- Treatment time can be critical: the length of time the treatment process takes is very often critical on imported products as delays can affect their quality or marketability. **Solution:** Ensure products are pest free prior to export.

## 4.6 Examples of regulations affecting use of MB and its alternatives

For decades, MB was included in a large number of phytosanitary regulations worldwide. Some parties have reduced and even discontinued MB quarantine use completely, while others have increased requirements for MB use on grounds of ensuring phytosanitary safety.

India, for example, increased its QPS reported **use** of MB by 539%, from 329 tonnes in 2015 to 2,104 tonnes in 2020; it then reduced to 1,541 tonnes in 2022. India's Plant Quarantine Order of 2003 seems to be the underlying reason for the increase in this MB use. The Order sets MB as the only accepted treatment to guarantee freedom from regulated pests in imported products. Phosphine, heat or cold treatments are rarely mentioned and if they are, they appear as complementary treatments to be used jointly with MB. Sulfuryl fluoride is not mentioned in this regulation.

The United States is the world's largest user of MB for QPS, however consumption has been on a downward trend over the past 20 years; consumption peaked at 4,677 tonnes in 2014 and was reported at 1,278 tonnes in 2022. The United States is the only party classifying preplant soil uses as QPS on the basis of Section 419 amending the Plant Protection Act in the 2002 Farm Bill (USDA, 2004). This amendment requires the Secretary of Agriculture, *"upon request of State or local authorities, to determine whether a MBr treatment or application required by those authorities to prevent the introduction, establishment or spread of plant pests or noxious weeds should be authorized as an official control or official requirement".*

The two examples above illustrate how regulations can lead to the continued use of MB, even when alternatives exist.

## 4.7 Case studies on progress in replacing MB uses for QPS applications

Despite the lack of incentive for the adoption of alternatives to MB for QPS uses, many parties have made good progress in adopting alternatives. Some examples are described below:

### *4.7.1 Fumigant and non-fumigant treatments used as QPS treatments in Morocco*

Morocco's MB consumption has slightly increased from 9.2 tons (2018) to 10 tons (2022). Phosphine is widely used instead of MB and to control post-harvest pests. Its registration will be reassessed in September 2024. MB will be considered for reregistration in June 2024.

Morocco uses MB partly as a result of bilateral arrangements some importing parties require fumigation (MB or phosphine) for specific Moroccan agricultural exports. These products include wooden packaging materials, spices, aromatic and medicinal plants, and crops like capers, carob, mint, fennel, and coriander.

Morocco also uses MB or phosphine fumigation for certain imported goods like tea, coffee, dates, and nuts, depending on agreements with the exporting country.

Currently, non-chemical QPS options like irradiation, controlled atmosphere, and radiofrequency are not commercially used in Morocco. However, irradiation is gaining traction as a potential alternative to MB. Research in citrus-producing parties, including Morocco, shows promising results.

For exported wood products and citrus fruits, Morocco primarily relies on high and low temperatures, respectively, as QPS treatments.

Since January 2019, Morocco has implemented the ISPM 15 standard that mandates treatment of all wooden packaging materials used for export. The National Office for Health Security of Food Products (ONSSA) enforces these controls.

Data from the U.S. Department of Agriculture (USDA, 2024a) shows a significant increase (156%) in Moroccan citrus exports to the United States during 2021-2022. Cold storage is the primary method for ensuring citrus fruits are free of live fruit fly larvae. This method, accepted by several of Morocco's trading partners including the United States, Canada, Japan, China, Europe, and Russia, requires temperatures below 3°C for at least two weeks to be effective. The IPPC CPM (Commission on Phytosanitary Measures) has approved this treatment.

The USDA has implemented additional safeguards for various citrus varieties (tangerines, clementine oranges, mandarins, and sweet oranges) exported to the United States. These safeguards include regular orchard inspection and pre-cooling/temperature standards at Moroccan packing houses and ports. Notably, cold temperature treatment not only controls fruit flies but also extends the shelf life of citrus fruits.

#### *4.7.2 China's efforts to reduce MB in QPS uses:*

As a party to the Montreal Protocol, China is actively working to minimise MB use for QPS. This includes:

**Wooden packaging materials (WPM)**: Heat treatment technology has almost completely replaced MB fumigation for treating WPM. From 2012-2014, 897.8 tonnes of MB were used for WPM, averaging about 300 tonnes a year. In 2023, only 2 tonnes were used for this purpose, with heat now being the primary treatment of choice (Fenfen pers. comm., 2024).

**Imported logs**: MB is still used to treat imported logs that may harbor quarantine pests, however, China is actively developing recycling technologies to minimise emissions from this use.

**Export fruit treatments**: Research on alternative treatments like cold and steam heat treatments is ongoing to reduce reliance on methyl bromide for exported fruits (refs).

#### *4.7.3 New fumigant registrations for QPS uses in the Philippines:*

New fumigant options have been registered in the past two years and show potential to replace MB use:

**Cylinderised Phosphine** ($PH_3$), is being used on export commodities including cut flowers. This product shows promise for replacing MB in other parties, particularly in cut flower exports and has been in use in other parties, such as Colombia, as reported previously by MBTOC (TEAP, 2017).

Trials further demonstrate the effectiveness of cylinderised phosphine where a 1-day fumigation at 1,000 ppm for tobacco cut fillers eliminated the need for longer exposures typically required with MB. Information on specific commodities and structures suitable for this specific kind pf $PH_3$ treatment is still, however, needed.

**Sulfuryl Fluoride** (SF) is now registered and a potential one-to-one replacement for MB when fumigating commodities and structures, including WPM. If successfully implemented, SF could significantly reduce reliance on MB for these uses in the Philippines and also in other parties.

Currently the SF registrant, Plant Quarantine services, the Fertilizer and Pesticide Authority, and industry stakeholders are collaborating to develop accreditation training and registration programs for quarantine and WPM service providers. This initiative aims to facilitate the adoption of SF as an alternative to MB for WPM treatment.

Information on specific commodities and structures suitable for SF treatment is still lacking.

#### *4.7.4 Türkiye case study and policy*

Türkiye became a party to the Montreal Protocol in 1991 and its commitment to the Protocol has led to a significant reduction in MB use for QPS purposes. A multi-pronged approach involving regulations, alternative fumigants, and new techniques is part of a successful phase-out strategy.

Regulations like the "Regulation on Reducing the Use of Methyl Bromide in Agriculture" were enacted promptly (June 2000). As a result, Türkiye has a comprehensive system to control MB use for QPS purposes. Imports are managed by a licensed company, and all MB goes to designated authorities. Application requires official supervision and licensed personnel, with fumigation on exports based on importing country requirements and with approval from Turkish authorities.

Türkiye has adopted alternative fumigants for quarantine treatments, including phosphine, SF, and others. Details on these alternatives are available in the Turkish Register (MAF, 2024). Moving Forward, a stepwise approach has been adopted and Türkiye continues to phase out MB for QPS uses through several initiatives for example:

a) **Reduced Imports**: MB imports in 2024 are less than 50% of those in 2023.

b) **Re-export fumigation ban**: MB fumigation is no longer allowed for products intended for being re-exported (effective April 1, 2024).

c) **Alternative techniques**: Türkiye is promoting alternative methods like solarisation, mulching, and ISPMs to further reduce reliance on MB.

#### *4.7.5 Bangladesh lifts fumigation requirements on U.S. cotton*

Bangladesh ranks as the second global importer of cotton and as such, one of the top 10 export destinations for U.S. cotton. During the past 50 years, U.S. cotton fiber exports to Bangladesh were fumigated with MB on arrival, to prevent entrance of the boll weevil (*Anthonomus grandis*), even when US APHIS launched a Boll Weevil Eradication Program in 1978 that successfully eradicated this pest from more than 99% of the U.S. cotton acreage (USDA, 2024b). After years of collaboration between US and Bangladesh authorities, import requirements were finally amended in 2023, exempting the United States from the list of parties required to fumigate cotton on arrival USDA/FAS, 2024).

MBTOC notes, however, that Bangladesh does not report any QPS consumption under Article 7 of the Montreal Protocol.

#### *4.7.6 Minimising MB use in Japan through efficient use and adoption of alternatives*

Japan has adopted a phosphine gas generator that can be attached to fumigation chambers and silo facilities and accelerates treatment. Phosphine gas is sent with a stream of nitrogen or $CO_2$ gas and takes only two days, saving labor. No residues are left in treated grain. Aluminum phosphide in paper bags can be suspended in silos above the grain layer, for treatments lasting 3 – 7 days.

Methyl Iodide (MI) is registered for controlling quarantine pests of timber and wood and for treatment of chestnuts in fumigation tents or chambers.

Heat treatment is now adopted for the majority of WPMs; in 2022, only 1225 kg of MB were used for this purpose.

A systems approach has been approved in Japan for fresh cherries from the United States and New Zealand coming into Japan. The pest of concern is codling moth.

A MB fumigation standard has been developed and adopted, to minimise MB use on logs, timber and grain. These include soaking in water for 30 days (in the case of logs), inspection for quarantine pests and ensuring high gas retention capability and gas tightness in treatment chambers.

### 4.8. The changing scene for MB use and currently available alternatives for key quarantine target pests

#### *4.8.1 Update on the Khapra beetle*

*Trogoderma granarium* is a much-feared pest of stored foodstuffs, typically grains such as rice and wheat and similar granular edible commodities. It is currently listed as present in 75 parties across the Middle East, Asia, Africa, and the Mediterranean. Several khapra-free parties, including the United

States, Japan, Australia, have strict QPS regulations in place to prevent introduction of infested material and associated transportation.

MB fumigation at high dosage rates and extended exposure times is typically specified as the acceptable treatment against *T. granarium* (all stages of development, including the very tolerant diapausing stage are controlled).

There are very few recognized alternatives worldwide. MB fumigation remains the treatment of choice against this quarantine pest, in many parties, it is the sole approved treatment.

However, U.S. treatment schedules have long specified heat treatment as an alternative, and Australia has recently allowed use CAs as QPS treatment according to rates as below (DAFF, 2024).

**Table 4-2 Controlled Atmosphere Treatments: Atmospheric pressure rates**

| Temperature | Concentration | Pressure | Minimum Exposure period |
|---|---|---|---|
| 25°C or above | Carbon dioxide (CO2) - 80% or above | Normal atmospheric pressure | 28 consecutive days (672 hours) |
| Greater than or equal to 25°C and less than 28°C | Oxygen (O2) - 1% or less | Normal atmospheric pressure | 22 consecutive days (528 hours) |
| 28°C or above | Oxygen (O2) - 1% or less | Normal atmospheric pressure | 12 consecutive days (288 hours) |

Products that may be treated with controlled atmosphere include rice, cashew nuts, almonds, macadamias, and other edible nuts, cacao beans, coffee, spices and many other dry products.

Controlled atmosphere treatments can be applied in rooms or chambers as well as containers equipped with CA equipment, well-sealed tarped (sheeted) bag stacks (six-side sealing) or CA 'Cocoons'.

Worldwide there are more than 500 purpose-built facilities in operation for use with CA on the products specified above. One such country, Vietnam, has more than 100.

### *4.8.2 Sulfuryl Fluoride (SF)*

A recent study by Bragard *et al*. (2023) highlight the effectiveness of SF in controlling the emerald ash borer (*Agrilus planipennis*), a major threat to ash trees. SF is also the preferred alternative to methyl bromide for pest control in various settings, including flour mills and other large structures for stored product protection, churches, houses and cultural buildings containing infested wood and furniture (non-QPS uses).

While SF offers a valuable alternative to methyl bromide, it is also a potent greenhouse gas with a high GWP. Recognizing the environmental impact of SF, the EU has implemented stricter regulations for all fluorinated gases, including both $SF_6$ and SF used in fumigation (effective March 2024). Its key points are:

- Operators using SF for pest control must use measures to prevent its release into the atmosphere.
- When technically and economically feasible, operators must recapture and collect emitted SF gas.
- Documentation of recapture efforts or justifications for not recapturing must be provided.

- Individual EU member states may further restrict the use of SF for import, export, and local pest control.

However, currently available commercial recapture systems are expensive and not yet widely available. In addition, recapture doesn't guarantee 100% recovery of the gas used. In conclusion, SF is a valuable tool for pest control, but there are important concerns related to its environmental impact. Current EU regulations represent a step towards balancing the effectiveness of SF with environmental protection.

#### *4.8.3 Methyl iodide for registration for new commodities in Japan*

MB cannot be applied to vegetables like squash, asparagus, and broccoli for quarantine treatments. This restriction exists because acceptable daily intake (ADI) of residues that can remain on vegetables are exceeded when using MB.

As an alternative to MB, MI, previously registered for fumigating timber and fresh chestnuts with an ADI of 0.005 mg/kg/day, is currently being reviewed for use on fresh vegetables such as asparagus, and broccoli. The Food Safety Commission's expert committee in Japan has proposed an acute reference dose (ARfD) of 0.035 mg/kg/day for the general population. If approved, this would allow the registration of MI as a fumigant for these three vegetables to go forward as an alternative to MB (FSC, 2024).

#### *4.8.4 Economic consequences of losing QPS fumigant registration*

Major challenges arise from the lack of harmonisation among pesticide regulations from different parties. Chemicals registered in one nation might be restricted or even banned in others, creating significant hurdles for international trade, which impact both imports and exports of certain agricultural products.

A recent example to illustrate this point is the ban imposed on phosphine fumigation for cereals destined for non-EU export by the French National Food Safety Agency (ANSES) in April 2023, despite its requirement by other importing parties. This caused significant concern amongst French cereal exporters, which led ANSES to re-authorize phosphine use just a month later.

While measuring the economic impact of such disruptions is complex, it involves different perspectives:

- Exporter impact: Will exporters divert delivery to ports with less stringent regulations?
- Importer impact: How will importing nations be affected?
- Long-term effects: Would sustained bans lead to trade declines and changes in net revenue for both importers and exporters?

Exporting parties might have valid reasons for restrictions, such as environmental protection or poverty alleviation efforts. In such cases, purely financial evaluations would not suffice. A comprehensive analysis should also incorporate social costs and benefits, specific to each situation.

The magnitude of economic consequences hinges on the role these commodities play in the import and export portfolios of trading partners.

#### *4.8.5 Update on methyl iodide research in Australia*

MI is a potential direct replacement for MB in fumigation applications. MI has several advantages over MB, for example it breaks down through photolysis, posing no significant threat to the stratospheric ozone layer, plus it is non-flammable and has no global warming potential.

Australia registered MI for pests and weed control in strawberry runner production in December 2022 (TEAP, 2022), Research now focuses on MI for QPS treatments and has shown that MI provides very good control of grain pests (*Tribolium castaneum* and *Sitophilus oryzae*) at lower application rates than MB in laboratory and silo experiments. Economic analyses suggest MI is marginally more expensive than MB for wheat grain treatment, but the impact of this on gross margins is negligible. MI effectively controlled snails, termites, wood rot fungus, and green peach aphid in chamber experiments.

Field trials confirmed the effectiveness of MI for controlling various pests in commodities like logs, grain, hay, and roses. Importantly, MI required significantly lower application rates compared to MB. Concentrations of MI during treatment remained below safe thresholds. Existing MB recapture technologies can also be used with MI, minimising potential emission risks.

Further research with MI is needed to expand efficacy data for specific commodities and pests, secure regulatory approvals for wider application, address potential industry concerns and develop strategic research programs. Forest and Wood Products Australia recently approved further field evaluations of MI for export logs.

#### *4.8.6 Update on microwave research for QPS from Australia*

In laboratory experiments, McFarlane *et al* (2023) demonstrated that microwave radiation effectively kills various QPS pests including weed seeds (ryegrass, oat, wild oats), ants in hay, termites in timber, snails, red flour beetles (in non-food grain), etc. Effectiveness of this treatment depends on factors like applied energy, temperature reached, and exposure time.

Industrial microwave systems show potential for large-scale hay treatment (a commodity for which MB has been used in the past). Moisture content of hay prior to treatment is critical for optimal microwave absorption. Microwave treatment can enhance hay digestibility for livestock.

Wood Treatment Considerations: Application equipment with horned antennas effectively project microwaves for targeted termite control in wood. Moisture content and type of wood (softwood vs. hardwood) influence the heating process and required energy input.

Microwave radiation can also be used to eradicate snails and termites at relatively low energy inputs. Grain treatment requires higher energy levels, which can damage the grain for food purposes.

Two designs for commercial microwave units have been developed: a conveyor system for continuous grain or woodchip treatment, and a large chamber for treating hay bales or pallets.

Estimated cost ranges from A$130,000 to A$300,000, depending on the application and at this time, further development of commercial-scale microwave units is needed. Priority should be given to applications offering additional benefits beyond pest control, such as improved hay digestibility and reduced moisture content in wood products. While active research on microwave technology for QPS is currently on hold, applications for its continuation are underway (McFarlane *et al,* 2022*)*.

#### *4.8.7 Update on ethane dinitrile (EDN = $C_2N_2$)*

EDN is primarily used as a post-harvest phytosanitary treatment of import and export timber and logs for controlling insects, nematodes, and pathogens. It is also effective as a pre-plant soil treatment for controlling nematodes, pathogens and weeds in turfgrass, sports turf, and golf courses as well as in some horticultural crops such as strawberries, melons, and cut flower production.

EDN is already registered in Australia, Türkiye and Malaysia for timber and logs and pre-plant soil treatment, and in South Korea, Russia, New Zealand and Uruguay for timber and logs only. Most recently, EDN has been approved for use in South Africa for timber and logs and as a pre-plant soil treatment (Draslovka, pers. comm., 2024)

Although an EDN formulation (97% GA) is registered, it is not fully accepted on trade between parties. However, South Korea is fumigating large, imported log stacks on arrival.

#### *4.8.8 Update on hydrogen cyanide (Bluefume=HCN)*

HCN is used for structural fumigation for empty structures such mills, warehouses, food factories, poultry farms. It also has application on fresh produce as a post-harvest treatment for selected commodities like bananas, pineapples, citrus, for aircraft and ship-hold fumigation, grain and pulse treatment for controlling storage pests and for controlling the brown marmorated stinkbug (BMSB) on cut flowers and dormant nursery stock (bulbs, etc.)

HCN is currently registered in Australia, the EU, Pakistan, South Africa and Singapore for structural fumigation; in Malaysia and New Zealand for structural fumigation and post-harvest treatments; and in Morocco and Mauritius for aircraft and structural fumigation.

HCN can potentially replace 100% of log and timber MB use.

#### *4.8.9 Update on ethyl formate (eFume = $C_3H_6O_2$)*

EF is used as a post-harvest treatment for most fresh fruit and vegetable commodities, as well as on grain, nuts, dried fruits dates and pulses treatment for the control of stored product pests. It efficiently controls the brown marmorated stink bug (BMSB), a quarantine pest for Australia and New Zealand.

EF is currently registered Malaysia, New Zealand, Australia, Tunisia, Philippines, South Korea, South Africa and Chinese Taiwan for grain and pulses post-harvest treatments.

**Table 4-3 Registration changes of EDN, HCN and EF/CO2 mix in 2023**

| Product | Country/region | Use Pattern |
|---|---|---|
| EDN | Australia | Timber and logs (major label changes) |
| EDN | Türkiye | Soil and timber |
| EDN | Uruguay | Timber and logs |
| HCN | Australia | Treatment of empty structures |
| HCN | South Africa | Treatment empty structures |
| HCN | Slovenia | Treatment empty structures |
| EF | New Zealand | Cereal grains, fruits and vegetables |
| EF | Australia | BMSB control (Label change) |
| EF | Australia | Cereal grains, fruits and vegetables |
| EF | Chinese Taiwan | Fruits and vegetables |

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# 5 Medical and Chemicals TOC (MCTOC) Progress Report

## 5.1 Introduction

This report of the MCTOC provides information on: a response to decision XXXV/6 on updated information on very short-lived substances (VSLS); a response to decision XXXV/8 on feedstock uses including further information on the production and use of controlled substances for chemical feedstock and a response to decision XXXV/9 on abating emissions of CTC. There is also an update of information on medical and other aerosol uses. There is no compelling new information available on process agent uses, *n*-propyl bromide, laboratory and analytical uses, and destruction technologies.

Decisions XXXV/6, XXXV/8, and XXXV/9 request the TEAP to prepare its responses to these decisions in cooperation, or in consultation with, the SAP. The TEAP and its MCTOC cooperated and consulted with the SAP in its preparation of these decision responses through an online consultation meeting, subsequent exchanges of email communications, and final editing review of the report.

TEAP and its MCTOC acknowledge the contributions from the SAP co-chairs, Lucy Carpenter (UK), David Fahey (USA), Kenneth Jucks (USA), and Bonfils Safari (Rwanda), and from the Panel members Steve Montzka (USA), Matthew Rigby (UK) and Luke Western (UK) and are grateful for assistance in the preparation of this report.

## 5.2 Response to Decision XXXV/6 on Very Short-lived Substances (VSLS)

Decision XXXV/6 requests the TEAP, in cooperation with the SAP, to include in its 2024 progress report, for consideration by the Open-ended Working Group of the Parties to the Montreal Protocol at its forty-sixth meeting (OEWG-46):

(a) Updated information on VSLS, including their ODP and the impact of each of the VSLS on the stratospheric ozone layer, in quantifiable terms;

(b) Information on alternatives to VSLS in the main applications for which they are currently used, including information on availability, technical feasibility, economic viability, safety and sustainability.

VSLS are not controlled under the Montreal Protocol. Therefore, parties to the Montreal Protocol are not required to submit data on production and use of VSLS to the Ozone Secretariat. Information provided in this progress report is based upon information obtained from industry experts and from publicly available government and industry data.

Many substances not controlled under the Montreal Protocol being evaluated by atmospheric scientists are chlorinated hydrocarbons with a very low, but non-zero, ODP. Collectively they are known as very short-lived substances (VSLS, chlorinated VSLS or Cl-VSLS) because of their atmospheric lifetimes of less than 6 months. These chemicals include dichloromethane (DCM), trichloromethane (chloroform, CFM), 1,2-dichloroethane (ethylene dichloride, EDC), trichloroethylene (TCE), and perchloroethylene (PCE). These five VSLS are very high-volume chemical products that form the focus of this response.[15]

Each of these chemicals are used as feedstocks, and some also have considerable emissive solvent use. Feedstock usage of both EDC and CFM is more than 90% for each, with some solvent use.

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[15] Dichloromethane (CAS 75-09-2, methylene chloride, DCM); trichloromethane (CAS 67-66-3, chloroform, CFM); 1,2-dichloroethane (CAS 107-06-2, ethylene dichloride, EDC); trichloroethylene (CAS 79-01-6, TCE); and perchloroethylene (CAS 127-18-4, tetrachloroethylene, PCE).

EDC's main feedstock application is the production of vinyl chloride monomer to PVC, the third largest of the global plastics production. EDC can also be used as a feedstock for both TCE and PCE manufacture and for ethyleneamines production.

Chlorinated VSLS have a relatively small, but growing, contribution to total tropospheric chlorine, assessed at 4% in 2020.[16,17,18,19,20] The increasing influence is a result of increases in the abundance of chlorine in VSLS chemicals overall, and because chlorine from the controlled substances is decreasing.

### *5.2.1 Updated Information on VSLS*

The 2022 MCTOC Assessment Report[21] provided comprehensive information on the 2020 global markets, and expected developments, for the VSLS[22] including DCM, CFM, TCE, PCE, and EDC.

Each of these chemicals is used as feedstock, and some also have considerable emissive solvent use. CFM and EDC trend towards 100% feedstock use, although CFM has continued use as a process agent solvent in the pharmaceutical industry. An update on the trajectory of these substances from 2020 to 2022 is set out in Table 5-1 below, each with a comment on its global volume development in both emissive and feedstock uses. DCM is predominantly used as a solvent, and TCE/PCE are partly used as solvents. In some regions, solvent applications of VSLS have shown some small growth in 2021 and 2022 versus 2020, which was heavily COVID-influenced. In feedstock applications, there is some limited regional downward impact on TCE (for HFC-134a) and PCE (for HFC-125, HFC-134a) in non-Article 5 parties due to Kigali Amendment measures for production and consumption of controlled HFCs. The effect is limited because the production of controlled fluorocarbons in non-A5 parties contributes a small percentage of the global production of fluorocarbons, which has overall increased since 2020.

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[16] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Laube, J. and Tegtmeier, S., (Lead Authors), Fernandez, R.P., Harrison, J., Hu, L., Krummel, P., Mahieu, E., Park, S., Western, L., Update on Ozone-Depleting Substances (ODSs) and Other Gases of Interest to the Montreal Protocol, Chapter 1. "*Total tropospheric chlorine from VSL source gases and their stratospheric entrainment increased by about 10 ppt between 2016 and 2020. The input of chlorine VSLSs to the stratosphere now amounts to 130 ±30 ppt, corresponding to contribution of 4.0% relative to the total chlorine input*."

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[21] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022.

[22] VSLS, very short-lived substance(s), is used to describe one single substance and/or a number of substances. It may be used for brominated, chlorinated, or iodinated substances. The term Cl-VSLS is specific to chlorinated substances.

**Table 5-1 Updated information on chlorinated very short-lived substances**

| Product | 2024 Developments since the MCTOC Assessment Report 2022[23] |
| --- | --- |
| **Dichloromethane (DCM, methylene chloride, $CH_2Cl_2$)** | *DCM is feedstock to*: ***HFC-32***<br>The global production of DCM for all uses since 2020 is expected to be flat to showing a modest increase, at about 1,750-1,900 ktonnes. The locus of production and use continues to drift to Asia (S and NE), where some new chloromethanes (CMs) capacity has been brought on-stream, whilst it was announced that one CMs plant in Europe would close in 2023. There appears to be some small contraction in general purpose solvent applications, perhaps due to increased awareness of regulations. These are based on the risk potential of DCM as a potential carcinogen and of possible in-use asphyxiation. Process agent solvent uses in pharmaceuticals and other contained systems continue growth. A large proportion of the feedstock use of DCM to HFC-32 is in Article 5 parties. The production volume of HFC-32 is believed to have grown by >20% since 2020. There is a new production site for HFC-32 in the United Arab Emirates. Additional capacity in India and China has been added. Feedstock use of DCM is about 25% of total production. Significant volumes of HFC-32 produced in Article 5 parties are intended for use in non-Article 5 parties[24]. |
| **Trichloromethane (CFM, chloroform, $CHCl_3$)** | *CFM is feedstock to:* ***HCFC-22***<br>The most important use of CFM is in its use as feedstock to HCFC-22. In the period 2020-22, production of HCFC-22 globally has continued to increase. This is despite reduced production quota levels of -35% baseline as of January 2020, impacting emissive applications of HCFC-22. The growth is due to significant (10+% pa) increases in the use of HCFC-22 as steppingstone to several important fluoropolymers[25], and potentially to HFC-125. Production of CFM in 2022 globally is likely in the range 1.7-1.9 million tonnes, of which up to 30-60 ktonnes are likely used as a process agent. Source emissions of CFM from China have been explored in a new paper[26], which notes a total bottom-up inventory of 104 (84-126) ktonnes in 2020 (An et. al., 2023). The study attributes the largest sources of anthropogenic releases to be from the pulp and paper industry[27] (20-35%) and from production leakage at CMs factories (10-25%). Globally, natural emissions from sea and land contribute more than 50% of detected CFM emissions. |

[23] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022.

[24] DCM is not regulated by the Montreal Protocol: "Article 5 and non-Article 5 parties" are used, here and elsewhere, in reference to VSLS as a proxy for those parties geographically that are known to the Montreal Protocol as Article 5 and non-Article 5 parties.

[25] Examples: polytetrafluoroethylene (PTFE); polyethylenetrifluoroethylene (EFTE); poly hexafluoropropylene (HFP); polyfluorinated ethylene-propylene (FEP);

[26] Minde An, Luke M. Western, Jianxin Hu, Bo Yao, Jens Mühle, Anita L. Ganesan, Ronald G. Prinn, Paul B. Krummel, Ryan Hossaini, Xuekun Fang, Simon O'Doherty, Ray F. Weiss, Dickon Young, and Matthew Rigby, Anthropogenic Chloroform Emissions from China Drive Changes in Global Emissions, *Environmental Science & Technology*, 2023, **57** (37), 13925-13936. https://doi.org/10.1021/acs.est.3c01898.

[27] In the context of product substitution, this is likely due to direct chlorine bleaching of pulp. In this case, a process change to chloride dioxide bleaching (ECF- Elemental Chlorine Free) has been shown to all but eliminate CFM by-product formation.

| | |
|---|---|
| **Ethylene dichloride (EDC, 1,2-dichloroethane, $C_2H_4Cl_2$)** | *EDC is feedstock to:* ***VCM (for PVC)***<br>EDC is close to 100% used as a feedstock to vinyl chloride monomer (VCM), and its production and consumption is tied to demand for PVC. Solvent uses remain unquantified but are expected to be small. 2020 production of PVC was negatively impacted by COVID, and it is believed that global EDC output has now returned to close to 2018 levels at around 53-55 million tonnes, following improved conditions in the construction (70% of PVC use) and automotive industries (16% of PVC use). |
| **Trichloroethylene (TCE, $C_2HCl_3$)** | *TCE is feedstock to:* ***HFC-134a;*** *(small) to* ***HCFC-123 and CFC-113a***<br>TCE is mainly used as feedstock to HFC-134a (75%) with the balance of consumption in emissive solvent applications (25%). It is unclear if production of monochloroacetic acid (MCAA) by the hydrolysis of TCE is still commercial practice, as compared with the chlorination of acetic acid. TCE is characterised as a human carcinogen by any means of exposure, and as such its emissive use in some non-Article 5 parties has all but disappeared due to regulatory prohibition. Despite this classification, TCE's solvent presence in the global market seems to be about par with the reduced 2020 demand at about 100–110 ktonnes, and this is mainly in Asia, where production continues in three parties. The United States is considering a domestic ban on production and use of TCE for all applications including feedstock, but this could be superseded by the domestic legislative reduction in HFC-134a under the American Innovation and Manufacturing (AIM) Act and its ratification of the Kigali Amendment. At least one HFC-134a plant in a non-Article 5 party has closed since 2020, and compliance with the Kigali Amendment in non-Article 5 parties has led to reductions in TCE feedstock use. However, production of HFC-134a in Article 5 parties has shown continued growth. Global HFC-134a production output is believed to have risen by about 20% since 2020, similarly elevating TCE use as feedstock to close to 300 ktonnes. |
| **Perchloroethylene (PCE, tetrachloroethylene, $C_2Cl_4$)** | *PCE is feedstock to:* ***CFC-113, HFC-125, and HFC-134a.***<br>PCE production has increased during 2021-22, based almost entirely on growth as feedstock in the production of fluorocarbons, and this use consumes 70% of overall production. Based on Article 7 data for 2022, CFC-113 production appears to have expanded by some 25% over 2022. It is used to produce chlorotrifluoroethene (CTFE), an important monomer with new uses developing in fluoropolymer formulations for the electronics industry. CFC-113 is used to produce CFC-113a, which can be processed into HFO-1336mzz, HFC-134a, and various trifluoroacetic acid derivatives. PCE has also grown on the back of an increase in HFC-125 production in Article 5 parties. Solvent consumption appears to be stable. Increased legislation against emissions from dry cleaners has continued to reduce already quite small consumption in non-Article 5 parties, but dry-cleaning is a very minor use in Article 5 parties, where industrial metal cleaning is a more significant market. |

### 5.2.2 *The atmospheric impact of VSLS*

Implementation of the Montreal Protocol has identified, and is in the final stages of eliminating, the production and consumption of long-lived controlled substances containing chlorine and/or bromine. Because they are long-lived (lifetimes longer than ~6 months), most if not all of their emission reaches the stratosphere and augments stratospheric chlorine or bromine abundance, no matter the location and season of the emission. These ODS are largely anthropogenic in origin, with few natural sources, and it is possible to link their increased abundance to the growth in industrialisation.

By contrast, VSLS have atmospheric lifetimes of less than 6 months. Some VSLS have natural sources, to a greater or lesser extent, such as terrestrial and oceanic chloroform, and this background level is considered for the VSLS under current review. As a result of their short lifetimes, a smaller fraction of their emission reaches the stratosphere to deplete stratospheric ozone, although this fraction and the ozone impact depends on the location and season of emission. VSLSs also participate in various photochemical cycles that contribute to a small net removal of global tropospheric ozone. There is a consequent reduction in the amount of chlorine liberated from VSLS available to enter the stratosphere; some undegraded VSLS may also be transported to the stratosphere. The stratospheric impact of VSLS depends on the region where VSLS are emitted and the seasonality of the speed at which they and their degradation products are transported to the stratosphere. Large industrial sources of VSLS, coupled with their short lifetimes, lead to pronounced regional variability in the ozone impact of those emissions.

This is the context in which to consider the observation reported in "The Scientific Assessment of Ozone Depletion: 2022"[28] (SAP 2022) that 89% of global DCM emissions have been estimated to emanate from Asia (Claxton *et al.*, 2020[29]). Of the likely source regions, emissions from Asia produce the largest potential for stratospheric ozone depletion.[30,31,32,33] This is owing to its proximity to the tropics, monsoonal flows, and efficient troposphere-to-stratosphere transport of air originating from industrialised East Asia. Asia is the largest consumer of DCM and is also the largest production region for chloromethanes (e.g., DCM, CFM).

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[28] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022.

[29] Claxton, Tom, Hossaini, Ryan, Wilson, Chris, Montzka, Stephen A., Chipperfield, Martyn P., Wild, Oliver, Bednarz, Ewa M., Carpenter, Lucy J., Andrews, Stephen J., Hackenberg, Sina C., Mühle, Jens, Oram, David, Park, Sunyoung, Park, Mi Kyung, Atlas, Elliot, Navarro, Maria, Schauffler, Sue, Sherry, David, Vollmer, Martin, Schuck, Tanja, Engel, Andreas, Krummel, Paul B., Maione, Michela, Arduini, Jgor, Saito, Takuya, Yokouchi, Yoko, O'Doherty, Simon, Young, Dickon and Lunder, Chris, A synthesis inversion to constrain global emissions of two very short lived chlorocarbons: Dichloromethane, and Perchloroethylene*, Journal of Geophysical Research: Atmospheres*, 2020, **125** (12). ISSN 2169-897X; https://ueaeprints.uea.ac.uk/id/eprint/75919

[30] Laura L. Pan, Elliot L. Atlas, Shawn B. Honomichl, Paul A. Newman, *et al.*, East Asian summer monsoon delivers large abundances of very short-lived organic chlorine substances to the lower stratosphere, 2024, *PNAS*, **121** (12), e2318716121. https://doi.org/10.1073/pnas.2318716121

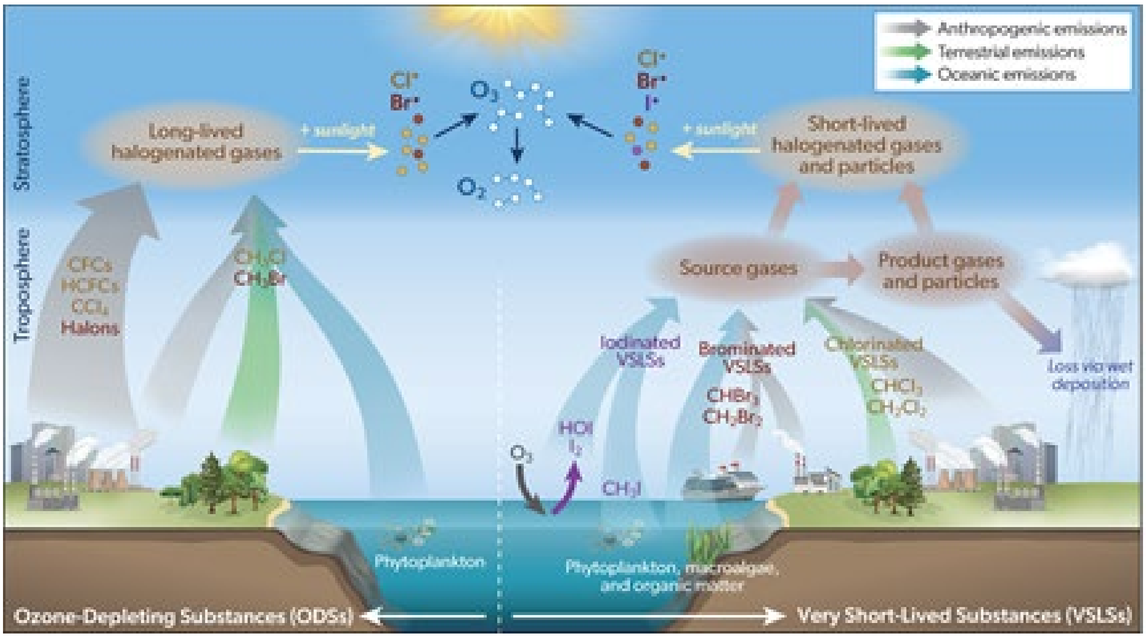
[31] Brioude, J. *et al*., Variations in ozone depletion potentials of very short-lived substances with season and emission region, *Geophys. Res. Lett*., 2010, **37** (19), L19804. https://doi.org/10.1029/2010GL044856.

[32] Oram, D. E., *et al.*, A growing threat to the ozone layer from short-lived anthropogenic chlorocarbons, *Atmos. Chem. Phys.*, 2017, **17** (19), 11929–11941. https://doi.org/10.5194/acp-17-11929-2017, 2017.

[33] Adcock, K. E., Fraser, P. J., Hall, B. D., Langenfelds, R. L., Lee, G., Montzka, S. A., *et al*. Aircraft-based observations of ozone-depleting substances in the upper troposphere and lower stratosphere in and above the Asian summer monsoon, *J. Geophys. Res. – Atmos*, 2021, **126** (1), e2020JD033137. https://doi.org/10.1029/2020JD033137, 2021.

The different sources of chlorine and pathways by which it is injected into the stratosphere are illustrated in Figure 5-1, which is taken from SAP 2022[34] (Box 1-3, Figure 1, p83).

**Figure 5-1** **Schematic of long-lived ozone-depleting substances (ODSs) and halogenated very short-lived substances (VSLSs)**




The following is a summary of conclusions concerning VSLS in SAP 2022:

- Tropospheric chlorine from Cl-VSLS source gases increased by about 10 ppt[35] between 2016 and 2020.
- The estimated input of chlorine from Cl-VSLS to the stratosphere also increased by about 10 ppt and amounted to 130±30 ppt in 2020, contributing about 4% of the total chlorine input.[36] For comparison, the estimated contribution of Cl-VSLS in 2016 was 120±40ppt.
- Unlike emissions of long-lived halocarbons (controlled substances) that efficiently deliver almost all of their chlorine to the stratosphere, only a fraction of an emitted VSLS reaches the stratosphere, augmenting stratospheric chlorine and ozone depletion. Furthermore, this fraction varies by VSLS and depends on the season and location of emission, thus rendering an ODP for a VSLS emission also dependent on these variables.
- The stratospheric ozone impact of Cl-VSLS relative to long-lived ODS may be roughly estimated from the fraction of VSLS chlorine relative to total chlorine from all sources in air entering the stratosphere.[37] The fraction is a few percent of total chlorine abundance, which is

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[34] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022.

[35] ppt is parts per trillion.

[36] See World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Figure ES-2, p18.

[37] See World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Table 1-7, column Contribution to Total Cl (%), p91.

the approximate upper limit for the likely VSLS contribution to global chlorine-catalysed ozone depletion in recent years.

- "*Emissions of $CH_2Cl_2$, the dominant anthropogenic VSLS chlorine gas, continue to increase and augment ozone-depleting chlorine in the atmosphere. Future projections are uncertain due to the highly variable emissions over the past few years. If $CH_2Cl_2$ emissions continue at their current level, they will continue to deplete approximately 1 DU*[38] *of global, annual average ozone. Elimination of these emissions would rapidly reverse this depletion.*"[39]

Existing information on ODPs for VSLS is collated in the Annex to SAP 2022[40] and remains unchanged. The SAP will update the Annex with new information about VSLS ODPs in the 2026 Assessment Report. Studies of ozone depletion due to VSLS evaluate the transport of chlorine through the troposphere and subsequent injection into the stratosphere.

Recent studies providing updates of ozone depletion impact for VSLS indicate that between 2010-2019, Cl-VSLS reduced total column ozone by, on average, ~2-3 Dobson Units (DU)[41] in the springtime high latitudes and by ~0.5-1 DU in the tropics (Bednarz *et al.*, 2023).[42] Cl-VSLS impacts during the recent cold Arctic winter of 2019/2020 are also quantified to have resulted in ozone reductions of up to 6% in the lower stratosphere and ~6 DU in the total column by the end of March.

Anthropogenic emissions of CFM also cause small enhancements in stratospheric chlorine above natural levels, and they are expected also to contribute to ozone depletion. The atmospheric abundance of CFM has not increased as rapidly or steadily over the past decade as has DCM, in fact its global abundance decreased from 2018 to 2020 (SAP 2022, Chapter 1, Figure 1-7).

A calculation of the growth in ppt (parts per trillion) of three Cl-VSLS, DCM ($CH_2Cl_2$), CFM ($CHCl_3$), and perchloroethylene (PCE, $C_2Cl_4$), and their annual assessed emissions in ktonnes is reproduced here from Table 1-4 of SAP 2022.[43]

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[38] The Dobson Unit is the most common unit for measuring ozone concentration. One Dobson Unit is the number of molecules of ozone that would be required to create a layer of pure ozone 0.01 mm thick at a temperature of 0 degrees Celsius and a pressure of 1 atmosphere (the air pressure at the surface of the Earth). Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 mm thick. www.ozonewatch.gsfc.nasa.gov.

[39] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Exec Summary, pp29-30, Figure ES-8.

[40] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Annex: Summary of Abundances, Lifetimes, ODPs, Res, GWPs, and GTPs, Table A-5, pp. 468–471.

[41] One Dobson Unit is the number of molecules of ozone that would be required to create a layer of pure ozone 0.01 mm thick at a temperature of 0 degrees Celsius and a pressure of 1 atmosphere (the air pressure at the surface of the Earth). Over the Earth's surface, the ozone layer's average thickness is about 300 Dobson Units or a layer that is 3 mm thick. www.ozonewatch.gsfc.nasa.gov.

[42] Bednarz, E. M., Hossaini, R., and Chipperfield, M. P., Atmospheric impacts of chlorinated very short-lived substances over the recent past – Part 2: Impacts on ozone, *Atmos. Chem. Phys*., 2023, **23**, 13701–13711. https://doi.org/10.5194/acp-23-13701-2023.

[43] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Table 1-4.

**Table 5-2** **Table 1-4, SAP 2022, Annual global mean mole fractions of Cl-VSLS (DCM ($CH_2Cl_2$), CFM ($CHCl_3$), PCE ($C_2Cl_4$)) and estimated emissions from AGAGE and NOAA networks**

**Table 1-4.** Annual global mean mole fractions of chlorinated VSL SGs and estimated emissions (including 1-sigma uncertainties) from the global networks. Emissions based on AGAGE and NOAA surface data were calculated using a global 12-box model (Cunnold et al., 1983; Rigby et al., 2013), identical to the global emissions shown in **Figure 1-3** for longer-lived ODSs. The calculations assume parameterized global steady-state total lifetimes of 0.54, 0.52, and 0.40 years for $CH_2Cl_2$, $CHCl_3$, and $C_2Cl_4$, respectively.

| Compound | Annual Mean Mole Fraction (ppt) | | | Growth (2019–2020) | | Annual Global Emissions (Gg $yr^{-1}$) | | | Network |
|---|---|---|---|---|---|---|---|---|---|
| | 2016 | 2019 | 2020 | ppt $yr^{-1}$ | % $yr^{-1}$ | 2016 | 2019 | 2020 | |
| $CH_2Cl_2$ | 32.7 | 37.1 | 38.3 | 1.2 | 3.2 | 943 (±179) | 1061 (±203) | 1130 (±211) | AGAGE |
| | 38.4 | 44.2 | 45.5 | 1.3 | 3.0 | 1126 (±204) | 1328 (±235) | 1328 (±242) | NOAA |
| $CHCl_3$ | 9.0 | 8.7 | 8.7 | 0.0 | 0.0 | 345 (±70) | 335 (±69) | 339 (±70) | AGAGE |
| $C_2Cl_4$ | 1.07 | 1.05 | 1.01 | −0.04 | −3.8 | 83 (±42) | 86 (±40) | 80 (±39) | AGAGE |
| | 1.21 | 1.19 | 1.12 | −0.07 | −5.9 | 102 (±50) | 98 (±49) | 91 (±47) | NOAA |

For this report, SAP has provided updated data for DCM for 2020 (revised data), 2021, and 2022, based on information from the Advanced Global Atmospheric Gases Experiment (AGAGE) and the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) networks, as presented in Table 5-3.

**Table 5-3 SAP update (March 2024) for mole fractions and emissions of DCM ($CH_2Cl_2$) from NOAA and AGAGE networks**

| Network | Annual Mean Mole Fraction (ppt) | | | | Change in ppt* 2020-2022 | | Annual Global Emissions (Gg year, ktonnes) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 Revised† | 2021† | 2022† | ppt | % Annual | 2019 | 2020 Revised† | 2021† | 2022† |
| **AGAGE** | 37.1 | 38.4 | 41.7 | 41.2 | 2.8 | 3.6 | 1062 (±204) | 1131 (±211) | 1211 (±227) | 1149 (±226) |
| **NOAA** | 44.2 | 45.1 | 50.1 | 48.8 | 3.7 | 4.0 | 1301 (±236) | 1334 (±243) | 1523 (±268) | 1412 (±263) |

***Notes:***

**†** *In March 2024, SAP provided updated data for DCM for 2021, and 2022, based on information available from the networks of the Advanced Global Atmospheric Gases Experiment (AGAGE) and the United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA). In this update, the values for 2020 have been revised slightly'*

** Change in ppt has been calculated by MCTOC from data provided by SAP.*

AGAGE and NOAA data continue to display an apparent calibration difference for DCM of approximately 10% at sites where both regularly report measurements of this chemical (NOAA>AGAGE). The differences in global mean mole fractions and inferred emissions (Table 5-3) are slightly larger (~20%). SAP 2022[44] notes these differences and suggests that they arise in part from global means being derived from results obtained by these networks at different remote locations[45]. Such differences are possible for VSLS given the large gradients in atmospheric concentrations exhibited in the remote atmosphere. The global rate of change measured for DCM has varied between 0 and 10% per year since 2015, including during the 2020-2022 period, making it difficult to attribute any change during that period to the COVID pandemic.

The subject of VSLS and their magnitude as one group of contributors to the depletion of stratospheric ozone will continue to be assessed by science bodies such as APARC[46] and the UK InHALE project[47], and regular updates can be anticipated, including further papers on the subject of IOD values. These will be reported to the Montreal Protocol by the SAP.

### *5.2.3 Alternatives to very short-lived substances*

Broadly speaking, there are three uses for this category of chlorinated organic chemicals;

- Open and emissive uses, such as foam blowing agent and general solvent
- Contained use as a process agent solvent
- Use as feedstock

#### 5.2.3.1 Open and emissive solvent uses

The term *general solvent*, or open and emissive solvent uses, comprises the many emissive uses of VSLS, encompassing many applications including paint-stripping; metal cleaning and degreasing; dry-cleaning and fabric treatment; pigment, resin and adhesive carriers; and all the many specific uses within these broad categories. DCM is also used in many parties as a foam blowing agent, either historically or reprised during the phase-down and elimination of fluorocarbons.

Alternatives to halogenated solvents were extensively studied by previous reports issued by the UNEP Solvents, Coatings and Adhesives Technical Options Committee (STOC) in its 1998 and 2002

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[44] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. p80.

[45] L.J. Carpenter and S. Reimann (Lead Authors), J.B. Burkholder, C. Clerbaux, B.D. Hall, R. Hossaini, J.C. Laube, and S.A. Yvon-Lewis, Ozone-Depleting Substances (ODSs) and Other Gases of Interest to the Montreal Protocol, Chapter 1, *Scientific Assessment of Ozone Depletion: 2014, Global Ozone Research and Monitoring Project – Report No. 55*, World Meteorological Organization, Geneva, Switzerland, 2014.

[46] APARC (formerly SPARC) noted in their APARC newsletter n°62, March 2024, p20, that the "*new APARC community activity will address many…impacts of VSLS on stratospheric ozone concentra-tions and trends…through a model intercomparison project (MIP). Given the many uncertainties related to their impacts, such an assess-ment of VSLS requires a multi-model approach and an international effort, which is being performed in the framework of this new APARC activity.*" https://www.aparc-climate.org/publications/newsletter/aparc-newsletter-no-62/.

[47] The InHALE project (Investigating HALocarbon impacts on the global Environment) is a four-year UK NERC programme "*…to provide the evidence base needed to support the Montreal Protocol. New scientific developments are needed in several interlinked disciplines*". APARC's work will aid in this programme. https://inhale.blogs.bristol.ac.uk/work-packages/

Assessment Reports[48]. These studies considered the major solvent ODS, which included CFC-113, 1,1,1-trichloroethane, and CTC, and concluded with reviewing solvent options for the use of HCFC-141b and HCFC-225 *(isomers).* The final STOC report (2002) contained an appendix[49] which included recommendations for the safe use of chlorinated solvents. The report's overarching recommendations were given in a cascade of preferences, which are described in detail in the report:

- "No-clean" water cleaning
- Saponifier or detergent cleaning
- Hydrocarbon-surfactant cleaning ("semi-aqueous")
- Hydrocarbon solvent cleaning (where the toxicity is lower than halocarbons)
- Halocarbon solvent cleaning
- Hydrocarbon solvent cleaning (where the toxicity is higher than halocarbons).

The 2002 STOC Assessment Report recalled this preferred hierarchy, noting that halocarbon solvent cleaning, along with the use of toxic hydrocarbons, were amongst the *least preferred* options.

One clearly identifiable sector of general solvent use is paint-stripping. DCM is the largest solvent produced within the VSLS group and one of its major uses is in paint-stripping, where it may be as much as 75-95% of the formulation.[50] In some parties and regions, this use of DCM has been banned, in both consumer and industrial preparations, due to the risk of asphyxiation and its classification as a 2B possible human carcinogen. Various alternatives with similar paint removal capability have been proposed, which include benzyl alcohol, dibasic esters such as methyl adipate or methyl glutarate; and 1-methyl-2-pyrrolidone. Characteristics such as water-solubility, flammability, environmental impact, and toxicological profile must be carefully evaluated against their intended purposes, and the possible use of some non-halogenated alternatives noted here does not necessarily imply a recommendation.

Considerable efforts have been undertaken during 2002-2020 to phase out HCFC-141b and HCFC-225 as part of the HCFC Phase-out Management Plan (HPMP). The Multilateral Fund Implementing Agencies have acquired a great deal of knowledge in this sector. Such work can inform parties that have completed the transition away from HCFCs. It is suggested that, with some prudence about the out-of-date recommendations, the 1998 and 2002 STOC reports remain a useful source of information on alternatives. Also, solvent and process materials and technology suppliers, especially of non-halogenated solvents, are presumed to have extensive technical ability to offer sound alternative solutions when required. In general, though, solvent user groups tend to find their own best and most suitable method for their needs, and it is almost always the most technically and economically viable solution, including any new capital investments.

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[48] UNEP, 1998. *1998 Report of the Solvents, Coatings and Adhesives Technical Options Committee*, 1998 Assessment. https://ozone.unep.org/sites/default/files/2019-05/STOC1998.pdf.

UNEP, 2002. *2002 Report of the Solvents, Coatings and Adhesives Technical Options Committee*, 2002 Assessment. https://ozone.unep.org/sites/default/files/2019-05/STOC2002.pdf.

[49] UNEP, 2002. *2002 Report of the Solvents, Coatings and Adhesives Technical Options Committee*, 2002 Assessment, A.2. Appendix 2. The Proper Use of Halogenated Solvents, pp67-88. STOC remarked that the subject was particularly controversial as there are contradictions between the national regulations of different countries and the interpretation of known scientific data. https://ozone.unep.org/sites/default/files/2019-05/STOC2002.pdf.

[50] Other common additives include methanol as a penetrating agent and co-solvent, and cellulosic or wax-based thickening agents to reduce the rate of evaporation of DCM.

DCM has a long history in the polyurethane foam industry as a blowing agent for slabstock and other flexible foams. DCM promotes the production of very soft and light foam mattresses. However, DCM is banned for this use in the United States, there are severe restrictions on its use in Europe, and in China new regulations prohibit the use of DCM in open applications, including foam blowing, as of 2025. There are precedents in use controls of polyurethane blowing agents: the phase-out of CFCs and HCFCs led to increased use of not-in-kind alternatives, such as water or carbon dioxide, being adopted. These techniques may lead to a firmer foam structure than DCM alone. Multilateral Fund Implementing Agencies, and polyurethane technology and equipment suppliers, have great familiarity with foam blowing alternatives.

As indicated above, the selection of alternatives to solvent uses of VSLS should be determined on a case-by-case basis, as needed. Users can discuss options with suppliers of alternatives within their own parties for their specific applications.

#### 5.2.3.2 Process solvent and analytical uses

Alternatives to Cl-VSLS in many of the *process solvent* applications, similar to defined process agent uses of controlled substances in the Montreal Protocol, will be on a case-by-case basis as they are used to provide a specific effect, often a combination of selective solvation, volatility, solubilisation of the reaction product, and inertness in the desired reaction process. The evaluation of alternatives must include the necessity to avoid the creation of unwanted by-products, as well as to ensure that the yields of the final products are not affected.

Recent studies on available alternatives include those by Jordan *et al*.[51] and Lynch *et al*.[52].

The very comprehensive Jordan study finds that the chlorinated VSLS solvents that are commonly employed in organic and medicinal chemistry include DCM, CFM, DCE, and TCE. The study is principally concerned with the production of pharmaceutical active ingredients and observes that solvents have long been recognized as one of the biggest contributors to the cradle-to-gate life cycle impact of pharmaceuticals. Many possible alternative solvents are evaluated.

The Lynch study, focussed on pharmaceuticals, explores sustainable alternatives to DCM in the laboratory analysis of small, common drug molecules, and experimentally identifies bio-derived esters to replace DCM within thin-layer chromatography.

#### 5.2.3.3 Feedstock use

Except for DCM, of which about 75% is consumed in emissive applications, the major use of Cl-VSLS is as feedstock. This topic has been reviewed in the 2022 MCTOC Assessment Report as well as updates on feedstock in this progress report. Table 5-4 gives examples of products or processes that exist as potential alternative routes to VSLS feedstocks, and possibly why existing routes may have been selected.

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[51] Andrew Jordan, Patrick Stoy, Helen F. Sneddon, Chlorinated Solvents: Their Advantages, Disadvantages, and Alternatives in Organic and Medicinal Chemistry, *Chemical Reviews*, 2021, **121** (3), 1582-1622. DOI: 10.1021/acs.chemrev.0c00709.

[52] Lynch, J., Sherwood, J.R., McElroy, R., *et al.,* 2023. *Dichloromethane replacement : towards greener chromatography via Kirkwood-Buff integrals,* Analytical methods, pp. 596-605. ISSN 1759-9679. DOI: 10.1039/d2ay01266a; https://eprints.whiterose.ac.uk/194979/

**Table 5.4 Exemplar feedstock uses of chlorinated VSLS and alternative routes**

| Cl-VSLS feedstock | Product | Alternative in use | Comment |
|---|---|---|---|
| **EDC** | Vinyl chloride monomer (VCM) for PVC, co-polymers, HFC-152a | Acetylene → VCM by direct hydro-chlorination. 20% global VCM market. | Acetylene route requires very high energy to produce intermediate calcium carbide. Reaction currently catalysed by mercury chloride (replacements to mercury catalyst are under trial). |
| **EDC** | Vinyl chloride monomer (VCM) for PVC, co-polymers, HFC-152a | Ethane chlorination (not in use) | Avoids cost of cracking fossil-based hydrocarbons to ethylene. Not proven to work on industrial scale. |
| **EDC** | Ethyleneamines | Reaction of monoethanolamine (MEA) with ammonia. | Depends on production facilities. Non-chlorine site more likely to use MEA route. MEA route more selective to ethylenediamine. EDC route gives a broader range of ethyleneamines. |
| **TCE** | HFC-134a | PCE | PCE chosen where HFC-134a intermediate already in place in producer facilities. |

Chlorinated hydrocarbons are in general chosen as reactants because the chlorine atom is readily replaced by fluorine in the case of fluorocarbons, and by nitrogen in the EDC-based production of ethyleneamines. For fluorocarbons, ideally the chlorocarbon structure is chosen to minimise the process steps to produce the desired end-product.[53]

Cl-VSLS are not controlled substances under the Montreal Protocol, but they are feedstocks for several controlled substances, their alternatives (e.g., HFOs) and other chemicals.

## 5.3 Response to Decision XXXV/8 on feedstock uses

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.[54] Similarly, the definition of consumption excludes controlled substances entirely used as feedstock, nevertheless,

[53] The chlorine should be in the same place within the carbon framework for the substitution of fluorine. For example, the addition of HF to dichloromethane reacts to difluoromethane (HFC-32), or the reaction of CTC with VCM allows the formation of the chlorocarbon feedstock 1,1,1,3,3-pentachloropropane (HCC-240fa). HCC-240fa is fluorinated in a series of reactions to become 1,1,1,3,3-pentafluoropropane-(HFC-245fa).

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

imports and exports of controlled substances to be used entirely as feedstock must be reported by parties.

### *5.3.1 Decision XXXV/8: Feedstock uses*

*Taking note* of the 2022 assessment reports of the Scientific Assessment Panel and the Technology and Economic Assessment Panel, which highlight the significant increase in the production of controlled substances used as feedstock and the increased emissions of such substances,

To request the Technology and Economic Assessment Panel, in cooperation with the Scientific Assessment Panel as appropriate, to provide in its 2024 progress report an update on the emissions from feedstock production, as by-products and from feedstock use of controlled substances, including the following:

a) Sources of such emissions, including percentage increases with respect to increased production of controlled substances to be used for feedstock applications;
b) A comparison of estimates of annual global emissions of controlled substances by species based on bottom-up calculations and estimates made by the Scientific Assessment Panel on the basis of atmospheric observations;
c) Methodology adopted for estimating the emissions;
d) Updated information on alternatives, including information on technical feasibility, economic viability, safety and sustainability;
e) Information on best practices and technologies for minimising emissions.

### *5.3.2 Sources of emissions, including percentage increases with respect to increased production of controlled substances to be used for feedstock applications;*

#### 5.3.2.1 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 years up to and including 2022 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[55] had reported use of ODS as feedstock; in 2022, 15 parties[56] reported feedstock use of ODS, while ten of these parties also produced ODS for feedstock uses.

In 2022, total production and import reported for feedstock uses of ODS was 1,943,134 metric tonnes, a significant increase compared to 2021 (2021: 1,755,171 metric tonnes[57]), and an increase of 66% over the last ten years. Figure 5.1 shows that, comparing 2022 with 2021 and 2020, the most notable difference is the increase in Annex C1 (HCFCs). The 2022 reported total production and import of

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

[56] This total includes all parties that imported ODS feedstock, one of these parties reported <0.1 tonne. It also includes the European Union as an importer, European Union Member States report their own production for feedstock use. Although most reporting parties are the same for 2021 and 2022, there are some differences.

[57] The 2021 feedstock production was correctly stated as 1,755,171 tonnes in the 2023 TEAP Progress Report – Volume 1 in the equivalent text but the 2023 TEAP Progress Report – Volume 1, Table 5-1, contained an error, reporting the total ODS feedstock as 1,750,516 metric tonnes.

ODS for feedstock use in metric tonnes represents 685,204 ODP tonnes.[58] The overall increase in ODS feedstock uses over the last 10 years has been mostly due to the increase in feedstock uses of Annex C1 (HCFCs), particularly HCFC-22, while increasing market demand of HFOs is driving a more recent increase in carbon tetrachloride (CTC) feedstock use.

**Figure 5-2 Annual reported ODS for feedstock use, categorised by Montreal Protocol Group, 2002–2022 (metric tonnes)[59]**

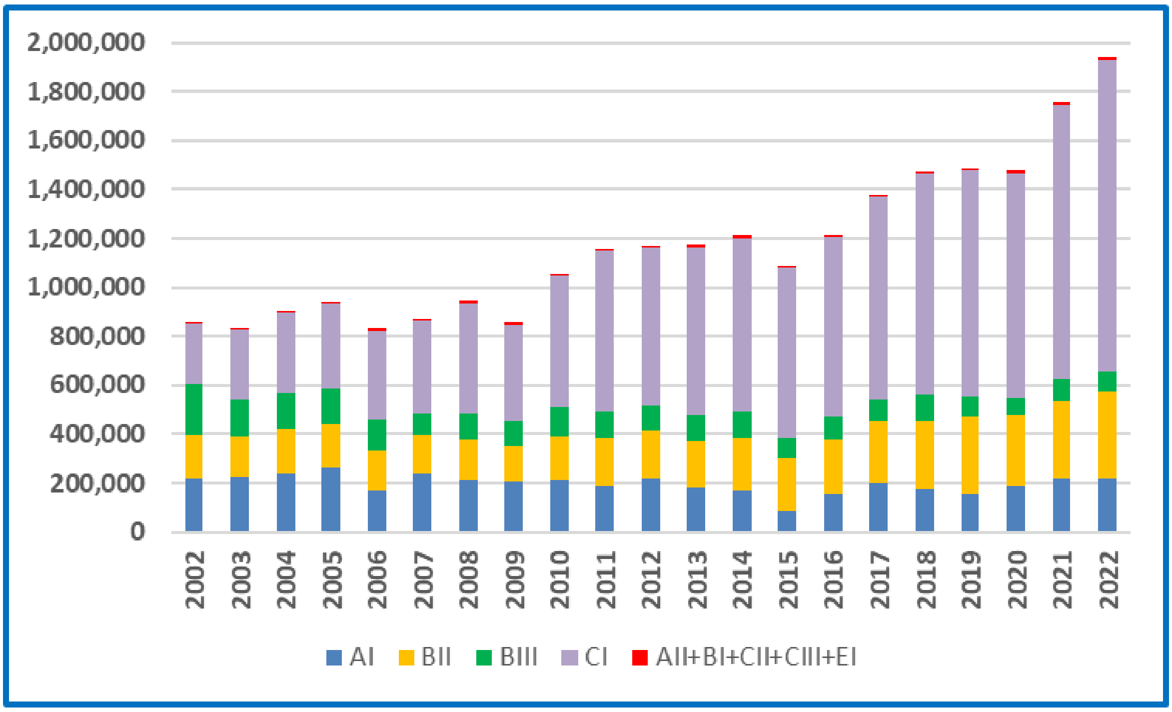



Table 5-5 shows the CAGR (Compound Annual Growth Rate) over 10 years for ODS for feedstock use, categorised by Montreal Protocol Group. This shows that CAGR over this period is highest for BII (CTC) and CI (HCFCs). While the minor groups (AII+BI+CII+CIII+EI) have similar growth, these are a very small percentage of total feedstock use (0.6% in 2012 and in 2022). The percentage shares for the Annexes are also shown in Table 5-1 for the years 2012 and 2022, showing decreasing shares for AI and BIII, and a significantly increased share for CI.

[58] While ODP tonnes are included, it should be noted that presenting production for feedstock use in ODP tonnes, these are tonnes produced for feedstock, not tonnes emitted. 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.

[59] 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 5-5 CAGR over 10 years for ODS used as feedstock, categorised by Montreal Protocol Group, and their shares of total feedstock use 2012–2022**

| Annex | Substances | CAGR % over 10 years 2012-2022 (note) | % Share of total ODS feedstock use (metric tonnes) | |
|---|---|---|---|---|
| | | | 2012 | 2022 |
| AI | CFCs -11, -12, -113, -114, -115 | -0.2 | 19.0 | 11.2 |
| BII | Carbon tetrachloride | 6.4 | 16.5 | 18.4 |
| BIII | 1,1,1-Trichloroethane | -2.2 | 8.7 | 4.2 |
| CI | HCFCs | 7.0 | 55.3 | 65.5 |
| AII+BI+CII+CIII+EI | Annex AII Halons 1211, 1301, 2402;<br>Annex BI CFCs -13, -111, -112, -211, -212, -213, -214, -215, -216, -217;<br>Annex CII HBFCs;<br>Annex CIII bromochloromethane;<br>Annex EI methyl bromide. | 5.6 | 0.6 | 0.6 |

***Note:*** *CAGR is Compound Annual Growth Rate over 10 years ((2022 value/2012 value)$^{1/10}$-1)x100*

Table 5-6 shows the amounts of ODS used as feedstock in 2021 and 2022 and shows the percentage changes over 1 year and 5 years. Overall, reported total feedstock use has increased by 41.3% over 5 years from 2017, and 10.7% from 2021 to 2022. The 5-year percentage increase is considered a helpful comparison as the increase from 2021 to 2022 could be influenced by an acceleration due to lower-than-expected manufacturing resulting from COVID pandemic impacts.

**Table 5-6 Reported amounts of ODS used as feedstock in 2021 and 2022, showing percentage changes over 1 year and 5 years, and CAGR % over 10 years**

| **Substance** | **ODP** | **Metric tonnes** | | **% Change over 1 year** | **% Change over 5 years 2017 -2022** | **CAGR % over 10 years 2012-2022** *note 1* |
|---|---|---|---|---|---|---|
| | | **2021** | **2022** | | | |
| HCFC-22 | 0.055 | 847,248 | 968,775 | 14.3 | 53.2 | 7.3 |
| Carbon tetrachloride Annex BII | 1.1 | 319,792 | 357,987 | 11.9 | 40.2 | 6.4 |
| HCFC-142b | 0.065 | 220,212 | 235,353 | 6.9 | 60.2 | 8.4 |
| CFC-113 and CFC-113a *(note 2)* | 0.8 | 169,875 | 174,512 | 2.7 | *note 3* | *note 3* |
| 1,1,1-Trichloroethane (methyl chloroform) Annex BIII | 0.1 | 86,889 | 81,400 | -6.3 | -5.6 | -2.2 |
| Bromochloromethane Annex CIII | 0.12 | 5,094 | 7,079 | 39.0 | 256.6 | 19.7 |
| Methyl Bromide Annex E1 | 0.6 | 2,617 | 2,537 | -3.1 | -22.0 | -4.9 |
| Bromotrifluoromethane (Halon 1301) | 10 | 1,796 | 2,307 | 28.4 | *note 2* | *note 2* |
| CFC-114, HCFC-124, HCFC-141b, HCFC-244 | | *note 2* | 10,000 to 100,000 | 11.4 *note 4* | 5.0 *note 4* | -1.4 *note 4* |
| HCFC-123, HCFC-133a, HCFC-21, HCFC-242 | | *note 2* | 1000 to 10,000 | | | |
| HCFC-225ca, HCFC-225cb, HCFC-241, HCFC-243 | | *note 2* | 10 to 1000 | | | |
| Other Substances | | | <10 | | | |
| **Total Tonnes** | | **1,755,171** *note 5* | **1,943,134** | 10.7 | 41.3 | 5.2 |
| *Total ODP tonnes (note 6)* | | *630,305 note 5* | *685,204* | *8.7* | *30.2* | *3.9* |

***Explanatory notes:***

*Note 1: CAGR is Compound Annual Growth Rate over 10 years ((2022 value/2012 value)$^{1/10}$-1)x100*

*Note 2: Data Confidentiality. 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. The confidentiality rule applied is that there must be at least 3 reporting parties for the substance, with each party having greater than a 5% share. Some of the substances have changed the reported bands from 2021 to 2022.*

*Note 3: CFC-113a reported data is incomplete before 2020, so a percentage increase is not given. See UNEP/OzL.Pro/ExCom/90/39, 23 June 2022, Report of the sub-group on the production sector, Agenda item 3.*

*Note 4: The percentage changes are shown for the substances in all three bands, i.e., 10 to 100,000 metric tonnes. This is because some of the substances have changed bands for the years 2017, 2021 and 2022. For these substances, there was a decrease between 2017 and 2021, which is why the increase from 2021 to 2022 is larger than the increase from 2017 to 2022 as a percentage and as metric tonnes.*

*Note 5: The equivalent table in the 2023 TEAP Progress Report – Volume 1, Table 5-1, had two small errors reporting total ODS feedstock as 1,750,516 metric tonnes and 629,732 ODP tonnes. However, the text in section 5.2.2 of the 2023 Progress Report correctly stated the quantity in metric tonnes.*

*Note 6: While the corresponding ODP tonnes are shown, it should be noted that these are ODP tonnes produced for feedstock, not ODP tonnes emitted. 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 are calculated from the reported data but for some reports it is not certain that the correct isomer is identified.*

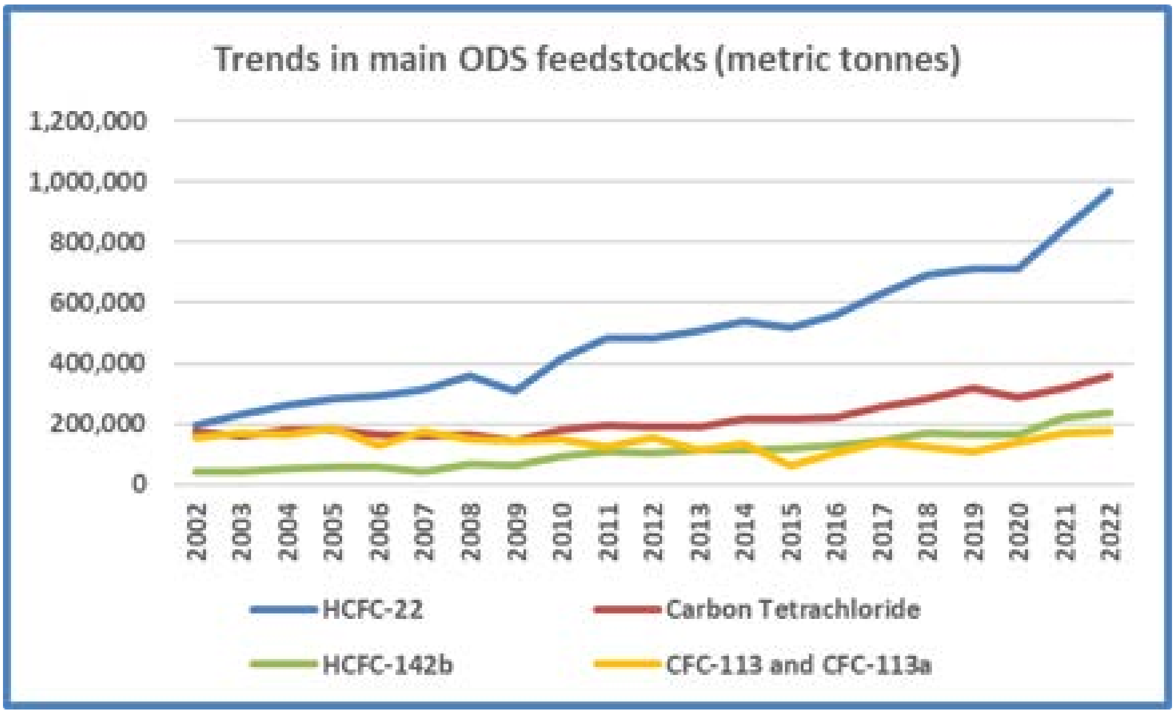
The proportions of the largest ODS feedstocks in 2022 were similar to 2021: HCFC-22 (50% of the total mass quantity, an increase from 48% in 2021), CTC (18%), and HCFC-142b (12%). HCFC-22 is, by a considerable margin, the largest feedstock used, with 968,775 metric tonnes reported in 2022, compared to 847,248 metric tonnes in 2021. Several other feedstocks have increased quantities in 2022 compared to 2021, which explains why the HCFC-22 percentage share has only increased by about 2%.

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[60] has increased in recent years, due to growing demand for lower GWP HCFO/HFOs and perchloroethylene (PCE). In addition, there has been a marked increase in reported feedstock use of HCFC-244 and HCFC-21, which are both used as feedstocks for different routes to manufacture HFO-1234yf.

The trends in the production for feedstock use for the main ODS feedstocks are shown in Figure 5-3.

[60] More information on CTC production and its uses as feedstock can be found in the 2022 MCTOC Assessment Report and in chapter 5 of this report.

**Figure 5-3 Trends in annual reported production for feedstock use of the current main ODS for the years 2002–2022 (metric tonnes)**




### 5.3.2.2 Production of HFCs used as feedstocks

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 parties that ratified the Kigali Amendment before the end of 2019, with that 2019 Article 7 data reported during 2020. The feedstock data reported for 2022 is incomplete due to the timing of reporting obligations, for example, depending on when some parties ratified. However, the United States has published production of HFCs for feedstock use for 2022 as a requirement of the American Innovation and Manufacturing (AIM) Act.[61] The feedstock production is HFC-245fa: 13,350 tonnes and HFC-152a: 3798 tonnes. The quantities of reported HFC feedstock for 2022 are shown in Table 5-7 and include the published United States' data. Due to the limited data available, percentage changes over time in feedstock use are not included in Table 5-7. The total reported quantities of HFC feedstocks are considerably lower than ODS feedstocks.

[61] Expanded HFC Data | US EPA

**Table 5-7 Reported or published amounts of HFC used as feedstock in 2022**

| Substance | GWP | 2022 Tonnes |
|---|---|---|
| HFC-152a | 124 | 100,000 to 1,000,000 |
| HFC-245fa (United States only)[62] | 1030 | 13,350 |
| HFC-23 | 14,800 | 1071 |
| HFC-125, HFC-236fa, HFC-32, HFC-134a, HFC-41 | | 10 to 1000 |

***Explanatory notes:***

*Note 1: Percentage changes are not shown as the HFC feedstock data reported or published before 2022 is incomplete.*

*Note 2: Data Confidentiality. For some substances, due to the limited number of parties reporting production for feedstock use or imports for feedstock use, quantities have been approximated. The confidentiality rule applied is that there must be at least 3 reporting parties for the substance, with each party having greater than a 5% share.*

The most broadly used chemical process to produce vinyl fluoride (used to produce polyvinylfluoride) is the dehydrofluorination of 1,1-difluoroethane (HFC-152a)[63]. 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.

#### 5.3.2.3 Feedstock applications of controlled substances

Table 5-8 shows some feedstock applications for controlled substances, although the list is not exhaustive. Parties report amounts of controlled substances used as feedstock to the Ozone Secretariat, but they do not report how they are used. Processes are proprietary and there is no official source to define the manufacturing routes followed and their efficacy. The table provides some examples and is the product of the collective experience and knowledge of MCTOC members. Products included are both intermediates as well as final products, including fluoropolymers.

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[62] No other party has reported >1 tonne for 2022.

[63] 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 5-8 Feedstock applications of controlled substances (non-exhaustive list)**

| Feedstock | Products | Further conversion products | Comments |
|---|---|---|---|
| CFC-113 | Chlorotrifluoroethylene | Chlorotrifluoroethylene based polymers | Polymers include poly-chlorotrifluoroethylene (PCTFE), and poly-fluoroethylene vinyl ether (PFEVE). |
| CFC-113 | CFC-113a | | CFC-113a may be an intermediate and may be transported off-site for use as a feedstock. |
| CFC-113a | Trifluoroacetic acid (TFA) and pesticides (including cyhalothrin) | | Starting with CFC-113, CFC-113a is as an intermediate for TFA. Alternatively, CFC-113a may be directly produced as the starting feedstock (See line above). TFA is a pesticide and medical intermediate. |
| CFC-113, CFC-113a, CFC-114a, HCFC-124 | HFC-134a | | One sequence for production of HFC-134a begins with CFC-113, which is converted to CFC-113a, then to CFC-114a and HCFC-124a as intermediates. |
| CFC-113a | HFO-1336mzz isomers | | Low GWP alternatives for HFC-245fa and HCFC-123. |
| CTC | CFC-11 and CFC-12 | | Production and consumption of these CFCs has fallen to zero based on reported data. However, a small quantity of CFC-12 (<100 tonnes) is intermittently reported for feedstock use. It is not known for what the CFC-12 was used. |
| CTC | With water to make $CO_2$ and HCl: the HCl is subsequently reacted with methanol to make methyl chloride and water | Methyl chloride in chloromethanes (CMs) plant converted to dichloromethane (DCM) and chloroform (CFM) | A method of recycling CTC into useful products rather than destruction operated in CMs plant complex. |
| CTC | Perchloroethylene | | High volume use as solvent and feedstock |
| CTC | With hydrogen to make chloroform with methane and HCl as by-products | Chloroform is used to make HCFC-22 | A method of recycling CTC into useful products rather than destruction operated in CMs plant complex |
| CTC | Chlorocarbons including vinyl chloride, chloropropanes chloropropenes and hydrochlorofluropropanes (HCFC-241, 242, 243, 244) | Feedstocks for production of HFC-245fa and some HFOs and HCFOs: HFO-1234yf, HCFO-1233zd, and HFO-1234ze. | HFOs and HCFOs are ultra-low GWP fluorocarbons used in refrigeration, air conditioning and insulation and production is increasing. |
| CTC | With acrylonitrile, intermediates | Pyrethroid pesticides. | $CCl_3$ groups in molecules of intermediates become $=CCl_2$ groups in pyrethroids. |
| CTC | With 2-chloropropene - Intermediates | Production of HFC-365mfc | |
| CTC | With vinylidene chloride - Intermediates | Production of HFC-236fa | |

| Feedstock | Products | Further conversion products | Comments |
|---|---|---|---|
| CTC | With benzene to make triphenylchloromethane (trityl chloride) | Intermediate for dyes and pharmaceuticals such as antiviral drugs | Trityl chloride is an efficient tritylation agent. |
| CTC | With 1,3-dichloro-4-fluorobenzene to make 2,4-dichloro-5-fluorobenzoyl chloride (DCFBC) | Intermediate for example in the synthesis of highly active antibacterial agent ciprofloxacin | |
| CTC | With methyl 3,3-dimethyl-4-pentenoate to produce methyl 4,6,6,6-tetrachloro-3,3-dimethylhexanoate | | |
| 1,1,1-trichloroethane | HCFC-141b, -142b, and HFC-143a | | Note that an alternative process uses 1,1-dichloroethylene (vinylidene chloride, VDC) as feedstock; VDC is not an ODS. |
| HCFC-21 | HCFC-225 isomers | | Reaction of TFE with HCFC-21 to give HCFC-225 isomers. Product used as a solvent or intermediate |
| HCFC-225ca | HFO-1234yf and HCFO-1224yd | | HCFC-225 (produced from TFE and HCFC-21) can be further reacted to produce HFO-1234yf and HCFO-1224yd |
| HCFC-22 | Tetrafluoroethylene (TFE, HFO-1114) | Polymerized to homopolymer (PTFE) and also co-polymers.<br>Route to HFC-125 | Very high-volume use. Work has been done for decades to find an alternative commercial route to TFE, without success. |
| HCFC-22 | Hexafluoropropylene (HFP, HFO-1216) | Co-produced with TFE and used as monomer or copolymer, e.g., FEP. Route to HFO-1234yf. Route to HFC-227ea. | Fluorinated ethylene-propylene polymers (FEP) |
| HCFC-22 | With 2,2,2-trifluoroethanol, then chlorination to anaesthetic isoflurane $CF_3CHClOCHF_2$ | Isoflurane by reaction with hydrogen fluoride (HF) is converted to anaesthetic desflurane $CF_3CHFOCHF_2$ | |
| HCFC-22 | Sulfentrazone | | Sulfentrazone (*N*-{2,4-Dichloro-5-[4-(difluoromethyl)-3-methyl-5-oxo-4,5-dihydro-1*H*-1,2,4-triazol-1-yl] phenyl} methanesulfonamide) is a broad-spectrum herbicide. |
| HCFC-123 | HCFC-124, HFC-125 | | |
| HCFC-124 | HFC-125 | | |
| HCFC-123 | Production of TFA | | |

| Feedstock | Products | Further conversion products | Comments |
|---|---|---|---|
| HCFC-133a | HCFC-123, CFC-113a | | HCFC-133a can be transformed to HCFC-123 by chlorination and further to CFC-113a |
| HCFC-133a | Production of trifluoroethanol | | |
| Bromotrifluoromethane | Production of the pesticide fipronil and other chemicals | | Bromotrifluoromethane may also be an intermediate when HFC-23 is used as a starting material in the production of fipronil and other chemicals. Bromotrifluoromethane is used as feedstock in the preparation of chemicals including fipronil (insecticide), mefloquine (antimalarial), and DPP-IV inhibitor (antidiabetic). $CF_3$ generated from bromotrifluoromethane can be introduced into a wide range of organic molecules by nucleophilic substitution. |
| HCFC-141b | HCFC-142b, HFC-143a | | |
| HCFC-142b | Vinylidene fluoride (HFO-1132a) | Polymerised to poly-vinylidene fluoride or co-polymers. | Products are fluorinated elastomers and fluororesins.<br>Vinylidene fluoride is a very low temperature refrigerant |
| Bromochloromethane | 2-(Thiocyanomethyl)-thiobenzothiazole (TCMTB) | | TCMTB is a biocide used in the leather industry |
| HFC-152a | HCFC-142b | Vinylidene fluoride, and subsequent polymerisation products (as above for HCFC-142b). | Photochlorination to obtain HCFC-142b, followed by dehydrochlorination to obtain vinylidene fluoride. |
| HFC-23 | Production of Halon 1301 by bromination for use as a feedstock | | HFC-23 is converted to bromotrifluoromethane by bromination. Bromotrifluoromethane is then used as feedstock in the preparation of chemicals including fipronil (insecticide), mefloquine (antimalarial), and DPP-IV inhibitor (antidiabetic). $CF_3$ generated from bromotrifluoromethane can be introduced into a wide range of organic molecules by nucleophilic substitution. |
| HFC-23 | With chloroform to make HCFC-22 and HCFC-21 | | Demonstration plant to use HFC-23 as a feedstock with high selectivity and to avoid process inefficiencies in the HCFC-22 production process. Note when integrated with HCFC-22 production process, HFC-23 is an intermediate and not a feedstock |
| HFC-125 | Reaction with iodine to produce $C_2F_5I$ | $C_2F_5I$ is reacted with TFE to produce telomers that can be further reacted | |

### *5.3.3 A comparison of estimates of annual global emissions of controlled substances by species based on bottom-up calculations and atmosphere-based estimates made by SAP*

Some controlled substance feedstocks and by-products have non-feedstock uses (e.g., HCFCs, HFCs) or have emissions from banks of RACHP equipment or foams. Significant emissions from these non-feedstock sources, unless well characterised, can prevent a direct comparison of estimates of annual global emissions from feedstock production and use with estimates from atmospheric observations. However, emissions of some substances, estimated from atmospheric monitoring, show marked increases in emissions that can be explained by emissions related to feedstock production and use.

Examples of substances having significant emissions from non-feedstock sources are HCFC-22, which has a large bank in RACHP equipment, estimated at over 1 million tonnes in 2022[64] and HFC-152a, which is used in aerosols[65] (immediate release) and XPS foams.[66]

The Scientific Assessment of Ozone Depletion: 2022 (SAP 2022)[67] in Table 1-1 reports global annual emissions of ODS for 2016 and 2020, calculated based on the AGAGE and NOAA observations. The SAP 2022 emissions can be compared with bottom-up emissions calculated using the MCTOC *most likely* emission factors applied to the amount of production of each substance for feedstock use. The MCTOC emission factors apply to the production and use of feedstocks, which means that for by-products separate bottom-up emissions calculations would be required. The substances were selected if they meet these criteria of, i) from feedstock use only, and ii) no bank or minor emissions from a bank. Even using these selection criteria, there may also be emissions from other sources, such as a by-product in other processes. Any such emissions would contribute to the emissions estimated from atmospheric monitoring and such emissions would affect the comparison estimated using MCTOC *most likely* emission factors. Carbon tetrachloride emissions are discussed later in this chapter. HFC-23 emissions will be in a separate report later this year addressing Decision XXXV/7, Emissions of HFC-23. The substances selected for the requested comparison of emission estimates are 1,1,1-trichloroethane (methyl chloroform), CFC-114 and CFC-114a, CFC-113 and CFC-113a, HCFC-124, HCFC-133a and CFC-115 by-product.

#### 5.3.3.1 MCTOC emission factors

Emissions of controlled substances during their production, distribution and feedstock use contribute to overall global emissions. MCTOC developed a range of emissions factors for feedstock plant types (modern and 1960s-1980s) and feedstock use. These are explained in detail in the 2022 MCTOC Assessment Report.[68] Global emissions for each substance are estimated using the *most likely* emission factors, not considering regional variations in emission rates. Distribution emissions depend on specific supply chains and containers used. Most feedstocks are supplied in bulk or delivered by

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[64] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022. Figure 8.1, Total estimated ODS and HFC banks, several sources, 2010–2050 (ktonnes).

[65] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022. Section 9.1.3, Aerosols in different regions.

[66] UNEP, 2022. *2022 Flexible and Rigid Foams Technical Options Committee Report*, 2022 Assessment. Section 2.15 Extruded polystyrene (XPS).

[67] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

[68] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022. Section 2.5.5, Emission factors for production and distribution and use as feedstock for controlled substances. This section contains an explanation for the derivation of the emission factors. Section 2.5.6, Estimated emissions of controlled substances from production, distribution and feedstock use, summarises the emission factors.

pipeline and, for this estimate, an emission factor of 0.5% is used for distribution emissions (towards the lower end of the *most likely* range). Emission factors for feedstock use may be influenced by the specific substance. Liquids at ambient temperatures, e.g., CTC and 1,1,1-trichloroethane, may have higher emission factors if stored in atmospheric tanks (not-pressurised). Liquified gases, e.g., HCFCs and HFCs, would be at the lower end of the range as they are stored in an enclosed system. Table 5-9 summarises the MCTOC emission factors.

**Table 5-9 MCTOC emission factors for modern-day, regulated manufacturing from production, supply chain, and use of feedstock (by weight of production)**

| | Most Likely Range % | Most likely % |
|---|---|---|
| Feedstock production emission factor | 0.9–4 | 2.5 |
| Distribution losses through shipping and storage in supply chain (see note 2) | 0.3–1.2 | 0.5 |
| Losses from feedstock conversion process including maintenance | 0.3–0.9 | 0.6 |
| **Total emission factor** | **1.5–6.1** | **3.6** |

***Explanatory Notes:***

*Note 1. This is a summary of the emission factors in 2022 MCTOC Assessment Report, sections 2.5.5 and 2.5.6 (Tables 2-6, 2-7 and 2-9). For more information on derivation of the most likely emission factor refer to the 2022 MCTOC Assessment Report.*

*Note 2. Most feedstocks are delivered by bulk supply or pipeline \ and, for this emission estimate, a factor of 0.5% is used for distribution (towards the lower end of the most likely range).*

It is assumed that any emissions from feedstock production and use occur in the same year as reported as required by Article 7. This allows a simple comparison between the emissions reported in SAP 2022 with those estimated using the MCTOC emission factors. However, it is worth noting that feedstock use may occur in the year following the reported production year and/or production reported in the previous year could be used in addition to the reported production. This should not be a significant factor as feedstock production and distribution together are the main source of emissions according to the MCTOC emission factors.

#### 5.3.3.2 1,1,1-Trichloroethane (methyl chloroform)

The 1,1,1-trichloroethane (TCA, methyl chloroform, $CH_3CCl_3$) emissions comparison is straightforward. It is only used as a feedstock and there is not a bank. Historically it was used as a solvent and in aerosol formulations with short banking times. The AFEAS emission function assumes 50% release in the year of manufacture and 50% in the following year. Production of TCA for use as feedstock occurs only in non-Article 5 parties, according to the reported data. There are two routes currently used to produce it from vinyl chloride monomer (VCM). One route chlorinates VCM to 1,1,2-trichloroethane, then dehydrochlorination (loss of HCl), to vinylidene chloride (VDC), which is then hydrochlorinated to TCA. The other route hydrochlorinates VCM to 1,1-dichloroethane, which is (photo)chlorinated to TCA with 1,1,2-trichloroethane as a significant co-product. TCA is used as a feedstock to produce HCFC-141b, HCFC-142b, and HFC-143a. Another production route to these substances is used that does not require TCA.

Table 5-10 has a comparison of the top-down emissions estimates reported by SAP with the bottom-up emissions calculated from the MCTOC *most likely* factors. For this substance, the central estimates are in reasonable agreement, particularly for the NOAA emission estimates. The MCTOC *most likely* range lower estimate is also similar to the lower estimated emissions reported by SAP, but the MCTOC high end estimate is significantly more than those reported by SAP. Even so, emissions of

1,1,1-trichloroethane are within the MCTOC *most likely* range, which is meant to have general applicability across all substances and conditions for modern and well-maintained facilities.

**Table 5-10 1,1,1-Trichloroethane (methyl chloroform) comparison of estimates of annual global emissions**

| $CH_3CCl_3$ (methyl chloroform) | | 2016 | 2020 |
|---|---|---|---|
| Emissions, Gg | AGAGE<br>NOAA | 2.2±2.0<br>2.9±1.8 | 2.3±1.1<br>2.2±1.0 |
| Emissions, tonnes | AGAGE<br>NOAA | 2200±2000<br>2900±1800 | 2300±1100<br>2200±1000 |
| Reported production for feedstock use, tonnes | | 93,036 | 69,199 |
| Emission factor percent | AGAGE<br>NOAA | 2.4±2.1<br>3.1±1.9 | 3.3±1.6<br>3.2±1.4 |
| Emission factor percent | MCTOC | 3.6 (1.5 -6.1) | |
| Emissions, tonnes | MCTOC | 3350 (1400–5700) | 2500 (1000–4200) |

*AGAGE Advanced Global Atmospheric Gases Experiment (atmospheric monitoring surface sites).*

*NOAA National Oceanic and Atmospheric Administration (United States)*

*AGAGE and NOAA emissions data taken from SAP 2022, Table 1-1.*[69]

#### 5.3.3.3 CFC-114 and CFC-114a

Although CFC-114 is reported for feedstock production, MCTOC understands that this quantity is actually all the isomer, CFC-114a. This means that no CFC-114 isomer is reported for use as feedstock. The isomer CFC-114a is used as a feedstock for one route for the production of HFC-134a. The overall process is perchloroethylene → CFC-113→ CFC-113a → CFC-114a → HFC-134a. Due to the limited number of parties reporting this substance (no Article 5 parties), the data confidentiality rules applied require quantities to be approximated. This does not prevent a comparison by using emissions factors, which would maintain confidentiality. However, SAP 2022 reports emissions of the sum of CFC-114/CFC-114a and does not report separate emissions for CFC-114a, but a 2023 paper[70] by Western *et al.*[71] reports CFC-114a emissions until 2020 based on atmospheric measurements.

Table 5-11 has the reported emissions estimates from the Western *et al.* paper. If all the emissions were due to the use of CFC-114a for the production of HFC-134a, the calculated emission factors would be <2% from the reported emissions and the reported production of CFC-114a for feedstock use. These are at the low end of the MCTOC emission factors *most likely* range. However, the EPA Toxics Release Inventory (TRI) report for the facility[72] producing HFC-134a by this route suggests an

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[69] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

[70] Western, L.M., Vollmer, M.K., Krummel, P.B. *et al.* Global increase of ozone-depleting chlorofluorocarbons from 2010 to 2020. *Nat. Geosci,* 2023, **16**, 309–313. https://doi.org/10.1038/s41561-023-01147-w

[71] Ibid., Western *et al.*, 2023.

[72] The EPA Toxics Release Inventory (TRI) https://www.epa.gov/toxics-release-inventory-tri-program/tri-data-and-tools does not appear to distinguish between CFC-114 and CFC-114a. Published data from TRI for 2020 states emissions of <1 tonne CFC-114 for the facility that produces HFC-134a. This would suggest an emission rate of <<0.1% for use of CFC-

emission rate of <<0.1% for the use of CFC-114a in this process. This would suggest that other sources contribute significantly to the emissions of CFC-114a, which would mean that the emission factors calculated using the MCTOC *most likely* range overstate emissions from this process.

**Table 5-11 Comparison of emission factors estimates for production and use of CFC-114a as feedstock**

| **CFC-114a** | | **2016** | **2020** |
|---|---|---|---|
| Emissions, Gg | Western *et al.* | 0.5±0.1 | 0.8±0.1 |
| Emissions, tonnes[73] | Western *et al.* | 500±100 | 800±100 |
| Production, tonnes | | 10,000 to 100,000 | |
| Emission factor percent | Western *et al.* | <2 | <2 |
| Emission factor percent | MCTOC | 3.6 (1.5–6.1) | |

Lickley *et al.*[74] reported that there was still a bank of CFC-114 in 2020. This is confirmed by recent reports. In the United States, CFC-114 was used in very large systems for uranium enrichment and its continued recovery from these systems was reported in 2022[75] and 2023.[76,77] According to these articles, an estimated 8.5 million lb. (approx. 3,856 tonnes) of CFC-114 were originally contained at the site. After a further 1 million lb. (456 tonnes) were recovered in 2023, over half the CFC-114 has now been removed for safe destruction since the project began in 2020. Refrigerant CFC-114 was usually supplied mixed with CFC-114a, as separation of the two isomers is difficult. A 2016 paper by Laube *et al.*[78] discussed the long-term trends for CFC-114 and CFC-114a and, according to the paper, the ratio of their emissions (CFC-114 and CFC-114a) remained nearly constant at around 9% CFC-

114a in this process. The Toxics Release Inventory (TRI) Program tracks the industrial management of toxic chemicals that may cause harm to human health and the environment. TRI data are reported by certain industrial and federal facilities. EPA makes these data available through multiple online tools, many of which add context to help make the reported data more understandable.

[73] The emissions are taken from Western *et al.,* Extended Data Fig. 4: Annual global mean emissions. Western, L.M., Vollmer, M.K., Krummel, P.B. *et al.,* Global increase of ozone-depleting chlorofluorocarbons from 2010 to 2020. *Nat. Geosci,* 2023, **16**, 309–313. https://doi.org/10.1038/s41561-023-01147-w.

[74] Lickley, M. J., Daniel, J. S., Fleming, E. L., Reimann, S., and Solomon, S.: Bayesian assessment of chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC) and halon banks suggest large reservoirs still present in old equipment, *Atmos. Chem. Phys.*, 2022, **22**, 11125–11136. https://doi.org/10.5194/acp-22-11125-2022.

[75] U.S. Department of Energy, 2022. *Paducah Removes 1 Million Pounds of Hazardous Refrigerant, Achieving Priority*, 20 December 2022. https://www.energy.gov/em/articles/paducah-removes-1-million-pounds-hazardous-refrigerant-achieving-priority. Accessed May 2024.

[76] U.S. Department of Energy, 2023. *Paducah Removes 1 Million Pounds of Hazardous Refrigerant in 2023*, 19 December 2023. https://www.energy.gov/pppo/articles/paducah-removes-1-million-pounds-hazardous-refrigerant-2023. Accessed May 2024.

[77] Colling Post, 2023. *Huge refrigerant removal operation continues at US nuclear plant*, 23 December 2023. https://www.coolingpost.com/features/huge-refrigerant-removal-operation-continues-at-us-nuclear-plant/. Accessed May 2024.

[78] Laube, J. C., Mohd Hanif, N., Martinerie, P., Gallacher, E., Fraser, P. J., Langenfelds, R., Brenninkmeijer, C. A. M., Schwander, J., Witrant, E., Wang, J.-L., Ou-Yang, C.-F., Gooch, L. J., Reeves, C. E., Sturges, W. T., and Oram, D. E.: Tropospheric observations of CFC-114 and CFC-114a with a focus on long-term trends and emissions, *Atmos. Chem. Phys.*, 2016, **16**, 15347–15358. https://doi.org/10.5194/acp-16-15347-2016,.

114a between 1978 and 1991. Any current bank of CFC-114 will also result in emissions of CFC-114a.

CFC-114 may also be emitted from the process used to produce HFC-125 from perchloroethylene (PCE). Analyses of the streams within HFC-125 plants indicate that low levels (less than a few thousand ppm[79]) of CFC-113/-114/-115 are present. The source of this CFC-113/-114/-115 is believed to be due to a combination of factors, including impurities in the PCE feedstock being precursors to CFC-113/-114/-115, the composition and status of the catalyst, the possible presence of other oxidising substances and dismutation/disproportionation reactions with some of the later intermediates, such as HCFC-123 being more likely to produce CFC-113/-114/-115 than others.[80] However, HFC-125 production is not thought to be a major source of CFC-114 emissions, as the sum of CFC-114/CFC-114a is typically only a minor impurity in the HFC-125 product stream. One commercial route previously operated to produce CFC-114/CFC-114a used perchloroethylene and chlorine in a vapour phase route with hydrogen fluoride. It is also possible that CFC-114 is a by-product from the production of CFC-113 from perchloroethylene (discussed below).

Vollmer *et al*.[81] reported the analysis of a diluted sample of HFC-134a from a container of the high-purity substance. They found the sum of CFC-114/CFC-114a present at 2.8x10-5 mol mol-1 of HFC-134a. Using this information and assuming this is representative for all HFC-134a production, even that not produced by the CFC-114a route, then global HFC-134a emissions of 245 ± 27 Gg yr–1 in 2020 reported in SAP 2022[82] would result in ΣCFC-114 (CFC-114/CFC-114a) emissions of about 11 tonnes in 2020. This is not a significant contributor to the CFC-114 emissions reported in SAP 2022 (see Table 5-12).

[79] ppm is parts per million.

[80] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022. Section 2.3.6, CFC-113, CFC-114, CFC-115 by-production on HFC-125 plants.

[81] Vollmer, M. K., Young, D., Trudinger, C. M., Mühle, J., Henne, S., Rigby, M., Park, S., Li, S., Guillevic, M., Mitrevski, B., Harth, C. M., Miller, B. R., Reimann, S., Yao, B., Steele, L. P., Wyss, S. A., Lunder, C. R., Arduini, J., McCulloch, A., Wu, S., Rhee, T. S., Wang, R. H. J., Salameh, P. K., Hermansen, O., Hill, M., Langenfelds, R. L., Ivy, D., O'Doherty, S., Krummel, P. B., Maione, M., Etheridge, D. M., Zhou, L., Fraser, P. J., Prinn, R. G., Weiss, R. F., and Simmonds, P. G.: Atmospheric histories and emissions of chlorofluorocarbons CFC-13 ($CClF_3$), ΣCFC-114 ($C_2Cl_2F_4$), and CFC-115 ($C_2ClF_5$), Atmos. Chem. Phys., 18, 979–1002, https://doi.org/10.5194/acp-18-979-2018, 2018.

[82] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022*, GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Section 2.2.1.1, HFC-134a ($CH_2FCF_3$). https://ozone.unep.org/science/assessment/sap.

**Table 5-12 Emissions of CFC-114 reported in SAP 2022**

| CFC-114 (CFC-114 + CFC-114a) | | 2016 | 2020 |
|---|---|---|---|
| Emissions, Gg | AGAGE | 2.3±0.9 | 2.6±0.9 |
| Emissions, tonnes | | 2300 | 2600 |

*AGAGE emissions data taken from SAP 2022, Table 1-1.*[83]

### 5.3.3.4 CFC-113 and CFC-113a

CFC-113 and CFC-113a are only used as feedstock and no production of CFC-113a was reported before 2018. Historically most CFC-113 was used as a solvent, with a small percentage used in heat pumps. According to Lickley *et al.*[84], the emissions of CFC-113 from any remaining bank are essentially zero from about 2005 onwards. CFC-113a reported data is incomplete before 2020.[85] In addition, due to the limited number of parties reporting these substances, the data confidentiality rules applied require approximate emission estimates. SAP 2022 reports CFC-113 but does not report CFC-113a emissions.

CFC-113 can be produced from perchloroethylene (PCE). This may be a potential source of CFC-114 emissions. It is known that both CFC-113 and CFC-114 can be produced in the same process from perchloroethylene in a liquid phase catalytic reaction with anhydrous hydrogen fluoride. This was the typical process used to co-produce CFC-113/CFC-114 historically.[86]

$CCl_2=CCl_2 + HF + Cl_2 \rightarrow C_2Cl_3F_3$ (CFC-113) + $C_2Cl_2F_4$ (CFC-114) +HCl

CFC-113 is a common feedstock or intermediate that can be used in the production of a range of chemicals including CFC-113a, chlorotrifluoroethylene (CTFE), HFC-134a, trifluoroacetic acid (TFA) and HFO-1336mzz. Although CFC-113a is commonly made by isomerisation of CFC-113, it can also be prepared by the fluorination of trichloroethylene to HCFC-133a, which is then chlorinated to produce a mixture of CFC-113a and HCFC-123 and distilled into different streams. The main feedstock or intermediate uses of CFC-113 and CFC-113a are shown in Figure 5-4.

[83] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

[84] Lickley, M. J., Daniel, J. S., Fleming, E. L., Reimann, S., and Solomon, S., Bayesian assessment of chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC) and halon banks suggest large reservoirs still present in old equipment, *Atmos. Chem. Phys*., 2022, **22**, 11125–11136. https://doi.org/10.5194/acp-22-11125-2022.

[85] UNEP, 2022. UNEP/OzL.Pro/ExCom/90/39, *Report of the sub-group on the production sector*, Agenda item 3, 23 June 2022.

[86] Unites States Environmental Protection Agency, 1989. *Locating and estimating air emissions from sources of perchloroethylene and trichloroethylene*, EPA-450/2-89-013, August 1989.

**Figure 5-4 Main Feedstock and Intermediate Uses of CFC-113 and CFC-113a**[87]

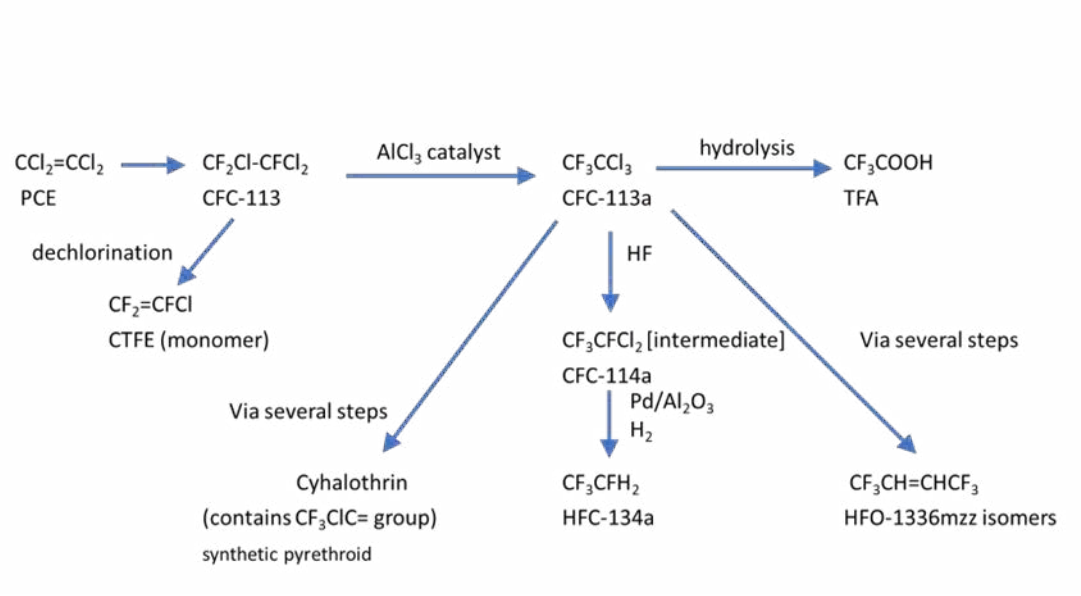


Table 5-13 has the reported emissions estimates from SAP 2022 for CFC-113. If all the emissions of CFC-113 were due to its reported production and use as feedstock, the calculated emission factors would be in the range 4–6.5% from the AGAGE/NOAA emission estimates. These are at the high end of the MCTOC emission factors *most likely* range, but this does not consider the wide uncertainty in the AGAGE/NOAA emission estimates. There may also be other sources of CFC-113 emissions (e.g., by-product), which would mean emissions due to this feedstock process would be lower, reducing the estimated emission factor. In addition, according to SAP, the top-down emission estimates for CFC-113 may also have a small contribution from CFC-113a, but this is not yet fully characterised.

**Table 5-13 Comparison of emission factor estimates for CFC-113**

| CFC-113 | | 2016 | 2020 |
|---|---|---|---|
| Emissions, Gg | AGAGE | 6.5±6.4 | 6.9±6.0 |
| | NOAA | 5.5±5.0 | 6.4±4.8 |
| Emissions, tonnes | AGAGE | 6500±6400 | 6900±6000 |
| | NOAA | 5500±5000 | 6400±4800 |
| Production, tonnes | | 100,000 to 1,000,000 | |
| Emission factor, percent | AGAGE/NOAA | 4–6.5 using AGAGE and NOAA emissions estimates | |
| Emission factor, percent | MCTOC | 3.6 (1.5–6.1) | |

*AGAGE and NOAA emissions data taken from SAP 2022, Table 1-1.*[88]

[87] UNEP, 2021. *2021 TEAP Progress Report*, Volume 1. Section 5.3.4. CFC-113 and CFC-113a feedstock and intermediate use and emissions.

[88] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion*: 2022, GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

The production of CFC-113 is in the range 100,000 to 1 million tonnes. If CFC-114 were a significant by-product from CFC-113 production, it would contribute to the observed current emissions of CFC-114.

#### 5.3.3.5 HCFC-124

SAP 2022 reports that emissions of HCFC-124 have continued to decline since 2016, with 2020 emissions of 3.0±0.7 Gg/year. The 2020 emissions were, however, slightly larger (up to ~0.4 Gg/year larger) than those in the three preceding years. In 2011, non-feedstock use of HCFC-124 was 5% of total reported production, reducing to about 1% by 2020. According to AFEAS,[89] most HCFC-124 was used in open cell foam (short banking time) and refrigeration (medium banking time), with <1% used (200 tonnes) in long banking time (2% release per year) applications for total production by end 2003. While there continues to be minor use of HCFC-124 in non-feedstock applications in 2020, these together with emissions from any small remaining bank cannot explain the reported top-down emissions. Due to the limited number of parties reporting this substance (no Article 5 parties), the data confidentiality rules applied require quantities to be approximated. This would not prevent a comparison by using emissions factors to maintain confidentiality. Table 5-14 shows the reported top-down emissions and compares the estimated emission factors. The top-down emission factor is higher than the MCTOC emission factors *most likely* range. Even taking into account the uncertainty in the top-down emission estimates, the emission factor would be higher than the MCTOC *most likely* range.

HCFC-124 is an intermediate in the production of HFC-125 from perchloroethylene, which accounts for over 90% of the HFC-125 production currently. Emissions of HCFC-124 intermediate from HFC-125 production would appear to make a significant contribution to total HCFC-124 emissions. HFC-125 production is discussed in detail in the section for CFC-115 by-product.

**Table 5-14 HCFC-124 comparison of estimates of top-down and bottom-up emission factors**

| HCFC-124 | | 2020 |
|---|---|---|
| Top-down emissions | SAP 2022 | 3.0±0.7 Gg (3000±700 tonnes) |
| Production, tonnes | | 10,000 to 100,000 |
| Top-down emission factor percent | | >8 |
| MCTOC emission factor percent | | 3.6 (1.5–6.1) |

*Emissions data taken from SAP 2022, Table 1-1.*[90]

#### 5.3.3.6 HCFC-133a

SAP 2022 reports emissions of HCFC-133a, which remained at around 2 Gg/year (2000 tonnes/year) between 2017 and 2020, following emissions of 2.8±0.4 Gg/year in 2016. HCFC-133a has only ever been used as a feedstock. The reported feedstock use of HCFC-133a in the period 2016 to 2020 was <1000 tonnes in 4 of these years with a similar quantity reported in the other year. The reported production for feedstock use, in this period, is about 50% or less than the estimated top-down emissions for these years. Even if emissions are about 10% from feedstock production use, this would only account for up to about 100 tonnes of the estimated top-down emissions. This suggests that over 90% of the reported emissions are due to emissions of intermediate HCFC-133a from the production

[89] AFEAS, 2003. Data is available at Advanced Global Atmospheric Gases Experiment (AGAGE), at https://agage.mit.edu/sites/default/files/documents/em-hcfc-124.pdf. Accessed April 2024.

[90] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

of HFC-134a. In 2020, about 250,000 tonnes of HFC-134a is estimated to have been produced. An emission factor of about 0.8% HCFC-133a intermediate, would result in about 2000 tonnes of emissions in 2020. It is unlikely that there will be significant emissions of HCFC-133a as an impurity in HFC-134a emissions from the refrigerant bank. This is because HCFC-133a is toxic and typically controlled to low levels as an impurity in HFC-134a.

#### 5.3.3.7 CFC-115 by-product from HFC-125 production

CFC-115 was used as a refrigerant as a component of R-502, used for low temperature refrigeration and in transport refrigeration. According to Vollmer *et al.* (2018)[91] emissions from the remaining bank of CFC-115 in 2016 were estimated as <10 tonnes, compared to <100 tonnes/year from 2008. This would suggest that virtually all current emissions are a result of CFC-115 as a by-product, noting that in the United States some refrigerant reclaimers currently (March 2024) indicate availability of cylinders of R-502, suggesting there may be some R-502 refrigeration systems still in operation.

The main route to produce HFC-125 is from perchloroethylene (PCE). Analyses of the streams within HFC-125 plants indicate that low levels (less than a few thousand ppm) of CFC-113/-114/-115 are present. The source of this CFC-113/-114/-115 is believed to be due to a combination of factors, including impurities in the PCE feedstock being precursors to CFC-113/-114/-115, the composition and status of the catalyst, the possible presence of other oxidising substances and dismutation/disproportionation reactions with some of the later intermediates, such as HCFC-123, being more likely to produce CFC-113/-114/-115 than others. CFC-115 is difficult to separate from HFC-125 with additional separation steps being required. As the CFC-115 has limited commercial value, except potentially as a feedstock for the production of hexafluoroethane (PFC-116), it is likely to be emitted unless abatement technology is installed.[92]

The concentration of CFC-115 produced as a by-product in this process from PCE varies with process conditions, catalyst performance and the specific production facility. It is typically in the range 1000–5000 ppm in the HFC-125, but according to information provided to MCTOC, can be as high as 10,000 ppm in the HFC-125 product stream. According to one patent[93], CFC-115 is usually included in HFC-125 at a concentration of a few thousand ppm or greater, but since CFC-115 and HFC-125 form an azeotropic mixture, they are difficult to separate by distillation, which is the commonly employed separation and purification method. If the CFC-115 is removed, then the final HFC-125 product can contain <100 ppm CFC-115. However, even if the CFC-115 is removed from the final product, this CFC-115 may still be emitted unless it is destroyed. Therefore, there are two potential sources of CFC-115 by-product emissions, i) emissions from production, and ii) emissions from refrigerants containing HFC-125 when these refrigerants are emitted to atmosphere. Refrigerant concentration ranges of CFC-115 impurity have been reported by Vollmer *et al.* (2018) based on analysis of laboratory air at AGAGE sites at times of air-conditioner leakage (R-410A containing 50% HFC-125). These measurements demonstrated impurities ranging from 0.7 to 11 x $10^{-4}$ mol CFC-115/mol HFC-125. This range is 70 ppm to 1100 ppm of CFC-115 in HFC-125, consistent with the typical range expected for refrigerant.

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[91] Vollmer, M. K., Young, D., Trudinger, C. M., Mühle, J., Henne, S., Rigby, M., Park, S., Li, S., Guillevic, M., Mitrevski, B., Harth, C. M., Miller, B. R., Reimann, S., Yao, B., Steele, L. P., Wyss, S. A., Lunder, C. R., Arduini, J., McCulloch, A., Wu, S., Rhee, T. S., Wang, R. H. J., Salameh, P. K., Hermansen, O., Hill, M., Langenfelds, R. L., Ivy, D., O'Doherty, S., Krummel, P. B., Maione, M., Etheridge, D. M., Zhou, L., Fraser, P. J., Prinn, R. G., Weiss, R. F., and Simmonds, P. G.: Atmospheric histories and emissions of chlorofluorocarbons CFC-13 ($CClF_3$), ΣCFC-114 ($C_2Cl_2F_4$), and CFC-115 ($C_2ClF_5$), *Atmos. Chem. Phys*., 2018, **18**, 979–1002. https://doi.org/10.5194/acp-18-979-2018.

[92] UNEP, 2022. *2022 Report of the Medical and Chemical Technical Options Committee*, 2022 Assessment, December 2022. Section 2.3.6, CFC-113, CFC-114, CFC-115 by-production on HFC-125 plants.

[93] Production and use of hexafluoroethane, WO2003014047A1

Top-down emission estimates of CFC-115 and HFC-125 are reported in SAP 2022. Any estimate of bottom-up emissions for CFC-115 by-product as a result of HFC-125 production has a high degree of uncertainty due to the following factors.

***Production of HFC-125 using the perchloroethylene (PCE) route—*** By 2020, MCTOC understands that probably over 90% of HFC-125 production used the PCE route. In earlier years, CDM projects for abatement of HFC-23 from HCFC-22 production encouraged the use of TFE as a feedstock to manufacture HFC-125 (TFE + HF → $C_2F_5H$ HFC-125), with perhaps up to about 20,000 tonnes annual production in the period until 2008. Vollmer *et al.* (2018) reported that 8 HFC-125 production facilities in China did not use the PCE route in 2017. However, the end of CDM projects and the availability of high quality PCE in China resulted in increased production of HFC-125 from PCE. This would explain why around 2017 there may possibly have been 7-8 producers with the capability of producing HFC-125 from TFE, but not necessarily actual production of HFC-125 from TFE (i.e., idled plants). The first major unit outside the United States to use PCE for HFC-125 production was in China in 2008/9. By 2017, in China, large integrated chloromethanes/fluorocarbon producers dominated HFC-125 production, with high quality PCE produced from CTC. Even so, PCE continues to be imported into China for feedstock use. For this calculation, it is assumed that all the recent HFC-125 production globally is from PCE.[94]

***CFC-115 by-product yield from HFC-125 production—*** It is assumed that 1000, 2000 and 5000 ppm CFC-115 is produced as by-product using the PCE route, based on industry experience and information available to MCTOC, although up to about 10,000 ppm may be present as by-product for some production quantities. Either it is separated to some extent, using additional steps potentially, achieving <100 ppm or it remains as an impurity at higher concentrations in the final HFC-125 product.

***Use of abatement technology to destroy CFC-115 by-product—*** It is assumed that there is no abatement of CFC-115 emissions in 2020 and earlier, although it is known that some relatively small production facilities historically used abatement. However, some CFC-115 by-product may be used for the production of hexafluoroethane (PFC-116), which is discussed below.

***CFC-115 impurity concentration in HFC-125 used as refrigerant—*** The experimental data in Vollmer *et al.* (2018) reported 70–1100 ppm as an impurity in the HFC-125. The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) sets out the requirements for classification and labelling of substances due to ozone depleting substance impurities. The 2009 revision (Chapter 4.2, Hazardous to the ozone layer) requires classification of a substance or mixture if it contains ≥0.1 % of any substance listed in the Annexes to the Montreal Protocol.[95] The major use of HFC-125 is as a component in refrigerants, with several widely used refrigerants having about 50% HFC-125 by weight,[96] which would potentially allow up to about 0.2% ODS impurities including CFC-115. If HFC-125 was supplied, e.g., for use as a fire extinguishant, then it should have <0.1% CFC-115 to avoid being classified (substances and mixtures hazardous to the ozone layer) under GHS, assuming it has no other ODS impurities. Emissions of HFC-125 are mainly from the refrigerant bank.

[94] It is likely that >90% of current global HFC-125 production is via the PCE route.

[95] United Nations Economic Commission for Europe, 2009. *Globally Harmonized System of Classification and Labelling of Chemicals (GHS)*, Third revised edition. https://unece.org/ghs-rev3-2009. Accessed May 2024.

[96] R-410A (50% HFC-125), R-404A (44%), R-507A (50%), R-452A (59%). Other widely used refrigerants have smaller percentages of HFC-125.

These scenarios are selected to provide a range of potential CFC-115 emissions associated with HFC-125 production:

i) 100 ppm CFC-115 in HFC-125 emissions (from refrigerant bank)

ii) 1000 ppm and 2000 ppm CFC-115 in HFC-125 emissions (from refrigerant bank)

iii) 1000 ppm, 2000 ppm and 5000 ppm CFC-115 emitted during production of HFC-125

Scenarios ii) and iii) are assumed to be mutually exclusive for a specific year's production. However, the refrigerant bank will have HFC-125 produced several years earlier, mainly depending on equipment lifetime, and it is possible that HFC-125 from earlier years contained higher or lower concentrations of CFC-115, with less or more being emitted during production.

Table 5-15 has SAP 2022 emission estimates for CFC-115 and HFC-125. The HFC-125 emissions will be predominantly from the refrigerant bank. The table also shows bottom-up emissions estimates, using the three scenarios. This shows that the refrigerant bank would be a minor contributor to CFC-115 emissions if the CFC-115 had been removed during production resulting in 100 ppm CFC-115. Assuming 2000 ppm CFC-115 in HFC-125 emissions from the bank would result in CFC-115 emissions of about 200 tonnes in 2020. It would require 2000 ppm of CFC-115 emitted from the HFC-125 product stream during production to meet the low end of the SAP 2022 emission range for CFC-115 for 2020. Emissions of CFC-115, assuming 5000 ppm in the HFC-125 product stream, would result in 1000 tonnes of emissions in 2020, which corresponds to the central estimate reported by SAP. Unless production practices have changed in recent years, for the fate of CFC-115, it does not seem possible to have significant emissions of CFC-115 impurity from the refrigerant bank and from production.

There are potentially other processes that may reduce or increase CFC-115 emissions. Patents have claimed the use of CFC-115 as an intermediate[97] (using CFC-114 as a starting material) or feedstock for the production of hexafluoroethane (PFC-116).[98] MCTOC understands that China produces about 1000 tonnes per year of PFC-116 for the application as etching gas in the semiconductor industry with most PFC-116 produced from CFC-115. MCTOC does not have information about PFC-116 production routes in other parties. In China, there are two possible sources of CFC-115, as the by-product of HFC-125 production and from CFC-113 or CFC-113a as feedstock for CFC-115 production. MCTOC understands that CFC-114 is not used as a feedstock as there is no production of CFC-114 in China at present. If the CFC-115 is sourced as a by-product from HFC-125 production, it would be reported as feedstock use, unless it is considered an intermediate, although no CFC-115 production has been reported by any party for feedstock use since the early 1990s, when in a single year <10 tonnes was reported for feedstock use. China does report the use of CFC-113 and CFC-113a as feedstock.

The production of PFC-116 using by-product CFC-115 from HFC-125 production would reduce CFC-115 emissions from this source. The production of CFC-115 from CFC-113 or CFC-113a could lead to additional emissions of CFC-115, depending on production technology and abatement methods used.

MCTOC is not aware of any other potential sources that could result in significant emissions of CFC-115 as a by-product or intermediate.

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[97] Production method of hexafluoroethane, CN105753635A. Claims a two-stage process from CFC-114, with CFC-115 generated in a first stage reaction and hexafluoroethane in a second stage reaction.

[98] Production and use of hexafluoroethane, WO2003014047A1. This lists several processes that are used including from CFC-114 or CFC-115 to produce hexafluoroethane.

**Table 5-15 CFC-115 by-product comparison of emission factor estimates**

| Top-down emissions estimates (SAP, 2022[99]) | | 2020 |
|---|---|---|
| Emissions CFC-115 | AGAGE | 1.0±0.6 Gg (1,000 ± 600 tonnes) |
| Emissions of HFC-125 | (mean of AGAGE and NOAA) | 88±6 Gg (88,000±6,000 tonnes) |
| Production of HFC-125 *estimate*, tonnes | | 150,000 |
| Emission factor based on HFC-125 production | | 0.7±0.4% |
| Emission factor based on HFC-125 emissions | | 1.1±0.7% |
| **Bottom-up CFC-115 emission estimates, tonnes** *(see note 1)* | | |
| Assuming 100 ppm CFC-115 in HFC-125 emissions (*see note 2*) | | 10 |
| Assuming 1000 ppm CFC-115 in HFC-125 emissions | | 100 |
| Assuming 2000 ppm CFC-115 in HFC-125 emissions | | 200 |
| Assuming 1000 ppm CFC-115 emitted during production of HFC-125 | | 200 |
| Assuming 2000 ppm CFC-115 emitted during production of HFC-125 | | 400 |
| Assuming 5000 ppm CFC-115 emitted during production of HFC-125 | | 1000 |

*Note 1: High concentrations of CFC-115 (1000ppm or 2000 ppm) are not considered to be additive for a specific year's production, see text for explanation.*

*Note 2: These are ppm in mol/mol.*

### 5.3.3.8 Bromotrifluoromethane (Halon 1301, $CF_3Br$)

A preliminary review of the patents and processes used to manufacture fipronil using $CF_3Br$ (TEAP Progress Report 2006) indicates that MCTOC's generic most likely emission factors developed for the more common halide substitution, chlorination, hydrochlorination or hydrofluorination reaction processes (see 2022 MCTOC Assessment Report and Table 5-9) may not be fully applicable to the specific use of $CF_3Br$ as a feedstock in the fipronil production processes.

Whilst the similar relevant properties of $CF_3Br$ compared with many of the other controlled substance feedstocks would suggest that the feedstock production and distribution losses emission factors in Table 5-9 should be generally applicable to $CF_3Br$, the emission factor for feedstock conversion including maintenance for the fipronil production processes may be less applicable. The reasons for this uncertainty are the differences in the way the controlled substances are used as feedstocks. The feedstock processes used to derive the most likely emission factors included in Table 5-9 were primarily based on data from large scale continuous processes where the feedstock was not fed to excess and where the feedstock did not leave the reaction section or loop. These are for processes with high overall conversion rates and yields requiring little or no recovery and recycle of unreacted feedstock from downstream in the process (e.g., CTC to CFC-12). The relevant process flowsheets and patents relating to the process routes to produce fipronil indicate material differences with the use of $CF_3Br$ feedstock; for example, small tonnage production and $CF_3Br$ being fed to excess and with lower yields, which would require the excess $CF_3Br$ to be recovered and recycled or incinerated. Any additional recovery and recycle steps would suggest that there may be additional $CF_3Br$ emission points and hence it is plausible that the emission factors for $CF_3Br$ for one or both process routes may

[99] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. Available at https://ozone.unep.org/science/assessment/sap.

be higher than the generic most likely emission factors for controlled substances in Table 5-9, especially if emissions destruction is not implemented.

MCTOC currently has insufficient operational data on the emissions from these commercially confidential process routes to determine whether the emission factors given in Table 5-9 are suitable for use with $CF_3Br$ used as a feedstock and hence is not able to produce a bottom-up estimate of emissions of $CF_3Br$ from its feedstock use. Parties that regulate and monitor the emissions from the facilities using these processes may have better knowledge of the relevant emission rates.

### *5.3.4 Methodology adopted for estimating the emissions*

#### 5.3.4.1 Emission factors for production, distribution and use as feedstock

Previously, MCTOC used an emission factor of 0.5%, based on HFC production default emission factor, 2006 IPCC Guidelines on National Greenhouse Gas Inventories, to estimate emissions from production of ODS for feedstock use.[100] In 2020, MCTOC[101] updated its emission factors for production and use of feedstock, taking into account the IPCC 2019 Refinement to the 2006 IPCC Guidelines (Tier 1) emission factor applicable to HFCs, which has a default emission factor of 4%, with a range between 0.1% to 20%. The unexpected emissions of CFC-11 prompted a further review of the emissions factors that could apply to a range of production plant vintages, design and operation and maintenance policies. The 2019 TEAP Task Force on Unexpected Emissions of CFC-11 estimated a range of emission rates scenarios for CFC-11 production and distribution:

- 4% by weight for low emissions
- 7% by weight for medium emissions
- 10% by weight for high emissions.

These were based on assumptions around combinations of modern, well-designed, operated and maintained facilities with low emission rates together with older facilities and some small micro-scale plants with considerably higher emission rates, and consider the long range of years of production for which the modelling extended (1930s to 2010s).

For the 2022 Assessment, MCTOC reviewed and revised emission factors, which are set out in the following Tables (5-16, 5-17, 5-18) for production, distribution, and feedstock use. The following points are important for the applicability of the emission factors:

- Controlled substances have a wide range of boiling points which affects the requirements for storage distribution handling and use. For example, HFC-32 boiling point -52°C, and 1,1,1-trichloroethane boiling point 74.1°C.
- Modern well designed, maintained and operated production units can have a range of emissions, including depending on abatement technologies used.
- Distribution emissions will depend on the transport and handling requirements, from pipeline, bulk transport, e.g., for feedstock use or equipment manufacturing such as car-air-conditioning, and bulk transport followed by repackaging into smaller containers for on-site Refrigeration and air-conditioning equipment charging and servicing. Emissions from storage and distribution of bulk quantities are likely to be significantly lower than during production.

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[100] UNEP, 2018. *2018 Report of the Medical and Chemical Technical Options Committee*, 2018 Assessment, December 2018.

[101] UNEP, 2020. *Report of the Technology and Economic Assessment Panel*, Volume 1, Progress Report, May 2020.

However, the contribution of emissions from distribution depends on where the distribution boundary is set. If it includes delivery to end user for refrigerants, large-scale use of disposable containers could lead to significantly increased emissions.

- Bulk feedstocks are typically consumed early in the subsequent chemical process, likely resulting in minimal rates of emissions. Emissions during feedstock production are likely to dominate related overall total emissions for feedstock production and use. For example, the reported emission rate for feedstock use in the EU was 0.03% in 2018.[102] Feedstock transported by pipeline between production plant and feedstock use plant will eliminate most distribution emissions. Distribution EF can be weighted for onsite/offsite feedstock use, e.g., in 2019, CTC was estimated as 50% onsite and 50% offsite feedstock use.
- By-product emissions, e.g., HFC-23 from HCFC-22 production, are not included in this section.

[102] UNEP, 2020. *Report of the Technology and Economic Assessment Panel*, Volume 1, Progress Report, May 2020.

**Table 5-16 Emission factors for modern-day, regulated manufacturing from production and supply chain (by weight of production)**

| **Production and supply chain emissions—<br>Current day in heavily regulated sophisticated plants** | **Low** | **Most Likely** | **High** |
|---|---|---|---|
| **Production** | | | |
| Losses from normal chemical plant production including maintenance [a] | 0.1% | 0.5–2% [b] | 4% |
| Losses when filling drums, tanks, cylinders and containers using quick-connects or hoses under vacuum return systems or other abatement | De minimis 0.1% | 0.4–2% | 3% |
| Production emission factor (most likely)<br>Emission factors from use as feedstock are different and additive | | 0.9–4%<br>Mean ~ 2.5% | |
| **Distribution** | | | |
| Losses from drums, isotanks, cylinders, and containers through shipping and storage in supply chain | De minimis 0.1% | 0.1–1% | 2% [c] |
| Non-returnable cylinder heels<br>Relevant only if non-returnable cylinders are used to a significant extent for distribution.<br>See explanation below for emission factors. | 3% | 4% | 6% [d] |
| Returnable cylinder, tank and other heels that are collected at end-of-life and likely recycled or destroyed includes maintenance and de-NAG and testing tanks and cylinders | De minimis 0.1% | 0.2% | 0.5% |
| Distribution emission factors to be used depend on knowledge of applicable supply chain but could *most likely* add 0.3–1.2% (excluding disposable cylinders).<br>EF this range will depend on distribution method. Pipeline transport to a feedstock plant would essentially eliminate these emissions. | | | |
| [a] Irregular leaks (hole in plant equipment or piping) are included in overall plant losses above (as determined by mass balance)<br>[b] Varies by chemical, boiling point, mitigation, and local regulations, ambient temperature etc.<br>[c] Includes an element for low frequency fugitive emissions due to container or fitting damage or relief stream activation resulting in an unintended leak.<br>[d] Values above 6% on individual cylinders or certain container substance combinations would be possible but would indicate that the container had not been fully emptied before the emission occurred either because it was deliberately vented or discarded prior to being fully emptied or the contents leaked in use or storage. | | | |

**Table 5-17 Emission factors for modern-day, regulated production for feedstock use (by weight of production)**

| Feedstock emissions from feedstock conversion plants—<br>Current Day in Heavily Regulated Sophisticated Plants | Low | Most Likely | High |
|---|---|---|---|
| **Production- feedstock processing** | | | |
| Losses from feedstock process including maintenance [a] | 0.1% | 0.3–0.9% [b]<br>Mean 0.6% | 3% |
| **Distribution -supply to feedstock processing production unit** | | | |
| Most deliveries in isotanks or pipeline so losses lower, accounting for supply chain losses under feedstock production (not counted here). | | | |
| [a] These losses are additive to production losses.<br>[b] Liquids at ambient temperatures e.g., CTC and 1,1,1-trichloroethane would be at the upper end if stored in atmospheric tanks (not-pressurised). Liquified gases e.g., HCFCs and HFCs would be at the lower end as stored in an enclosed system. | | | |

**Table 5-18 Emission factors for 1960-80s vintage, regulated manufacturing annual emissions from production (by weight of production)**

| Production emissions—<br>1960-80s, regulated manufacturing plants | Low | Most Likely | High |
|---|---|---|---|
| **Production** | | | |
| Losses from normal chemical plant production including maintenance [a] | 0.5–1% | 2–3% [b] | 4–5% |
| Losses when filling drums, tanks, cylinders and containers hoses typically without other abatement | 0.5–1% | 1–2% | 3% |
| Production emission factor (most likely) [c] | | 3–5%<br>Mean 4% | |
| **Distribution** | | | |
| Losses from drums, isotanks, cylinders, and containers through shipping and storage in supply chain | De minimis<br>0.1% | 0.5–1% [d] | 2.0% |
| Non-returnable cylinder heels<br>Relevant only if non-returnable cylinders are used to a significant extent for distribution.<br>See explanation below for emission factors. | 3% | 4% | 6% [e] |
| Returnable cylinder, tank and other heels that are collected at end-of-life and likely recycled includes maintenance and de-NAG and testing tanks and cylinders | De minimis<br>0.1% | 0.2% | 0.5% |

[a] Irregular leaks (hole in plant equipment or piping) are included in overall plant losses above (as determined by mass balance).
[b] Varies by chemical, boiling point, mitigation, and local regulations, ambient temperature etc.
[c] Higher emission factors were determined to be applicable for some small micro-scale plants with considerably higher emission rates (CFC-11 unexpected emissions).
[d] Includes an element due to some packages (typically disposibles) arriving at end destination empty due to leaks or relief stream activation e.g., due to high ambient temperatures *en route.*
[e] Values above 6% on individual cylinders or certain container substance combinations would be possible but would indicate that the container had not been fully emptied before the emission occurred either because it was deliberately vented or discarded prior to being fully emptied or the contents leaked in use or storage.

In summary, based on the assumptions used, the mean values for the *most likely* emission factors for modern day regulated manufacturing are:

i. Production 2.5% (0.9–4%)
ii. Feedstock process 0.6% (0.3–0.9%)
iii. Distribution by bulk supply (not pipeline) for large volume users (feedstock and equipment manufacturers) is expected to be towards the lower end of the most likely range (0.3–1.2%), as it excludes transfers to smaller packages.
iv. Supply using repackaged smaller containers, and in particular disposable containers, will contribute to additional emissions depending on their relative use for each controlled substance.

#### 5.3.4.2 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.
- 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.

### *5.3.5 Updated information on alternatives, including information on technical feasibility, economic viability, safety and sustainability*

There are various published sources (reports and patents) providing information on alternatives to the ODS feedstock currently used commercially, including the 2011 TEAP Progress Report, 2012 TEAP Progress Report and a Touchdown Consulting Report (2012).[103]

MCTOC has used these sources to review and update the list of available alternatives to ODS feedstock, together with including alternatives to large-volume HFC feedstock use.

Table 5-19 provides a non-exhaustive list of controlled substances reported with significant use as feedstock (>100 ktonnes per year in Tables 5-6 and 5-7) along with some potential and existing alternatives.

The outcome of the review indicates that only a few technically and commercially possible alternatives to the controlled substance feedstocks currently used have been identified and these alternatives do not cover all of those controlled substances. Those that are available are likely to require significant economic and technical hurdles to be overcome to be able to compete with, or replace, existing processes, equipment and supply chains that use controlled substance feedstocks. The absence of switching production to alternative (non-controlled substances) feedstocks suggests that in many cases these hurdles do not make it attractive to implement these alternatives.

This review only considers alternatives to the current use of controlled substance feedstocks to make a particular product, it does not consider whether there are alternatives to the product itself. Similarly, this review does not cover extremely complex alternative routes, which would be difficult to evaluate.

Table 5-20 provides a rating of commercialisation, the technical feasibility, economic viability, and safety risk aspects of alternative production routes to those using controlled substance as feedstocks. As the current and alternative production routes to the desired products generally use similar chemical building blocks (e.g., hydrocarbons, chlorine, and fluorine) and complex chemical production processes, it has not been possible to differentiate between the long-term sustainability of the different production routes in this report.

[103] Miller M. K., Batchelor T. A., 2012, *Feedstock uses of ODS: Information paper on feedstock uses of ozone-depleting substances*, Touchdown Consulting, December 2012. Prepared for the European Commission.

**Table 5-19 Potential and existing alternatives to current large scale control substance feedstock use**

| Controlled substance Feedstock | Product resulting from feedstock use | Examples of potential and existing alternatives to current feedstock to make the product | Comments |
|---|---|---|---|
| HCFC-22 | Tetrafluoroethylene (TFE) to Hexafluoropropylene (HFP, HFO-1216)/Polytetrafluoroethylene (PTFE) | HFC-23 can undergo high temperature pyrolysis to form TFE | EFCTC (European Fluoro-Carbon Technical Committee) produced a case study into the use of HCFC-22 and HFC-23 as alternative feedstock to make TFE in 2021[104] |
| | | Any source of fluorine will combine with carbon at temperature greater than 1500 °C to form difluorocarbene radicals (-$CF_2$-) which combine under appropriate conditions to give a large yield of $CF_2$:$CF_2$ | |
| | | Dehydrofluorination of HFC-125 or dehydrochlorination of HCFC-124 | Dehydrofluorination or dehydrochlorination could follow similar reaction processes to those used to produce HFOs. It is unlikely that these routes would be attractive as they are more complex than the HCFC-22 route |
| HCFC-142b | Vinylidene fluoride (VDF, HFO-1132a), which can be polymerized to polyvinylidene fluoride or to copolymers | VDF can be produced by hydrofluorination of vinylidene chloride (VDC, $C_2H_2Cl_2$) in the liquid phase, this process will pass through HCFC-142b as an intermediate/feedstock | |
| | | VDF can be produced by de- hydrofluorination of 1,1,1 trifluoroethane ($C_2H_3F_3$)) | |
| HCFC-142b | HFC-143a | HFC-143a can be made direct by hydrofluorination of VDC ($CH_2CCl_2$), this route passes through HCFC-142b as an intermediate | |
| | | HFC-143a can be made by the hydrofluorination of 1,1,1-trichloroethane (methyl chloroform) | |
| CFC-113 and CFC-113a | HFC-134a | HFC-134a can also be produced commercially by the reaction of trichloroethylene and hydrogen fluoride, through an HCFC-133a intermediate | As the HCFC-133a is consumed in situ it is not typically reported as a feedstock use |
| CFC-113 | Chlorotrifluoro-ethylene | Chlorotrifluoroethylene can be produced in different ways, but they all involve the de-chlorination of CFC-113 | |
| CFC-113 | CFC-113a | CFC-113a along with CFC-113 can be made directly by hydrofluorination of hexachloroethane | |
| CFC-113a | Tri-Fluoroacetic acid (TFA) | Trifluoroacetic acid can also be produced from HCFC-123 | |
| | | Trifluoroacetic acid can be prepared from trifluoroethanol through an oxidation reaction | |
| | | Trichloroacetyl chloride and anhydrous hydrogen fluoride (AHF) can be used as feedstock to produce | |

[104] EFCTC, 2021. *Feedstocks are used to make products having major societal value*, February 2021. https://www.fluorocarbons.org/wp-content/uploads/2021/02/2021_02_09_-EFCTC-Position-Paper_Feedstock_F.pdf. Accessed May 2024.

| Controlled substance Feedstock | Product resulting from feedstock use | Examples of potential and existing alternatives to current feedstock to make the product | Comments |
|---|---|---|---|
| | | trifluoroacetic acid by gas-phase fluorination followed with hydrolysis | |
| 1,1,1-trichloroethane (methyl chloroform) | HCFC-142b | HCFC-142b can be produced by hydrofluorination of vinylidene chloride ($C_2H_2Cl_2$) in the liquid phase | |
| | | HCFC-142b can be produced by hydrofluorination of acetylene ($C_2H_2$) to produce HFC-152a followed by chlorination | |
| | | HCFC-142b can be produced by the hydrofluorination of HCFC-141b | |
| | HFC-143a | HFC-143a can be produced by the hydrofluorination of HCFC-142b | |
| CTC | Perchloroethylene | A mixture of perchloroethylene and trichloroethylene can be made by the oxychlorination of ethylene | |
| | | Perchloroethylene can be made by the chlorination of ethylene dichloride (EDC) | |
| CTC | Methyl chloride and chloroform | Methyl chloride and chloroform can by produced by the chlorination/hydrochlorination of methanol and methane, this process can also co-produce CTC | Response to Decision XXXV/9 on abating emissions of CTC |
| CTC | Various intermediates en route to HFOs, including CTC reaction with chloroethylene (VCM) to form HC-240 fa used in the production of HFO-1234ze and the reaction with ethylene to form HC-250 fb used in the production of HFO-1234yf | Various alternative routes to HFO-1234yf have been suggested including via TFE/HFP and via Chlorotrifluoroethylene (CTFE) | See also the response to decision XXXV/9 |
| HCFC-244 | HFO 1234yf | Various alternative routes to HFO-1234yf have been suggested including via TFE/HFP which does not go through HCFC-244 | See also the response to decision XXXV/9 |
| CTC | 2,4-dichloro-5-fluorobenzoyl chloride | 2,4-dichloro-5-fluorobenzoyl chloride can be produced using 2,4-dichlorofluorobenzene and oxalyl chloride | Key intermediates for the production of ciprofloxacin and other quinolone antibiotics. |
| | | 2,4-dichloro-5-fluorobenzoyl chloride can be produced using 2,4-dichloro-5-fluoroacetophenone as raw material, undergoes oxidation with oxygen in a mixed acid system of nitric acid and sulfuric acid, followed by acylation with bis(trichloromethyl) carbonate (BTC), to obtain the target product 2,4-dichloro-5-fluorobenzoyl chloride | |
| | | 2,4-dichloro-5-fluorobenzoyl chloride can be produced using 2,4-dichloro-5-fluorotoluene as raw material, undergoes photochlorination, followed by reaction with water under the catalysis of FeCl3, to obtain the target product 2,4-dichloro-5-fluorobenzoyl chloride | |

| Controlled substance Feedstock | Product resulting from feedstock use | Examples of potential and existing alternatives to current feedstock to make the product | Comments |
|---|---|---|---|
| CTC | 2-methyl-3-trifluoromethyl aniline 11 | 2-chloro –5-trifluoromethyl aniline | Key intermediate for the production of anti-inflammatory and analgesic drugs such as flunisine meglumine. |
| CTC | Dichlorothrin 12 | Alternative route uses diethyl dichloromethyl phosphonate as raw material, to obtain the target product ethyl 3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane-1-carboxylate by reacting with ethyl 3,3-dimethyl-2-formylcyclopropanecarboxylate and potassium tert-butoxide | Key intermediate for the production of pyrethroid insecticides such as permethrin, cypermethrin, cyhalothrin, cyhalothrin, perfluthrin, perfluthrin and permethrin. |
| CTC | Triphenylchloromethane 13 | Alternative route uses triphenylmethanol as raw material, to obtain the target product triphenylmethyl chloride by reacting with bis(trichloromethyl) carbonate in an organic solvent | An amino protective reagent in the production of antihypertensive drugs such as cefloza and irbesartan. |
| | | Alternative route uses alkyl triphenylmethyl ether as raw material, to obtain the target product triphenylmethyl chloride by reacting with chlorinating reagents | |
| HFC-152a | HCFC-142b (see entry for HCFC-142b above) | HCFC-142b can be produced by hydrofluorination of vinylidene chloride ($C_2HCl_2$) in the liquid phase | |
| | | HCFC-142b can be produced by fluorination of 1,1,1-trichloroethane (methyl chloroform) | |
| | | HCFC-142b can be produced by the hydrofluorination of HCFC-141b | |
| HFC-152a | Vinyl fluoride which is polymerized to poly vinyl fluoride | Vinyl fluoride may also be made by the hydrofluorination of acetylene ($C_2H_2 + HF \rightarrow C_2H_3F$) | |
| | | Vinyl fluoride maybe de made by de- hydrochlorination of 1,1 Chlorofluoroethane (HCFC-151) | Little or no reported use of HCFC-151 as a feedstock |

**Table 5-20 Technical feasibility, economic viability and safety risk rating of various feedstocks included in Table 5-19**

| Product | Feedstock | Commercialisation | Technical feasibility | Economic viability | Safety risk |
|---|---|---|---|---|---|
| Tetra Fluoro Ethylene | HCFC-22 | Yes | High | High | Medium |
| | HFC-23 | No | High | Low | Medium |
| | Fluorine and carbon | No | Low | Low | High |
| | HFC-125 or HCFC-124 | No | Medium | Low | High |
| Vinylidene fluoride | HCFC-142b | Yes | High | High | Medium |
| | Hydrofluorination of vinylidene chloride ($C_2H_2Cl_2$) | No | Low | Low | High |
| | De-hydrofluorination of 1,1,1 trifluoroethane ($C_2H_3F_3$, HFC-143a) | No | Medium | Low | High |
| HFC-134a | CFC 113/113a | Yes | High | High | High |
| | Trichloroethylene | Yes | High | High | High |
| Chlorotrifluoro-ethylene | CFC-113 | Yes | High | High | Medium |
| HCFC-142b | Hydrofluorination of 1,1,1-trichloroethane (methyl chloroform) | Yes | High | High | High |
| | Hydrofluorination of vinylidene chloride ($C_2H_2Cl_2$) | Yes | High | High | High |
| | Hydrofluorination of acetylene ($C_2H_2$) to produce HFC-152a followed by chlorination | Yes | High | High | High |
| | Hydrofluorination of HCFC-141b | Yes | High | Low | High |
| Vinyl fluoride | HFC-152a | Yes | High | High | High |
| | Hydrofluorination of acetylene | Yes | High | High | High |
| | HCFC-151a | No | Medium | Medium | High |
| HFC-143a | HCFC-142b | Yes | High | High | High |
| | VDC (1,1 dichloroethylene) | Yes | High | High | High |
| | 1,1,1-trichloroethane (methyl chloroform) | Yes | High | High | High |
| Trifluoroacetic acid (TFA) | CFC-113a | Yes | High | High | High |
| | HCFC-123 | Yes | High | High | Medium |
| | Trifluoroethanol | Yes | Medium | Medium | Medium |
| | Trichloroacetyl chloride and hydrogen fluoride | Yes | High | High | High |
| Perchloroethylene | CTC | Yes | High | High | High |
| | EDC | Yes | High | High | High |

| Product | Feedstock | Commercialisation | Technical feasibility | Economic viability | Safety risk |
|---|---|---|---|---|---|
| | Ethylene | Yes | High | High | High |
| Methyl chloride and chloroform | CTC | Yes | High | Medium | High |
| | Methanol | Yes | High | High | High |
| | Methane | Yes | High | High | High |
| 2,4-dichloro-5-fluorobenzoyl chloride | CTC | Yes | High | High | Medium |
| | 2,4-dichlorofluorobenzene and oxalyl chloride | No | High | High | High |
| | 2,4-dichloro-5-fluoroacetophenone | No | Medium | High | High |
| | 2,4-dichloro-5-fluorotoluene | No | High | High | Medium |
| 2-methyl-3-trifluoromethyl aniline | CTC | Yes | High | High | High |
| | 2-chloro –5-trifluoromethyl aniline | No | Low | Low | High |
| Dichlorothrin | CTC | Yes | High | High | Low |
| | Diethyl dichloromethyl phosphonate | No | Low | Low | High |
| Triphenyl-chloromethane | CTC | Yes | High | High | Low |
| | triphenylmethanol | No | Medium | Medium | Medium |

**Explanation of ratings for technical feasibility, economic viability and safety risk:**

| | | |
|---|---|---|
| Technical feasibility (Note 1) | High | Process already used commercially at scale |
| | Medium | Similar process used at scale or process used in small scale application |
| | Low | Process not used commercially, and similar process not used commercially |
| Economic viability (Note 1) | High | Process economically viable at commercial scale |
| | Medium | Similar process economically viable at scale or process economically viable in small scale application |
| | Low | Process not economically viable commercially, and similar process not economically viable commercially |
| Safety Risk (Inherent hazard[15] of process) (Note 2) | High | Use of high hazard material or process conditions at large scale |
| | Medium | Use of medium hazard material or process conditions at large scale and or high hazard materials or process conditions at small scale |
| | Low | Use of low hazard materials or process conditions at scale and/or medium hazard materials or process conditions at small scale |

***Explanatory notes:***

*Note 1: The technical feasibility and economic viability of a given production route will depend on several factors including, but not limited to,*

- *Availability and cost suitability of the relevant feedstock*
- *Existing production assets that could be used or re-purposed to enable production of the desired product.*
- *Availability of relevant technical expertise*
- *Intellectual Property constraints*
- *Inherent safety of the process, including materials handled and availability and economic viability of the necessary material of construction.*
- *Impurity profile of the resultant product and it saleability*
- *Other regulatory impacts of the chosen production location*

*As many of these factors are likely to be producer specific it follows that different producers will view the different technical feasibility and economic viability of a given process route and feedstock choice differently.*

*Note 2: Globally it is expected that local regulations and customer/supply chain ESG requirements will act to ensure that a given process operation is safe to operate on a day-to-day basis. The nature of the chemicals, the quantity, and the conditions under which they are handled can have a material effect on the inherent safety of these operations.*

### *5.3.6 Information on best practices and technologies for minimising emissions*

There has been no update to information on best practices and technologies for minimising emissions since the 2023 TEAP Progress Report and the 2022 MCTOC Assessment Report, section 2.5 from the 2022 MCTOC Assessment Report on Production emissions and their mitigation, which are repeated here below for completeness.

#### 5.3.6.1 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.

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.

#### 5.3.6.2 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.

#### 5.3.6.3 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 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.

#### 5.3.6.4 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.

#### 5.3.6.5 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[105]; 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.

## 5.4 Response to Decision XXXV/9 on abating emissions of CTC

Decision XXXV/9 requests the TEAP, in consultation with the SAP, to provide in its 2024 progress report an update on the emissions of CTC, including the following:

(a) Emissions by source categories, including emissions as a percentage of total production of CTC with a description of the methodology used;

(b) Updated information on alternatives for CTC as feedstock applications including information on technical feasibility, economic viability, safety, and sustainability;

(c) Updated information on best practices and technologies, for minimising CTC emissions.

### *5.4.1 CTC production and emissions*

The 2022 MCTOC Assessment Report assessed CTC production in 2020, which was reported as 289 ktonnes globally, in what might now be considered as a COVID-related decline from the 2019 high of 317 ktonnes.[106] In 2022, production increased to 358 ktonnes, an 11.9% increase from 2021 production of 320 ktonnes. Figure 5-5 below presents an overview of applications of the global CTC production, and estimated emissions from each category of production and use for 2022. Most of the production growth is from consumption in the HFC and HFO/HCFO sector. The demand for the major CTC-based products HFO-1234yf, HFO-1234ze, and HCFO-1233zd has been predictably increasing due to the Kigali-driven phase-down of HFCs in non-A5 parties and in regions where they are regulated. One leading HFO producer has

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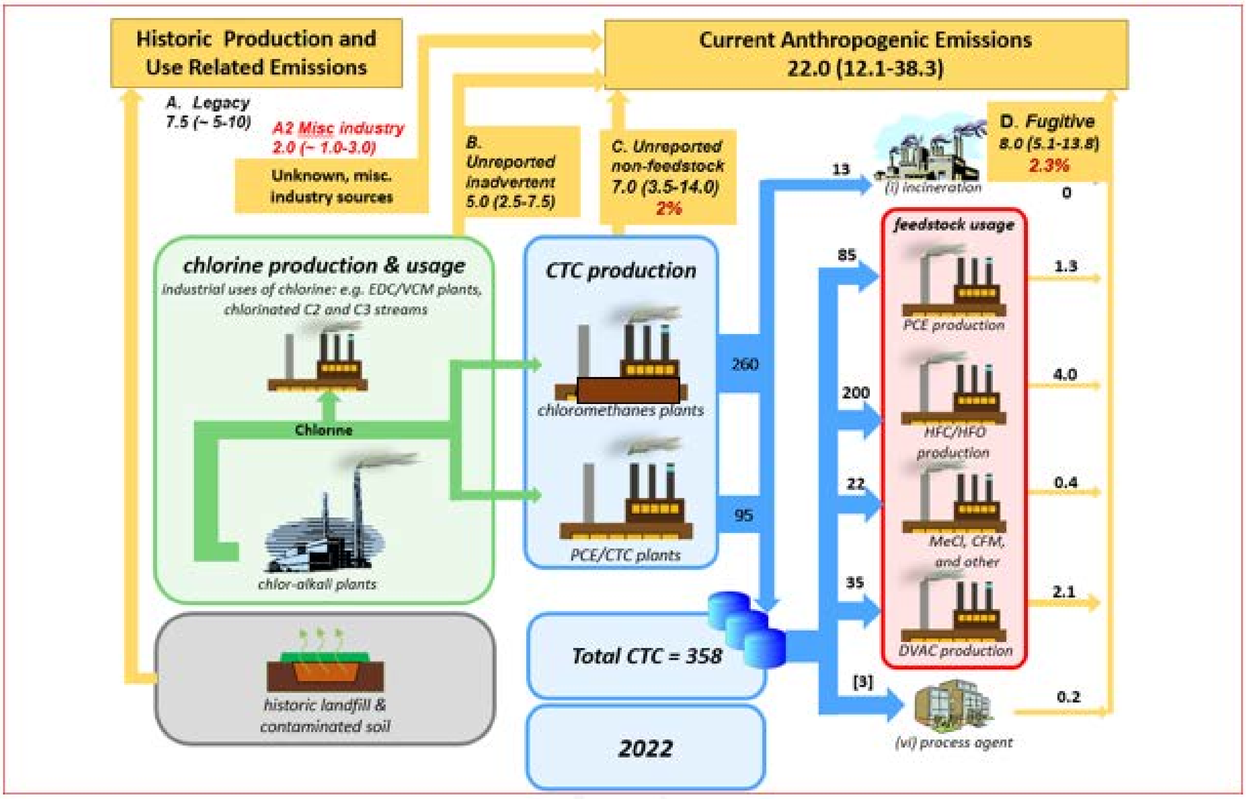
[105] For example, UNFCCC, National Inventory Submissions 2021 | UNFCCC.

[106] After CFC-11, CFC-12, and CTC became controlled substances.

announced an expansion in capacity. One producer has recently constructed an HCFO-1233zd plant in the United States. HCFO-1233zd is also produced in China, India, and Japan.

**Figure 5-5 Estimated global CTC production, usage, and bottom-up emissions, 2022 (ktonnes)**




***Explanatory Notes:***

*A) Legacy emissions arise from historic landfill disposal of contaminated waste, site contaminated soils, or from historic production or user sites of CTC, especially from older military sites where CTC was extensively used as both solvent and fire extinguisher.*

*A2) (New category) Emissions from industry not elsewhere specified or fully characterised. This is discussed below, in section 5.4.1.1 on Engineering and coatings.*

*B) Unreported inadvertent emissions may arise from other chlorination processes including EDC, VCM, and other chlorinated ethanes. Notably, the production of EDC and the cracking to VCM all produce waste streams that to a lesser or greater extent contain CTC. This was discussed in Chapter 2.8.7 of the 2022 MCTOC Assessment Report and is the subject of current scientific evaluation with a new study anticipated during 2024.*

*C) Unreported non-feedstock CTC emissions from chloromethanes plants are fugitive from pipework, compressors, valves and other junction points, and may arise from crude CTC production off CM production plants up to charging of finished CTC (via distillation or PCE/CTC unit) into intermediate storage, following by loading into transport mode-road or rail bulk shipment, or drums. The range of these emissions, according to MCTOC emission factors, is 0.9–4.0% of the total CTC output. The calculated mean production emissions factor for CTC used in the graphic is 2%, reflecting the modernity of most of the production units in China, which have a close to 70% stake in global CM-CTC production capacity. This aspect is further examined below. The percentage includes an uncertainty about the disposal of the distillate after crude CTC finishing.*

*D) Emissions from transport from the producer site to the feedstock user, possibly via intermediate storage, and then feedstock user-site emissions, are considered for CTC to be most likely to fall in the range 0.9–3.1%, with a mean value of 2.3%, according to the use and the proximity to the source of CTC. Although the upper range may be as high as 6%, or more. Emissions from the individual uses are based on factors such as pipeline transfer versus road transport, the potential for supplies of drummed material, and other multiple handing situations. The input volume to process agent is in brackets because the actual input goes unreported in parties where the emissions only are reported. The CTC production estimate for each user industry may have ±10% error.*

The increase in demand for CTC has led to some of its output being diverted from PCE production. The category of methyl chloride, CFM, and other uses now encompasses all applications of CTC that can be categorised outside the 3 main sectors of PCE, HFO/HCFOs, divinyl acid chloride (DVAC) production.

Based on Article 7 reported data of 358 ktonnes of CTC production for 2022, MCTOC estimates that 15.0 ktonnes (8.6–27.8 ktonnes, or 4.2% of total CTC production) of anthropogenic CTC emissions arise globally from CTC production, handling, supply chain, and use. A further 5.0 ktonnes (2.5–7.5 ktonnes) CTC emissions are estimated from anthropogenic non-chloromethanes production, notably the vinyl chain, which is currently the subject of further scientific investigation. Also, a new paper by Li, Huang, Hu *et al*.[107] seemed to indicate CTC emissions from industries not commonly associated with chloromethanes and CTC production, which is elaborated further below.

SAP has provided MCTOC with updated data for mean mole fraction and global emissions estimates for CTC for 2021 and 2022, and in this update the values for 2020 have been revised slightly (see Table 5-21).

[107] Li B, Huang J, Hu X, Zhang L, Ma M, Hu L, Chen D, Du Q, Sun Y, Cai Z, Chen A, Li X, Feng R, Prinn RG, Fang X. CCl4 emissions in eastern China during 2021-2022 and exploration of potential new sources, *Nat Commun*., 2024, **15** (1), 1725. doi: 10.1038/s41467-024-45981-x. PMID: 38409087; PMCID: PMC10897440.

**Table 5-21 SAP update (March 2024) for mole fractions and emissions of CTC ($CCl_4$) from NOAA and AGAGE networks**

| Network | Annual Mean Mole Fraction (ppt) | | | | | Change in ppt* 2020-2022 | | Annual Global Emissions (Gg year, ktonnes) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2016 | 2019 | 2020 Revised† | 2021† | 2022† | ppt | % Annual | 2016 | 2019 | 2020 Revised† | 2021† | 2022† |
| AGAGE | 79.92 | 77.4 | 76.4 | 75.4 | 74.5 | -1.9 | -1.0 | 42 (±15) | 41.8 (±14.4) | 41.6 (±14.5) | 43.4 (±14.2) | 43.6 (±14.1) |
| NOAA | 81.31 | 78.3 | 77.1 | 76.1 | 74.9 | -2.2 | -1.5 | 45 (±15) | 37.3 (±14.6) | 41.3 (±14.4) | 39.2 (±14.2) | 33.8 ±14.2) |

*Notes:*

*† In March 2024, SAP provided updated data for CTC for 2021, and 2022, based on information available from the networks of the Advanced Global Atmospheric Gases Experiment (AGAGE) and the United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA). In this update, the values for 2020 have been revised slightly.*

** Change in ppt has been calculated by MCTOC from data provided by SAP.*

While the AGAGE estimation of CTC emissions remains flat since 2016, the NOAA estimation of CTC emissions indicates a reducing trend. These differences are not unexpected. ***"These differences are likely related to known calibration-scale differences, although a higher discrepancy between inter-hemispheric differences derived from observations by the two networks has emerged since around 2018 (Figure 1-1)***."[108]

### *5.4.2 Recent scientific studies relating to chloromethanes and CTC*

In this section, those studies published since the SAP 2022 that provide new information concerning CTC emissions are reviewed.

#### 5.4.2.1 Engineering and coatings

A new study[109] (Li, Huang, Hu *et al*., 2024) considers emissions of CTC from Eastern China during 2021 and 2022. The study established the presence of more elevated levels of CTC than had been previously reported, as quantified by Park *et al*.[110] A separate measurement campaign of industrial exhaust emissions undertaken by Li *et al*. seemed to indicate that the manufacturing of general-purpose machinery, mainly manufacturing engines, excavators, and other heavy machinery, could be potential sources of CTC emissions. Other engineering sectors (electronics and automotive) and the coatings and resins sector were also considered to be contributing to CTC abundance in the regions studied.

As these elevated levels of CTC emissions seem to contribute new data, they have been provisionally added to Figure 5-5, Estimated global CTC production, usage, and bottom-up emissions, 2022. The sources of these elevated emissions remain unclear.

#### 5.4.2.2 Emissions from chloromethanes plants

A recent paper[111] (Li, Zhao *et al.*, 2023) provides analysis of outside boundary low levels emissions detected from a large, 400 ktonnes per year chloromethanes plant in Shandong Province. Its conclusions are consistent with MCTOC's emission factors and similar to MCTOC's most likely emission factor. It observes that the emission factors (kg/kg), those of DCM were 4% (±2), those of CFM were 2% (± 0.6) and of CTC were 3% (± 2). By extrapolation, the authors estimate that, based on 2020 output, chloromethanes plants in China emitted total 43±18 ktonnes of dichloromethane, and respectively 9.6 ± 3.9 ktonnes of chloroform and 2.2±1.6 ktonnes of CTC.

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[108] World Meteorological Organization (WMO), 2022. *Scientific Assessment of Ozone Depletion: 2022,* GAW Report No. 278, 509 pp.; WMO: Geneva, 2022. p75. Available at https://ozone.unep.org/science/assessment/sap.

[109] Li B, Huang J, Hu X, Zhang L, Ma M, Hu L, Chen D, Du Q, Sun Y, Cai Z, Chen A, Li X, Feng R, Prinn RG, Fang X. CCl4 emissions in eastern China during 2021-2022 and exploration of potential new sources, *Nat Commun.*, 2024, **15** (1), 1725. doi: 10.1038/s41467-024-45981-x. PMID: 38409087; PMCID: PMC10897440. More specifically, emissions of $CCl_4$ in eastern China were estimated to be 7.0 ± 1.6 Gg yr−1 in 2021, and 8.2 ± 1.8 Gg yr−1 in 2022.

[110] Li B, Huang J, Hu X, Zhang L, Ma M, Hu L, Chen D, Du Q, Sun Y, Cai Z, Chen A, Li X, Feng R, Prinn RG, Fang X. CCl4 emissions in eastern China during 2021-2022 and exploration of potential new sources. *Nat Commun*., 2024, **15** (1), 1725. doi: 10.1038/s41467-024-45981-x. PMID: 38409087; PMCID: PMC10897440. More specifically, emissions of CCl4 in eastern China were estimated to be 7.0 ± 1.6 Gg yr−1 in 2021, and 8.2 ± 1.8 Gg yr−1 in 2022.

[111] Bowei Li, Xingchen Zhao, Xinhe Li, Xiaoyi Hu, Liting Hu, Di Chen, Minde An, Yang Yang, Rui Feng, Liya Guo, Pengnan Jiang, Bo Yao, Jianxin Hu, Xuekun Fang, Emission factors of ozone-depleting chloromethanes during production processes based on field measurements surrounding a typical chloromethane plant in China, *Journal of Cleaner Production*, 2023, **414**, 137573. https://doi.org/10.1016/j.jclepro.2023.137573.

An ExCom paper[112] issued in 2022 about CTC production in China provides a table giving detailed estimates of CTC fugitive emissions from production, CTC conversion to other products at chloromethanes producers' sites (e.g., methyl chloride, CFM, PCE), and external consumers of CTC. In the light of the new study by Li, Zhao *et al*., these emissions may have been under-estimated based on chloromethanes and CTC production. However, MCTOC bottom-up emissions estimates already take account of such emissions.

### *5.4.3 Feedstock uses of CTC*

MCTOC described the main feedstock uses in its 2022 Assessment Report, which are:

(a) HFCs, HCFOs, and HFOs

(b) perchloroethylene

(c) divinyl acid chloride

(d) methyl chloride, chloroform, and others.

The use of CTC in these applications is quite specific, as described below.

- ***For HFCs, HCFOs and HFOs***, CTC is used because of its ability to react with olefins (ethylene, chloroethylene) to extend the chain length to a corresponding alkane with a specific chlorine distribution on the carbon backbone of the molecule. Letters after the chemical number identify the exact location of the chlorine and/or fluorine atoms on the carbon chain. Ethylene + CTC becomes 1,3,3,3-tetrachloropropane (HCC-250fb), the starting point for many processes with the end point being HFO-1234yf (2,3,3,3-tetrafluoropropene). Chloroethylene (vinyl chloride, VCM) reacts with CTC to form 1,1,1,3,3-pentachloropropane (HCC-240fa), in turn the starting point for the manufacture of HFC-245fa, HCFO-1233zd, and HFO-1234ze (the latter is 1,3,3,3-tetrafluoropropene).
- ***For perchloroethylene (PCE)***, the use of CTC for PCE production is a less attractive route, because it is a costly process to obtain a pure product with no CTC or other residues. The route exists mainly in China, to transform over-production of CTC from chloromethanes into a useful product, which otherwise would have to be imported in greater quantities. PCE is used in HFC-125, HFO-1336mzz, and CFC-113 production, and for demand for domestic solvents. There are many possible alternative reactants to enable PCE production, most frequently these being chlorocarbon co-product waste streams containing substances such as CFM, CTC, ethyl chloride and 1,1,2-trichloroethane from EDC production, or 1,2-dichloropropane from propylene oxide production. If acetylene is readily and cheaply available, PCE (and TCE) can readily be made from acetylene by chlorination, although PCE from this route is likely of inferior quality and this process has very high energy consumption.
- ***DVAC, divinyl acid chloride (or cypermethric acid chloride)*** is the common name used to describe the substance 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carbonyl chloride. DVAC is used as a basis for production of synthetic pyrethroids, such as permethrin, cypermethrin, cyhalothrin, and perfluthrin. Commercial reaction processes involve the use of CTC with either acrylonitrile or 4,6,6,6-tetrachloro-3,3-dimethylhexanoate and deliver yields of greater than 95%. Isomer distribution is the reason for the selection of CTC as the reactant. Non-CTC routes have been considered that use DCM and CFM as part of the reaction process, but the yields are considerably smaller, and extended by-product formation must be considered.

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[112] UNEP, 2022. UNEP/OzL.Pro/ExCom/90/9/Add.1, *Updated Report On The Production of CTC and its Feedstock Uses in China*, (decision 84/41(b) and (c)). .

- ***Other chloromethanes, other chemicals*** cover a large range of products that are linked only by the fact of having CTC as a starting material. CTC used to produce methyl chloride and CFM (and DCM) is by far not the simplest or most economic route to these lower molecular weight chloromethanes (lower than CTC). However, like perchloroethylene, it represents an avenue to use CM-CTC over-production as a means of conversion to other chemical products most useful to the site. A listing of some other products derived from CTC is to be found in Table 2.1 pp32-33 of the 2022 MCTOC Assessment Report and in this report, including 2-methyl-3-trifluoromethylaniline, triphenylmethyl chloride, and methylphosphonous dichloride.

MCTOC is unaware of alternatives to CTC or alternative processes[113] that would not disturb the vital isomer distribution of the major HFOs and HCFOs. MCTOC would welcome any information on technical feasibility, economic viability, safety and on such alternatives if parties have carried out such analyses.

#### 5.4.3.1 Outlook for CTC as feedstock

Based on the growth potential for HFO/HCFO derivatives in partial replacement for the existing uses of HCFCs and HFCs, it is very likely that CTC consumption in these applications will continue to grow. Although HFCs will start to be controlled as of 2024 in A5 Group 1 parties, present production of HFC-134a, HFC-245fa and HFC-365mfc in A5 parties may have increased in response to phase-downs in the non-A5 parties, and this may enable a larger market to open for HFO replacements. Non-A5 parties have made rapid progress in the introduction of non-fluorinated low GWP products. Notably, hydrocarbons refined from light naphtha or condensed natural gas liquids are gaining in popularity as refrigerant and heat pump fluids. This is due to improvements in modern equipment that have limited their flammability risks and to updated building regulations allowing for an increased fluid content.

### *5.4.4 Information on best practices and technologies, for minimising CTC emissions*

MCTOC reported in its 2022 Assessment Report, in the 2023 TEAP Progress Report, and repeated earlier in this report, on best practices and technologies for mitigating emissions. No further or different information is available for minimising CTC emissions.

## 5.5 Process agents

MCTOC reviewed the process agent data for 2022 reported to the Ozone Secretariat under decisions X/14(4) and XXI/3(1) by China, European Union, Israel, and the United States. MCTOC has not identified compelling new information to report to parties in this progress report on developments in laboratory and analytical uses. MCTOC reported fully on process agent uses in its 2022 Assessment Report.

## 5.6 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

[113] The first commercial production of HFO-1234yf was based on HCFC-22 and its processing through TFE and HFP in at least five subsequent stages. At present, capacity for 1234yf by this route exceeds >25ktpa capacity. Due to the very high energy consumption at the TFE/HFP level, this route is costlier than the CTC routes outlined, and with potentially higher by-product consequences.

developments in laboratory and analytical uses. MCTOC reported fully on laboratory and analytical uses in its 2022 Assessment Report.

## 5.7 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 fully on n-propyl bromide in its 2022 Assessment Report.

## 5.8 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 30th MOP 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 TEAP, 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.

## 5.9 Updates on metered dose inhalers and other aerosols

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.

### *5.9.1 Issues of transitioning to lower-GWP propellants in pMDIs*

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 GWP, which could create risks to inhaler markets and patient health. These include the regulatory approval and launch of lower GWP pMDIs, the availability and affordability of alternative devices, patient adaptability, the background of environmental legislation, continuity in, and stability of, the supply of pharmaceutical grade HFCs, and the rising cost of bulk HFC-134a and HFC-227ea propellants. This section elaborates further on some of these potential challenges. Background information can be found in the 2022 MCTOC Assessment Report, with updates in the 2023 TEAP Progress Report.

MCTOC understands that there may be ten or more companies globally with active programmes to develop pMDIs containing lower GWP propellants involving two lower GWP propellants (HFC-152a (GWP-100: 164 (AR6); 124 (AR4)) and HFO-1234ze(E) (GWP-100: 1.37 (AR6)). Development is a complex process involving new ways of manufacturing, new clinical trials, and new regulatory approvals. Only four companies have made public their development programs, both via press releases and open reporting of clinical trials. Three companies have the stated intent of launching a product in 2025. Despite the potential for studies to demonstrate bioequivalence based on limited studies (at least in the European Union, see below), each has embarked upon Phase 3 efficacy studies that will not apparently complete until mid-late 2025 (see Table 5-22). The feasibility of product launch in 2025 depends on successful research and development, and regulatory submission and approval. The first lower GWP pMDIs may not reach the market until 2026.

**Table 5-22 Registered Phase 3 clinical trials for lower-GWP propellants**

| **Drugs** | Budesonide, Glycopyrronium, Formoterol (BGF) HFO-1234ZE(E) vs BGF HFC-134A | Budesonide, Glycopyrronium, Formoterol (BGF) HFO-1234ZE(E) vs BGF HFC-134A vs Placebo | Beclometasone, Formoterol, Glycopyrronium (BDP/FF/GB) HFC-152A vs BDP/FF HFC-134A | Beclometasone, Formoterol, Glycopyrronium (BDP/FF/GB) HFC-152A vs BDP/FF/GB HFC-134A | Salbutamol HFC-152A vs Salbutamol HFC-134A |
|---|---|---|---|---|---|
| **Design** | 2 arm parallel RCT in COPD (mod. to severe) | 3 arm parallel RCT in COPD | 2 arm parallel RCT in COPD | 2 arm parallel RCT in asthma | 2 arm parallel RCT in asthma |
| **Duration** | 12 weeks (with 52-week extension) | 16 weeks | 52 weeks | 12 weeks | 12 weeks |
| **Primary endpoint** | Adverse events; changes in ECG, blood pressure, pulse, respiration rate, body temperature | Efficacy; $FEV_1$ AUC 0-4 hr and trough morning $FEV_1$ | Safety; trough morning $FEV_1$ at week 28 | Safety and tolerability; change in $FEV_1$ 10 minutes after dosing | Safety; number of participants with serious adverse events over study |
| **Enrolment Target** | 558 | 240 | 2934 | 513 | 420 |
| **Completion** | March 2024 | September 2025 | July 2024 | September 2025 | April 2025 |

***Explanatory Notes:***

- *RCT —Randomised clinical trial;*
- *FEV1 —forced expiratory volume in 1 second;*
- *AUC —Area under curve.*

It should be noted that only three inhalers in two classes of therapy have entered clinical trials; a brand of a single short-acting beta-agonist and two brands of a triple combination of corticosteroid, long-acting beta-agonist and long-acting anti-muscarinic (noting that triple therapies are only used by a small minority of patients worldwide). Many classes of inhaled therapies have yet to enter clinical trials.

The European Medicines Agency (EMA) guidance document recommends at least one safety study be conducted with the final product collecting adverse events such as bronchoconstriction, hoarseness, and cough over 3 months. It can be conducted with vehicle only (placebo) or with final product. For the triple combination products listed in Table 5-21, there have been additional studies of mucociliary clearance and bronchoconstriction using placebo products. It is not clear whether these reported studies could then be used to support other products using the same propellant where different excipients, components or drugs are used. If not, then without commencing additional clinical studies, it is unclear when these three companies and others intend to launch further lower GWP pMDI products. Given that other companies have not yet entered details of clinical trials into international databases, any competing products or other classes of therapy would appear to be some years behind in development. However, there have been recent agreements formed between the two major lower-GWP propellant manufacturers and CDMOs (contract development and manufacturing organisations) to build the capability to develop and manufacture pMDIs containing these propellants on behalf of other companies.[114,115] Several major pMDI manufacturers have made public commitments to net-zero greenhouse gas emissions by 2030, which would necessitate a transition to lower GWP propellants.

It is likely that the price of bulk HFC propellant currently used in pMDIs will increase as quotas for non-pharmaceutical uses tighten. There has already been a significant increase in the price of HFC-227ea. It is likely that HFC-134a will increase in price when the next major drop in HFC production for non-Article 5 parties comes into effect in 2025.[116] This may make some HFC pMDIs less attractive to manufacture from a commercial standpoint. Despite the rising price of HFC-227ea, it is used in 15% of pMDIs sold in the United States,[117] and a new generic budesonide-formoterol pMDI containing HFC-227ea has recently been launched.[118]

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[114] Orbia, 2023. *Kindeva Drug Delivery and Orbia Fluorinated Solutions (Koura) Announce Collaboration for Low GWP Propellant Conversion*. https://www.orbia.com/this-is-orbia/news-and-stories/Kindeva-Drug-Delivery-and-Orbia-Fluorinated-Solutions-Koura-Announce-Collaboration-for-Low-GWP-Propellant-Conversion/. Accessed March 2024.

[115] Honeywell, 2023. *Honeywell and Recipharm to Speed Development of Inhalers with a Near-Zero Global Warming Potential Propellant*, 17 August 2023. https://www.honeywell.com/us/en/press/2023/08/honeywell-and-recipharm-to-speed-development-of-inhalers-with-a-near-zero-global-warming-potential-propellant. Accessed May 2024.

[116] VDKF-Information, 2021. *Leichte Preissteigerungen für Kältemittel auf den oberen Ebenen der Lieferkette [Slight price increases for refrigerants at the upper levels of the supply chain]*, 7-8 Juli-August 2021. https://www.oekorecherche.de/sites/default/files/publikationen/vdkf_aug_2021_km_preise_kleinschmidt.pdf. Accessed May 2024.

[117] US EPA, 2021. *Market Characterization of the U.S. Metered Dose Inhaler Industry,* https://www.epa.gov/sites/default/files/2021-03/documents/epa-hq-oar-2021-0044-0002_attachment_1-mdis.pdf. Accessed April 2024.

[118] Viatris, 2022. *Viatris Inc. Announces Receipt of the First FDA Approval for Generic Version of Symbicort® Inhalation Aerosol, Breyna™ (Budesonide and Formoterol Fumarate Dihydrate Inhalation Aerosol), in Partnership with Kindeva*. https://newsroom.viatris.com/2022-03-16-Viatris-Inc-Announces-Receipt-of-the-First-FDA-Approval-for-Generic-Version-of-Symbicort-R-Inhalation-Aerosol,-Breyna-TM-Budesonide-and-Formoterol-Fumarate-Dihydrate-Inhalation-Aerosol-,-in-Partnership-with-Kindeva. Accessed April 2024.

Some companies could address any potential shortfall in propellant supply by small-scale local stockpiling for their own uses. The option of continued supply of propellants from Article 5 parties may also be available as production in Article 5 parties can continue according to their longer phase-down time frames under the Kigali Amendment; such sources would need to be qualified and approved by regulators of pharmaceuticals for use in a specific product. There has been no movement towards a possible industry-wide approach that was discussed in the 2023 TEAP Progress Report. The price of some new lower GWP pMDIs will increase as a result of the capital investment, research and development, and increased cost of propellants and valves. Finally, it is not clear that there is sufficient manufacturing capacity in the industry for DPIs to make up any shortfall in supply if current pMDI products are withdrawn from the market.

#### *5.9.2 Developments in companies in A5 parties*

The Kigali Amendment to the Montreal Protocol allows A5 parties until around 2047 to reduce their HFC consumption and production by 80% (A5 Group 1) or 85% (A5 Group 2) from their 2020 and 2024 baselines respectively. However, non-A5 parties have shorter timelines that will drive national and corporate policies, which may then have significant commercial impacts globally.

Therefore, the actions of pharmaceutical companies and regulations in Europe may well have consequences for A5 parties in the following way:

- Pharmaceutical companies may market their lower GWP pMDIs globally at the earliest opportunity, rather than latest. This could potentially mean lower GWP pMDIs are available in Article 5 parties from 2026 onwards.
- The reduction in use of HFCs in Europe/United States may lead to security of supply and commercial pricing concerns for Article 5 parties, including India.

Given these uncertainties, various generic pMDI manufacturers are initiating development of their own lower GWP pMDIs:

- At least 3 companies in India are working to reformulate their HFC-based SABA and LABA+ICS combination products with lower GWP propellants.
- At least 1 pharmaceutical company in Bangladesh is working on lower GWP pMDIs.
- Several generics manufacturers in Latin American parties are developing lower GWP pMDIs.

In conclusion, although the Kigali Amendment allows A5 parties until around 2047 to phase down HFCs, global legislation and corporate policies of major pharmaceutical companies may accelerate the introduction of lower GWP pMDIs in A5 parties well before this timeline.

#### *5.9.3 Global regulatory activity related to MDI products containing lower GWP propellants*

In parallel to developments within the industry, the EU approved an update to its F-gas regulations, that came into effect in February 2024.[119] The new regulations further accelerate the timetable for phase-down compared to the Kigali amendment (see Figure 5-6), leading to a total phase-out by 2050. In contrast to the 2014 regulations that have been replaced, pMDIs

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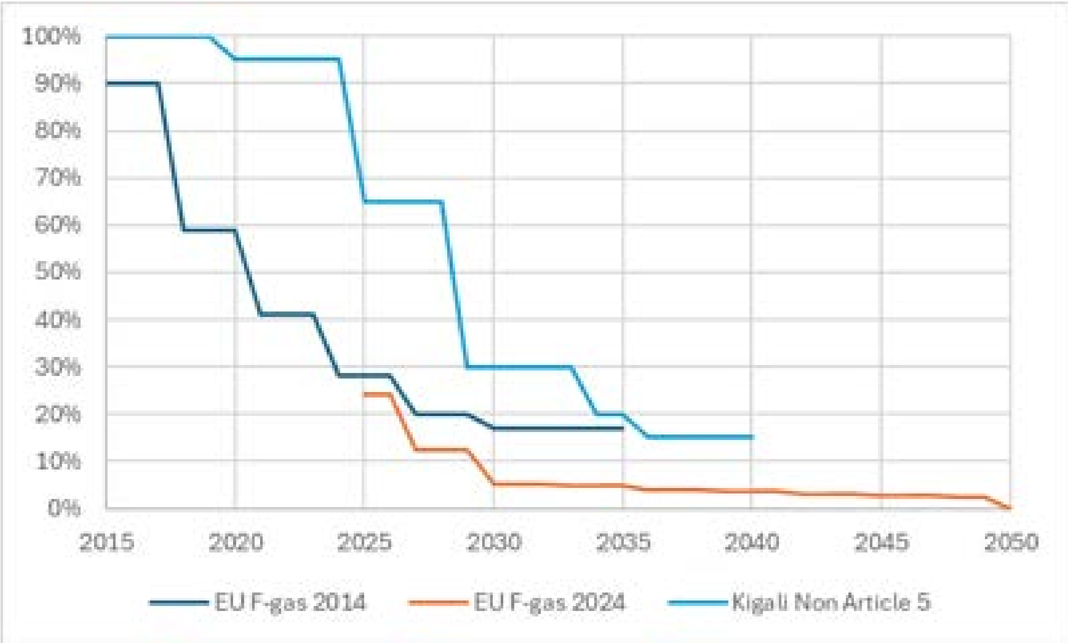
[119] European Commission, *EU-Rules – Guidance on the EU's F-gas Regulation and its legal framework*. https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-rules_en. Accessed March 2024.

are now included within the quota scheme, but specific provisions apply to the sector from 2025 to 2029 to help ensure stable supply of pMDIs. The two new lower-GWP pMDI propellants currently in development are subject to the regulations; HFC-152a is scheduled be phased out by 2050, and HFO-1234ze(E) is subject to regulation but not to phase-out. In the future, there may be opportunities to exempt critical uses such as propellants for pMDIs. Some companies have indicated that there may be too great a risk of insufficient commercial return to make it worthwhile investing in a lower-GWP development program.

**Figure 5-6 Revised phase-out schedule under EU F-Gas Regulations 2024**




Other significant changes for pMDI manufacturers include labelling and reporting requirements, and there are generally tighter controls for the import of products containing F-gases. In recognition of the potential impact on the health sector in general and inhalers in particular, the European Union has committed to publishing a review of this impact by 1 July 2028.

In 2023, the European Chemicals Agency (ECHA) also published proposed restrictions to control per- and polyfluoro-alkyl substances (PFAS).[120] While there were a limited number of derogations for listed technologies, these did not include the use of HFC-134a and HFC-227ea, nor HFOs as propellants in pMDIs. PFAS and the proposed ECHA restriction is discussed by TEAP elsewhere in this report.

The EMA issued a Q&A document in November 2023 related to the transition to pMDIs containing low GWP propellants.[121] As of March 2024, United States Food and Drug Administration (FDA) has not issued any formal guidance on replacing propellants in pMDIs,

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[120] European Chemicals Agency, 2024. *Registry of restriction intentions until outcome. Restriction on the manufacture, placing on the market and use of PFASs*, Last updated January 11th, 2024. https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b. Accessed April 3rd, 2024.

[121] European Medicines Agency, 2023. *Questions and answers on data requirements when transitioning to low global warming potential (LGWP) propellants in oral pressurised metered dose inhalers – Scientific guideline.* https://www.ema.europa.eu/en/questions-and-answers-data-requirements-when-transitioning-low-global-warming-potential-lgwp-propellants-oral-pressurised-metered-dose-inhalers-scientific-guideline. Accessed March 2024.

but has engaged in a workshop organised by industry representatives from the International Pharmaceutical Aerosol Consortium on Regulation and Science (IPAC-RS), with presentations from industry, FDA and EMA.[122]To facilitate further dialogue on the switch to lower GWP Propellants, IPAC-RS plans to convene a public workshop in June 2024, to discuss different regulatory approval pathways. The FDA has been invited to present at this meeting. Furthermore, FDA and the FDA-funded Center for Research on Complex Generics (CRCG) plan to hold a public workshop entitled *Navigating the Transition to Low Global Warming Potential Propellants* in December 2024.[123]

#### *5.9.4 Developments in asthma management*

The Global Initiative for Asthma (GINA) Strategy Report for 2023 includes a new recommendation to consider environmental impact as an important part of the shared decision-making process for inhaler selection.[124] This includes considering the propellant in pMDIs. A 2023 European Respiratory Society guideline recommends using as-needed inhaled corticosteroid (ICS) plus formoterol combination inhalers instead of regular ICS maintenance treatment plus as-needed reliever inhalers, or as-needed relievers alone.[125] These recommendations align with the GINA strategy. Prioritising combination inhalers in this way could reduce the total number of inhalers needed, and potentially increase uptake of DPIs as combination inhalers are more commonly available in the DPI format in Europe. Many international and national guidelines still do not make any comments or recommendations about the environmental impact of inhalers.

The GINA Strategy Report for 2023 also stated the aim to have asthma therapy available to all patients. However, many patients, especially in low- and middle-income parties, have very limited access to affordable inhalers.[126]

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) also increasingly advocates for the use of combination inhalers, and in their 2024 Annual Report states that the choice of inhaler has an environmental impact.[127]

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[122] International Pharmaceutical Aerosol Consortium on Regulation & Science (IPAC-RS), 2023. *IPAC-RS Workshop on the Transition to Low Global Warming Potential Propellants for Metered Dose Inhalers,* Wednesday, October 11, 2023. https://www.ipacrs.org/ipac-rsworkshoptransitiontolgwp. Accessed April 2024.

[123] FDA and the Center for Research on Complex Generics (CRCG), *Navigating the Transition to Low Global Warming Potential Propellants,* announcement for workshop to be held on December 2024. https://complexgenerics.org/education-training/navigating-the-transition-to-low-global-warming-potential-propellants/. Accessed April 2024.

[124] Global Initiative for Asthma, 2023. *Global Strategy for Asthma Management and Prevention*, Updated 2023. https://ginasthma.org/wp-content/uploads/2023/07/GINA-2023-Full-report-23_07_06-WMS.pdf. Accessed February 2024.

[125] Alberto Papi, Diogenes S. Ferreira, Ioana Agache, Eugenio Baraldi, Richard Beasley, Guy Brusselle, Courtney Coleman, Mina Gaga, Carolina Maria, Gotera Rivera, Erik Melén, Ian D. Pavord, Deborah Peñate Gómez, Daniel Schuermans, Antonio Spanevello, Thomy Tonia, Florence Schleich. European Respiratory Society Short Guidelines for the use of as-needed ICS/formoterol in mild Asthma*, European Respiratory Journal,* 2023, **63** (5), 2300047. doi: 10.1183/13993003.00047-2023.

[126] Stolbrink, M., Thomson, H., Hadfield, R. M., Ozoh, O. B., Nantanda, R., Jayasooriya, S., Allwood, B., Halpin, D. M. G., Salvi, S., de Oca, M. M., Mortimer, K., Rylance, S., The availability, cost, and affordability of essential medicines for asthma and COPD in low-income and middle-income countries: a systematic review, *The Lancet. Global Health,* 2022, **10** (10), e1423–e1442. https://doi.org/10.1016/S2214-109X(22)00330-8.

[127] Global Initiative for Chronic Obstructive Lung Disease, 2024. *Global Strategy for the Diagnosis, Management,*

### *5.9.5 Developments in aerosols*

Aerosol production globally continues to evolve with the greatest change in product mix occurring in the United States. VOC (volatile organic compound) regulations remain the primary driver of aerosol reformulation with some major categories moving from hydrocarbon LPG (liquefied petroleum gas) propellants to compressed air or nitrogen formulas. These reformulations have reduced LPG propellant consumption by more than 30 million pounds (~14000 tonnes).

In the United States, HFC-134a has almost disappeared in aerosol production (less than 1000 tonnes) with the exception of a handful of specialised exempt products (excluding pMDIs). HFO-1234ze has been the primary replacement for HFC-134a and there is modest but constant growth in this propellant category. Cost continues to be a factor that limits more conversions to HFO-1234ze, but small volumes of "high end" personal care products are using this propellant.

In the United States, HFC-152a continues to be the most commonly used propellant in personal care, usually blended with the hydrocarbon LPG propellant to control cost and vapour pressure. In Mexico, the use of HFC-152a is increasing in personal care products, but most of these brands are exported back to the United States by multi-national corporations. The lower GWP of HFC-152a means the industry is expecting to have this propellant available for a ten-year timeline.

Aerosol valve technology continues to evolve, allowing for effective use of some non-HFC propellants (such as nitrogen and compressed air) in more applications.

In Europe and Asia, especially in China, production continues to be largely LPG and dimethyl ether propellants. In South America, aerosol production is almost all LPG.

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*and Prevention of Chronic Obstructive Pulmonary Disease; 2024 Report*. https://goldcopd.org/2024-gold-report/. Accessed May 2024.

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

## 6.1 Introduction

In the first half of 2023, RTOC completed its organisational changes, which had started just after the release of the 2022 RTOC Assessment Report (RTOC AR2022). It was decided that all appointments would be two years (ending in 2024) to ensure on-going balance and sufficient expertise during the quadrennial assessment report writing. During 2023, parties appointed a fourth co-chair for RTOC, from the US who was already an RTOC member.

The changes in RTOC membership for the current quadrennium are presented as a list in Annex 5. In 2023 RTOC consisted of 43 members, with 22 from non-A5 parties and 21 from A5 parties with proper geographical balance. In addition, the gender balance was improved via a membership of 12 female and 31 male refrigeration experts. In 2024, one new member (male) from Japan was also added to the committee.

In 2023, RTOC organised one in-person meeting in Paris at the end of August, back-to-back with the 2023 International Congress of Refrigeration organized by the International Institute of Refrigeration (IIR). During the Congress, a special event was organised to present RTOC activities to the broader refrigeration community. During this in-person RTOC meeting, members initiated the discussion on the organisation of the RTOC 2026 assessment and suggested a schedule for achieving the progress toward publication of the report.

## 6.2 Updates to 2022 Assessment

In the following subsections, technology updates since the publication of the RTOC AR2022 are given, which follow the format of the RTOC AR2022.

### *6.2.1 Refrigerants*

Since the publication of the RTOC AR2022 report 18 new refrigerants have received designations and classifications from ASHRAE (formerly known as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Standard 34 and/or from the International Standards Organisation (ISO) 817. All 18 new refrigerants are zeotropic blends consisting of pure fluids which were listed in the RTOC AR2022 and are listed in the table below. Only the refrigerants published in the above standards are given in table 6-1 below (A1 – no flame propagation, A2L – lower flammability, A2 – flammable, A3 – higher flammability). GWP and ODP values are calculated based on Table 3.I-1 in the AR2022 report. The GWP 100-year values from the Montreal Protocol are also listed where available.

In addition, a corrigendum for Chapter 3-Refrigerants of the RTOC AR2022 is suggested as shown below based on the consensus of the RTOC during its plenary meeting in Bali, 2024.

**Table 3-5 and 3-6:**
*Add a footnote to columns named "GWP 100-year in Montreal Protocol":*

GWP values for blends are rounded and for information purposes only. These are not to be used directly when deriving amounts in CO2-eq. tonnes for reporting under the Montreal Protocol.

**Table 3.I-2 and 3.I-3:**
*Add a footnote to columns named "GWP 100-year in Montreal Protocol" and "ODP in Montreal Protocol":*

ODP and GWP values for blends are rounded and for information purposes only. These are not to be used directly when deriving amounts in ODP-tonnes and CO2-eq. tonnes respectively for reporting under the Montreal Protocol.

### *6.2.2 Factory-sealed domestic and commercial refrigeration appliances*

Globally, the domestic refrigeration industry is converting from HFC-134a to HC-600a at a faster rate than required for compliance by the Kigali Amendment.

The safety standard, International Electrotechnical Commission (IEC) 60335-2-89:2019/COR3:2023 specifies safety requirements for electrically operated commercial refrigerating appliances and icemakers. The refrigerant charge limits have been increased from 150 g to 500 g for the higher flammability A3 refrigerants. For lower flammability alternatives (A2 and A2L), the limit has been increased from 150 g to 1.2 kg.

Regional appliance safety standards, based on the IEC standards are updated periodically. Charge limits may vary, or additional safety features could be proposed or modified compared to the IEC standards.

Energy efficiency (EE) standards are being periodically updated as well. More A5 parties are also introducing EE standards for these types of equipment.

## Table 6-1 Data summary for new refrigerants

| Refrigerant Designation | Refrigerant Composition (Mass %) | Molecular Weight (kg/kmol) | Bubble Point/ Dew Point (°C) | Safety Class | GWP 100-year | GWP 20-year | ODP | GWP 100-year in Montreal Protocol[c] |
|---|---|---|---|---|---|---|---|---|
| R-454D | R-32/1234yf (43.0/57.0) | 75.4 | –48.8/–44.5 | A2L | 323 | 1 128 | | 290[a] |
| R-455B | R-744/32/1234yf (6.0/42.0/52.0) | 71.4 | –58.0/–46.7 | A2L | 315 | 1 102 | | 284[a] |
| R-455C | R-744/32/1234yf (3.0/43.0/54.0) | 73.1 | –53.4/–45.8 | A2L | 323 | 1 128 | | 290[a] |
| R-457D | R-32/1234yf/152a (4.0/82.0/14.0) | 99.2 | –34.5/–31.0 | A2L | 52 | 183 | | 44[a] |
| R-474B | R-1132(E)/R-1234yf (31.5/68.5) | 91.5 | –45.8/–38.4 | A2L | 1 | 1.7 | | [b] |
| R-475B | R-1234yf/134a/1234ze(E) (35.4/10.1/54.5) | 112.7 | –26.3/–25.5 | A2L | 149 | 413 | | 144[a] |
| R-478A | R-744/32/125/134a/152a/1234ze(E)/227ea (7.0/26.0/15.0/15.0/3.0/30.0/4.0) | 79.2 | –58.4/–37.4 | A2L | 1 136 | 2 560 | | 1 048[a] |
| R-479A | R-1132(E)/32/1234yf (28.0/21.5/50.5) | 77.3 | –50.4/–44.7 | A2L | 162 | 565 | | 145[a] |
| R-480A | R-744/1234ze(E)/227ea (5.0/86.0/9.0) | 108.6 | –46.5/–21.7 | A1 | 323 | 529 | | 290[a] |
| R-481A | R-32/125/134a/1233zd(E)/601a (16.9/6.3/74.4/1.8/0.6) | 88.6 | –38.3/–30.5 | A1 | 1 461 | 3 891 | $7.2 \times 10^{-6}$ | 1 398[a] |
| R-482A | R-134a/1234ze(E)/1224yd(Z) (10.0/83.5/6.5) | 114.4 | –19.6/–17.0 | A1 | 148 | 410 | | 143[a] |
| R-483A | R-290/600 (15.0/85.0) | 55.5 | –14.4/–4.8 | A3 | 1 | 1 | | [b] |
| R-484A | R-1270/600 (12.0/88.0) | 55.6 | –13.5/–4.1 | A3 | 1 | 1 | | [b] |
| R-485A | R-1132a/744/32 (10.0/69.0/21.0) | 47 | –81.6/–71.4 | A1/A2L[d] | 158 | 551 | | 142[a] |
| R-486A | R-1234yf/134a/13I1/1234ze(E) (21.9/6.3/38.0/33.8) | 134.4 | –25.7/–24.9 | A1 | 94 | 258 | 0.034 | 90[a] |
| R-487A | R-170/R-1270 (20.0/80.0) | 39 | –68.5/–53.2 | A3 | 1 | 1.4 | | [b] |
| R-488A | R-32/1234yf/152a/1234ze(E) (6.0/50.0/3.0/41.0) | 104.3 | –35.1/–28.0 | A2L | 50 | 177 | | 44[a] |
| R-489A | R-50/1150/600 (1.5/22.0/76.5) | 45.6 | –124.7/–13.3 | A3 | 1.4 | 2.2 | | b |

[a] Blend containing one or more components that are not regulated under the Montreal Protocol, and the GWP of the blend does not include the GWPs of these components.

[b] Blend containing no components that are regulated under the Montreal Protocol.

[c] Global Warming Potential (GWP) values for blends are rounded and for information purposes only. These are not to be used directly when deriving amounts in CO2-eq. tonnes for reporting under the Montreal Protocol.

[d] The safety class will depend on the details of the application.

### *6.2.3 Food retail and food service refrigeration*

The shift to refrigerants with GWPs <10 and <150 in new systems and retrofits to refrigerants with a GWP <1500 in existing systems, while also maintaining or improving EE, continues globally at a good pace, especially in non-A5 parties. The most common refrigerants being applied are R-744, HC-290, and HFO blends such as R-454C, R-454A and R-455A. In both non-Article 5 and Article 5 parties, R-448A and R-449A are replacing R-404A in existing as well as in new systems. R-450A and R-513A (with a GWP <600) continue to replace HFC-134a in many applications.

Since the publication of the RTOC AR2022, the United States has published refrigerant bans for supermarket retail refrigeration systems in 2026, and condensing units in 2027 (excluding the high-temperature side of cascade systems) and set a GWP limit of 150 for refrigerant charges greater than 200 lbs, and a GWP limit of 300 for less than 200 lb refrigerant charge.

Digitalization of systems using sensors, wireless and wired networks, software for diagnostics and prediction, as well as simple record-keeping is gaining momentum in food retail and food service applications, in both stationary and transport systems. This trend is driven by a strong need for food safety, food quality, reduction of food waste and efforts to improve equipment efficiency, safety and for better life cycle performance (lower carbon footprint) of systems.

### *6.2.4 Transport refrigeration*

The safety standard addressing the requirements and the risk analysis process for the use of flammable refrigerants in road vehicles the European Normative (EN) standard, EN 17893, was published in 2024. Regional standards for transport refrigeration are under development in some non-European regions.

Since the publication of the RTOC AR2022, the United States has published refrigerant bans for self-contained products and marine systems and has set a GWP limit of 700 for intermodal containers in the US, which will all be in effect in 2025.

Since 2022, the revised F-Gas Regulation in Europe has set requirements for leak prevention and service including mandatory leak checks. By July 2027, the EU Commission shall publish a report assessing whether cost-effective, technically feasible, energy-efficient, and reliable alternatives to HFCs exist, and where appropriate, put forward a legislative proposal. This aspect, combined with the potential regulation of PFAS, has created considerable uncertainty in the industry.

While field research continues, most new road transport refrigeration units use R-452A. Some systems, especially those for vans, have been developed using higher flammability A3 refrigerants. Because of serious concerns over the safe use of higher flammability A3 refrigerants, key players in the marine container segment are actively considering HFO-1234yf though not excluding other options.

### *6.2.5 Air conditioning/small-scale*

The publication of the revised international safety standard on air conditioners and heat pumps (IEC 60335-2-40: 2022) enables considerably more flammable refrigerant charge (per $m^2$ of room area). This suggests that it is possible to apply lower GWP flammable refrigerants across a wider scope of systems with appropriate safety measures.

The United States has limited the GWP for small-scale air conditioning to 700, as of 2025. The revised EU F-gas regulation has been published, which will either prohibit the use of fluorinated refrigerants entirely or will prohibit those with a GWP >150 – depending upon the type of system – at various points over the next ten years. This has led to the accelerated development of systems with low-GWP alternatives amongst manufacturers who sell products in the region. Elsewhere, there are increasingly more systems being developed with various HFC and HFO mixtures such as R-454A, R-454B, R-457A, R-452B, R-455A, R-459A, R-463A and R-513A as well as HFC-32.

The technical and scientific literature similarly reflects the escalated interest in lower GWP flammable alternatives with more research published on topical subjects such as leak detection, flammability mitigation techniques and risk assessment, specifically aimed at these system types.

### *6.2.6 Air conditioning/large-scale*

Air conditioning units and heat pumps with large capacities (over 20 kW), such as ducted split and package units, variable refrigerant flow (VRF) [128] systems, and multi-split units, continue to predominantly utilize R-410A as the primary refrigerant. In certain regions, HCFC-22 is still used in various applications, particularly in Africa and some Asian parties. The United States has limited the GWP for large-scale air conditioning to 700, as of the year 2025.

There is a growing trend towards the use of HFO refrigerants (HFO-1234ze and to a lesser extent HFO-1234yf) and HFC-HFO refrigerant blends, specifically R-454B. HFC-32 is experiencing rapid adoption, particularly in packaged systems in different regions including the Middle East, and North Africa. HFC-32 is predominantly used in smaller capacity equipment like mini and ducted split units, packaged units, and some multi-split systems. It is not commonly found in larger systems or VRF systems although it is available in some regions; however, three manufacturers in Japan have announced plans to launch these systems.

Over the past years, the implementation of safety standards, such as IEC-60335-2-40 and its related derivatives, has significantly increased in various regions to ensure the safe use of flammable refrigerants in air-to-air systems. This has led to the certification and use of safety standard products, primarily for A2L lower flammability refrigerants and, to a lesser extent, A3 higher flammability refrigerants.

### *6.2.7 Mobile Air Conditioning (MAC)*

HFC phase-down regulations in the EU, Japan, Korea and North America, are driving greater adoption of lower GWP HFC alternatives.  Most manufacturers are transitioning to HFO-1234yf with some using R-744. Lower GWP HFC alternatives to HFC-134a can be found across all on-road and off-road vehicle classes, including off-road heavy-duty equipment.

The HFC phase-down is spurring new HFO/HFC refrigerants for vehicle servicing.  Several blends are being investigated for light duty servicing namely R-444A, R-456A, R-480A and R-513A. R-458A is being investigated as a servicing option for HCFC-22 in buses.

Vehicle electrification is much more common across all vehicle classes including off-road heavy-duty equipment. Electrification requires holistic vehicle thermal management (heating

[128] Also referred to as a VRF system, variable refrigerant flow is a technology that circulates only the minimum amount of refrigerant needed during a single heating or cooling period. Unlike traditional HVAC systems that use a constant amount of energy to heat or cool an entire building, VRF AC systems provide zonal control, allowing for individual temperature settings in different areas or zones of a building. This zoning capability helps optimise energy consumption.

and cooling of the driver cabin along with battery cooling). The global automotive industry has sponsored a cooperative research program (SAE CRP) investigating low-GWP refrigerants suitable for electric vehicles.  Work is ongoing with project results expected in late 2025 or early 2026. Lower GWP HFC/HFO refrigerant blends and secondary loop R-290 are being investigated as part of this work, partly due to potential PFAS regulations.

### *6.2.8 Industrial refrigeration*

There has been significant growth in the use of natural refrigerants in addition to R-717 in several regions of the world, especially in large industrial systems. $CO_2$ is increasingly used with ammonia in cascaded systems while HCs and HFC/HFO blends are being applied in smaller systems. Refrigerant charge minimisation continues as a trend in industrial applications, such as in the conversion from flooded to direct expansion (DX) heat exchangers.

The United States has limited the GWP for industrial process refrigeration chillers to 700, as of 2026 and 2028 (depending on processing temperatures above -50°C). For other industrial process refrigeration equipment with an operating temperature above -30°C, with a charge size greater than 200 lbs, the GWP is limited to 150 in 2026, while equipment with smaller charges may use refrigerants with a maximum GWP of 300. Non-chiller, industrial process refrigeration equipment that operates from -30°C to -50°C, is limited to using refrigerants with a GWP below 700 as of 2028.

EE and cost savings are the main drivers for industrial heat pumps.  Most companies offer systems with either natural or HFC refrigerants.

### *6.2.9 Water heating heat pumps*

Water heating heat pumps for room heating and heating of domestic hot water are considered to play an important role in replacing fossil fuel heating to decarbonise the building and industry sectors, despite growth slowdown in some markets due to reduced gas prices, mainly in Europe.

The dominant refrigerants used in this sector are R-410A, HFC-32 and R-744. In Europe an increasing share of the market is expected to be converted to HC-290 in compliance with the revised EU F-gas regulation, especially the self-contained air-source type of systems. In China, the main refrigerant used is HFC-32, while HC-290 are in trials. In the United States, HFC/HFO blends and HFC alternatives, such as R-454B and HFC-32 are used to meet the US EPA requirement of GWP <700 beginning in the year 2025. In Japan, most water heating heat pumps are used primarily for domestic hot water heating and some room heating, and R-744 is the refrigerant of choice. In Australia, HC-290 and HFC-134a continue to dominate this application.

### *6.2.10 Not-In-Kind technologies*

Geothermal cooling is now an available technology gaining wider acceptance globally. Evaporative liquid desiccant AC is also considered an available technology. It combines direct and indirect evaporative cooling with liquid desiccants. It can operate at coefficients of performance (COPs)[129] superior to mechanical vapour compression although its capital cost is higher.

Finally, barocaloric cooling, a new solid-state cooling method using organic material as refrigerants to alleviate environmental issues and improve EE remains an emerging technology. This zero-carbon heating and cooling technology can potentially be deployed in many applications that include heating and air conditioning, domestic and commercial refrigeration, as well as refrigerated vehicles.

### *6.2.11 Servicing*

The revised F-gas regulation 2024/573 of the EU requires certification and training of technicians to also cover handling alternatives to F-gases. The regulation extended already existing requirements from the previous F-gas regulations for mandatory leak checks to HFO refrigerants. Several parties adjacent to the EU adapt or adopt regulations similar to the EU F-gas regulation.

The TEAP Decision XXXV/11 Lifecycle Refrigerant Management (LRM) Task Force Report lists the challenges to the accessibility to tools and infrastructure and recommendations to enable the proper management of refrigerants. It will be presented at the Montreal Protocol OEWG-46 in July 2024.

## 6.3 Response to Decision XXXV/10 on energy efficiency

Previous Decision XXXIV/3 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." More recently, Decision XXXVI/10 requests the following:

> *To request the Technology and Economic Assessment Panel to include in its 2024 progress report updates on the information identified in paragraph 1 (a) of decision XXXIV/3, taking into account discussions at the Thirty-Fifth Meeting of the Parties to the Montreal Protocol.*

### *6.3.1 Updates on energy efficiency while phasing down HFCs in the RACHP sectors*

According to the Global Cooling Stocktake Report 2023[130]; passive cooling, higher EE standards, and a faster phase down of climate warming refrigerants used in the cooling industry could avert up to 60% of the predicted emissions from the cooling sector by 2050. To deliver these benefits there would need to be concerted efforts in passive cooling, higher EE standards and a faster phase down of climate-warming refrigerants.

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[129] The coefficient of performance or COP (sometimes CP or CoP) of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work (energy) required. Higher COPs equate to higher efficiency, lower energy (power) consumption and thus lower operating costs.

[130] https://www.unep.org/resources/global-cooling-watch-2023

The Global Cooling Stocktake Report 2023 showed that cooling policies are in place in many parties, but their implementation effectiveness and integration vary: 80% of parties have established at least one of these three regulatory instruments, mentioned in the first paragraph, needed to move the cooling sector towards near-zero emissions but only 27% have established well-integrated regulatory frameworks. It is important to note that 35 parties have adopted policies such as national cooling action plans while some other parties have adopted other forms of climate action plans.

Seventy parties have signed up for the Global Cooling Pledge, which aims to reduce cooling-related emissions by 68% by 2050, increase access to sustainable cooling by 2030, and increase the global average efficiency of new air conditioners by 50%.[131]

Progress with regional approaches:

- The Southern African Development Community (SADC) has approved a harmonized regional Minimum Energy Performance Standards (MEPS) for AC and residential refrigerators based on the U4E model regulations[132].
- Two Middle Eastern parties have officially published regulations based on seasonal EE for implementation in 2025:
    - Bahrain has revised its regulation on energy labelling for small capacity AC up to 19 kW cooling capacity. While MEPS is kept at T1 and T3 condition the Energy label will be based on CSPF for high ambient as per ISO 16358-1:2013: AMD1:2019. The new law was issued in Oct 2023 for implementation in 2025.
    - Egypt has issued ES3795/2023 adopting Seasonal Energy Efficiency regulation for room and ducted AC in January 2024 to replace all previous regulations unifying the CSPF requirements for both fixed speed and inverter AC. Egypt regulation refers to ISO 16358-1: 2013 AMD1:2019 for high ambient recognizing the rising ambient temperature in Egypt. The regulation will be enforced in 2025.
- Saudi Arabia has notified WTO with a draft to adopt reporting seasonal EE for commercial AC along with MEPS.
- Other parties which are part of the Gulf Standards Organisation are still in draft stage revising their EE regulations to adopt Seasonal Energy Efficiency for room AC.

In the area of cold chain capacity building, an important development is the ACES project which became operational in March 2024[133]. It is important to note that pre-cooling, especially hydro pre-cooling, for fresh produce is gaining adoption in the cold chain. Pre-cooling improves produce shelf-life appreciably; especially when performed shortly post-harvest. This is particularly important in parties where the cold chain is weak, fragmented or non-existent.

There has been a recent interest in heat pump technology as means to decarbonize heat. The IEA estimated that heat pumps could reduce total global $CO_2$eq emissions by 500 million

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[131] https://coolcoalition.org/global-cooling-pledge/

[132] https://united4efficiency.org/harmonized-regional-meps-for-cooling-products-approved-for-sadc-region/

[133] https://united4efficiency.org/rwandas-environment-minister-formally-opens-africas-sustainable-cooling-and-cold-chain-centre/

tonnes by 2030[134]. However, current technology and deployment levels only meet 10% of global heating needs, well below what is needed to achieve net zero emissions by 2050. Further policy support and technical innovation are needed. Finally, it is important to note that heat pumps will be a growing refrigerant consuming segment in the years to come.

Environmentally harmful dumping of cooling equipment is widespread, with additional evidence presented for SE Asia[135].

The TEAP Decision XXXV/11 Lifecycle Refrigerant Management (LRM) Task Force Report has highlighted the value and impact of leak prevention (from design, through to installation, operation and servicing) on equipment EE and proper operation over its lifetime.

The Executive Committee (ExCom) to the Montreal Protocol Multilateral Fund (MLF) adopted decision 91/65 which created a funding window for EE projects. At their 93rd meeting, the ExCom approved 9 non-investment projects, 2 investment projects, and 4 preparation projects totalling over $4.5 million under this funding window as shown in table 6-2.

**Table 6.2 MLF EE funding window projects approved at 93rd ExCom**

| Party | Decision Type: | Funding | Decision Number[136] |
|---|---|---|---|
| Bolivia | Pilot project to maintain and/or enhance the EE of replacement technologies and equipment in the context of HFC phase-down (UNIDO) | $96,000 | 93/79 |
| Ecuador | | $190,000 | 93/80 |
| Egypt | | $285,000 | 93/81 |
| Nigeria | | $145,000 | 93/85 |
| Turkmenistan | | $142,000 | 93/87 |
| Kyrgyzstan | Pilot project to maintain and/or enhance the EE of replacement technologies and equipment in the context of HFC phase-down (UNEP) | $206,000 | 93/82 |
| Mexico | Energy-efficiency strategy for the Kigali HFC implementation plan (UNIDO) | $938,620 | 93/83 |
| Nicaragua | Pilot project to maintain and/or enhance the EE of replacement technologies and equipment in the context of HFC phase-down (non-investment activities) (UNIDO and UNEP) | $96,000 | 93/84 |

134 https://www.iea.org/energy-system/buildings/heat-pumps

135 https://www.clasp.ngo/research/all/pathways-to-prevent-dumping-of-climate-harming-room-air-conditioners-in-southeast-asia/

136 http://www.multilateralfund.org/93/Report%20of%20the%20ninetieth%20meeting%20of%20the%20Executive%20C/1/93105.pdf

| Party | Decision Type: | Funding | Decision Number[136] |
|---|---|---|---|
| South Africa | Pilot project to maintain and/or enhance the EE of replacement technologies and equipment in the context of HFC phase-down (UNIDO): replacement of one HCFC-based chiller and one HFC-based chiller, in the amount of US $350,000 | $350,000 | 93/86 |
| India | Conversion of the manufacturing of commercial refrigeration appliances at Rockwell Industries Limited from HFC-134a to propane (R-290) (technical assistance to enhance the EE of the converted equipment) (UNDP) | $150,000 | 93/89 |
| | Design and development of a pilot scale energy-efficient rotary compressor along with microchannel heat exchanger compatible with R-290 technology at Godrej & Boyce Mfg. Ltd., for use in manufacturing of room air conditioners (Germany) | $1,853,795 | 93/90 |
| Chile | Preparation of a pilot project for the use of R-744 (carbon dioxide) as an alternative refrigerant in heat pumps in industrial refrigeration (UNDP) | $30,000 | |
| Kenya | Preparation for a pilot project on EE (Germany) | $30,000 | |
| Malaysia | Preparation for a pilot project on EE in standalone commercial refrigeration sector (IBRD) | $30,000 | |
| Vietnam | | $30,000 | |
| **Total** | | **$4,572,415** | - |

# 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 potential inclusion of replacements of Montreal Protocol controlled substances in PFAS bans is creating uncertainty for industry regarding the long-term availability of certain alternatives to ODS and HFCs. Some manufacturers 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. 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.

Definitions of PFAS incorporated into potential future regional policies 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). 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. 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 most 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 precautionary restriction of around 10,000 PFAS, submitted in January 2023 by 5 parties, was opened for public consultation by the European Chemicals Agency (ECHA) that would apply to the European Economic Area.[137] ECHA has received thousands of comments during public consultation for review. The Socio-Economic Assessment Committee (SEAC) and Risk Assessment Committee (RAC) is continuing to review the proposal.[138] It has been estimated the process might conclude and bans may enter into force by 2029.

Under the current ECHA 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 (e.g., component or equipment), above certain concentration levels, with these restrictions applying 18 months after entry into force. Two options are considered: one with no derogations and the other with derogations, including time-limited use-specific derogations

[137] Authorities in Denmark, Germany, the Netherlands, Norway and Sweden prepared and submitted the proposal to ECHA on 13 January 2023.

[138] It has been estimated that ECHA might conclude its evaluation by mid-2026 followed by a draft proposal by the European Commission to amend REACH Annex VII for evaluation by the European Council and European Parliament with an expectation of entry into force by H1 or H2 2029.

(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.

The proposed restrictions by ECHA, 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.. Several uses relevant to the Montreal Protocol are proposed to be 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 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 2023, Canada accepted comments during public consultation considering the OECD PFAS definition of approximately 4700 chemicals[139].

The United States Environmental Protection Agency (U.S. EPA) has continued to implement their risk-based approach delineated in the "PFAS Strategic Roadmap: EPA's Commitments to Action 2021-2024"[140]. Some of the actions U.S. EPA has undertaken include evaluating the toxicity of approximately 2500 chemicals in groups based on their chemical make-up, mandating toxicity testing for commercial chemicals to represent each group, where no data is available, enacting drinking water standards for 6 chemicals and requiring funding for pollution remediation cleanup under its CERCLA policy and building an inventory by requiring retroactively reporting of import and production of PFAS chemicals.

For the purposes of inventory development, the U.S. EPA has included chemicals that structurally contain at least one of the following three sub-structures: (1) R-(CF2)-CF(R′)R″, where both the CF2 and CF moieties are saturated carbons; (2) R-CF2OCF2-R′, where R and R′ can either be F, O, or saturated carbons; (3) CF3C(CF3)R′R″, where R′ and R″ can either be F or saturated carbons. This is a narrower PFAS working definition than the EU REACH proposal. The U.S. EPA reporting programme now excludes certain HFCs, HFOs and 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 now provided an extension of its legislative ban[141] until 2040

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[139] 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

[140] 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.

[141] 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.

for the use of all PFAS chemicals, exempting heating, ventilation, air conditioning, and refrigeration equipment and refrigerants, aerosols, foams, metered dose inhalers, and other substances controlled under the Montreal Protocol. Maine defines PFAS 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 and fluoropolymers. Extensions past 2040 could be allowed.

- Minnesota has enacted the same legislation as Maine with a ban in 2032 unless a "currently unavoidable use" exemption is approved. It is, as yet, unclear whether Minnesota may make similar modifications to those made in Maine.

- Other states have proposed nearly identical legislation to the state of Minnesota; 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 in-kind 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, fire suppression agents in use as halon alternatives such as HFCs (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 controlled under the Montreal Protocol, would not be considered PFAS.

As an example, the leading candidate agent to replace Halon 1301 in cargo compartments of civil aircraft (the largest use of Halon 1301 on aircraft) is a 50%/50% blend of 2-BTP and carbon dioxide. The uncertainty of future regulation of 2-BTP as a PFAS is slowing down the development of this agent. Delaying transition to alternatives will prolong reliance on Halon 1301 which in turn would bring the run-out date closer to 2030 for all enduring uses.

A second example is the uncertainty being introduced by classifying the lower GWP fire suppressant FK-5-1-12 as a PFAS. Some 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 Amendment obligations.

A third example 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 plants, military, and oil and gas applications. The additional uncertainly surrounding the high GWP HFCs (except for HFC-23), being 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 organisations, including health and environmental authorities, standard-making organisations 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. 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 is a blend of HCFO-1233zd(E) with FK-5-1-12 but both components could be classified as PFAS. It is understood that the development of this agent has ceased with PFAS regulations being cited as one of the reasons.

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 by proposed PFAS 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 limited 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 pMDIs, propellants HFC-134a, HFC-227ea, and HFO-1234ze(E), that are currently used, under development, or being invested in, could be impacted. The proposed ban 18 months after the entry into force of the restriction is seen as a potential obstacle to the transition of pMDIs from higher-GWP propellants to lower-GWP alternatives. While there were a limited number of derogations, this did not include the use of HFC-134a and HFC-227ea, nor HFOs as propellants in pMDIs. This is leading to industry uncertainty, 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*

The proposed broad-range restrictions on PFAS chemicals could 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 lower GWP alternative refrigerants (which is crucial to meet HFC phase-down targets), (b) limit the EE of medium sized RACHP systems and (c) slow the roll-out of heat pumps (which are much needed to decarbonise heating). These three issues would likely lead to an increase in greenhouse gas emissions from the RACHP sector.

Another complicating issue is the fact that most of the fluoropolymers used as flexible seals and coatings 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. Fluoropolymers are used in many RACHP components, including those in systems using non-fluorocarbon refrigerants such as hydrocarbons.

Uncertainty created by the possible broad-ranging restrictions have spurred investigations of alternative technologies in several RACHP end-uses.

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

One long-time manufacturer[142] 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

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

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.

# 8 Dec XXVIII/2: Technical review of alternatives to HFCs

At their 28th MOP in 2016, the parties to the Montreal Protocol adopted Decision XXVIII/2, "Decision related to the amendment to phasedown hydrofluorocarbons." The Kigali Amendment to phase down HFCs entered into force on 1 January 2019. Decision XXVIII/2 established A5, Group 2 (G2) parties as Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates. All other A5 parties are Group 1 (G1). The compliance schedule for G1 parties is to freeze by 2024 and ultimately phase down HFCs to 20% (80% reduction) of their baseline by 2045, and for G2 parties to have a slower phase-down schedule with a freeze in 2028 and to ultimately phase down HFCs to 15% of their baseline (85% reduction) by 2047.

Decision XXVIII/2 included a request to the TEAP **under paragraph 5** "to conduct a technology review four or five years before 2028 to consider a compliance deferral of two years from the freeze date of 2028 for Article 5, group 2, parties to address growth above a certain threshold in relevant sectors." This chapter, as part of the TEAP 2024 Progress Report, responds to this request for a technical review of alternatives relevant to G2 parties.

## 8.1 Introduction

### *8.1.1 Relevance of September 2022 TEAP Report in response to Decision XXVIII/2, paragraph 4*

**Paragraph 4** of Decision XXVIII/2 included a request to the TEAP "to conduct periodic reviews of alternatives, using the criteria set out in paragraph 1 (a) of decision XXVI/9, in 2022 and every five years thereafter, and to provide technological and economic assessments of the latest available and emerging alternatives to hydrofluorocarbons [(HFCs)]." The text of Decision XXVI/9, "Response to the report by the Technology and Economic Assessment Panel on alternatives to ozone-depleting substances", and specifically the above referenced paragraph 1(a) criteria is as follows:

1. *To request the TEAP, if necessary, in consultation with external experts, to prepare a report identifying the full range of alternatives, including not-in-kind technologies, and identifying applications where alternatives fulfilling the criteria identified in paragraph 1(a) of the present decision are not available, and to make that report available for consideration by the [Open-ended Working Group (OEWG)] at its 36th meeting and an updated report to be submitted to the 27th [Meeting of the Parties (MOP)] that would:*
    a) *Update information on alternatives to [ozone-depleting substances (ODS)] in various sectors and subsectors and differentiating between parties operating under paragraph 1 of [Article 5 (A5)] and parties not so operating, considering energy efficiency, regional differences and high ambient temperature conditions in particular, and assessing whether they are:*
        i. *Commercially available;*
        ii. *Technically proven;*
        iii. *Environmentally sound;*
        iv. *Economically viable and cost effective;*
        v. *Safe to use in areas with high urban densities considering flammability and toxicity issues, including, where possible, risk characterization;*
        vi. *Easy to service and maintain;*

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

In 2022, TEAP prepared a report responding to paragraph 4 of Decision XXVIII/2. Information on alternatives to HFCs contained in that September 2022 report, "Volume 5: Decision XXVIII/2 TEAP Working Group Report: Information on Alternatives to HFCs," was based on the understanding and information available to the relevant TOCs (FTOC, FSTOC, MCTOC, and RTOC) at the time of preparation of the TOCs 2022 assessments, as part of the TEAP 2022 quadrennial assessment report. The September 2022 TEAP report focused on the status of alternatives for HFCs globally in the following sectors: foams; fire suppression; medical and chemical uses; RACHP.

### *8.1.2 Approach on response to Decision XXVIII/2 paragraph 5*

As a one-time assessment, to respond to **paragraph 5** of Decision XXVIII/2, TEAP is providing an updated technical review based on its September 2022 report responding to paragraph 4 of the same decision. The previous technical review focused on the status of alternatives for HFCs globally in the various sectors of use. This report focuses on the status of alternatives in sectors relevant to G2 parties, as requested by the decision. Where the information remains the same as that provided in the 2022 technical review, the reader is referred to the 2022 report for reference. To the extent that updated information was available to the TEAP in the preparation of this review, updated information as well as information that may be specific to G2 parties is noted in the relevant sections. The same sectors are covered in this review with a focus on updates to the refrigeration, air conditioning, and heat pumps sector, as information on other sectors has essentially remained unchanged from the 2022 review. The technical review of these sectors based on updates since the September 2022 report are in the following sections.

TEAP also considered the status of other relevant changes that have occurred since the parties adopted Decision XXVIII/2 in 2016 that are relevant to G2 parties, such as, standards for refrigerants and refrigeration and air conditioning equipment, technology conversion investment and demonstration projects approved, implemented or under implementation, and potential activities included in the 2024-2026 business plan under the MLF.

In accordance with the terms of reference provided by the decision, TEAP provides its technical review of alternatives to HFCs relative to G2 parties. TEAP did not attempt to qualify whether the alternatives will enable G2 parties to achieve certain reductions in HFC consumption by a certain date because such an assessment depends on other factors that are not related to the technical criteria TEAP was requested to assess. In addition, TEAP did not attempt to assess the relative ability of G2 parties to comply with the controls measures to phase down HFCs as adopted by the 28$^{th}$ MOP in 2016. TEAP provides its technical review and defers to parties to consider, or not, any changes to phasedown schedules.

TEAP established a working group from within its membership, including co-chairs of relevant TOCs, as follows:

| WG Member | Affiliation | Country | A5/NA5 |
|---|---|---|---|
| Omar Abdelaziz | RTOC Co-chair | Egypt | A5 |
| Suely Carvalho (Co-chair) | TEAP Senior Expert | Brazil | A5 |
| Sukumar Devotta | TEAP Senior Expert | India | A5 |
| Takeshi Eriguchi | MCTOC Co-chair | Japan | NA5 |
| Ray Gluckman | TEAP Senior Expert | UK | NA5 |
| Marco Gonzalez | TEAP Senior Expert | Costa Rica | A5 |
| Sergey Kopylov | FSTOC Co-chair | Russian Fed. | NA5 |
| Bella Maranion (Co-chair) | TEAP Co-chair | USA | NA5 |
| Marta Pizano | TEAP/MBTOC Co-chair | Colombia | A5 |

| | | | |
|---|---|---|---|
| Fabio Polonara | RTOC Co-chair | Italy | NA5 |
| Helen Walter-Terrinoni (Co-chair) | FTOC Co-chair | USA | NA5 |
| Shiqiu Zhang | TEAP Senior Expert | China | A5 |

TEAP is grateful for the efforts of the Working Group (WG) members. TEAP also appreciates the contributions of the following RTOC experts to the WG: Bassam Elassaad (Lebanon) and Mary Koban (USA).

The WG conducted its work electronically and through virtual meetings.

### 8.2 Information on alternatives for HFCs in the refrigeration, air conditioning, and heat pumps sectors relevant to G2 parties

This section focuses on the status of alternatives in the RACHP sectors relevant to G2 parties. Where the information remains the same as that provided in the previous technical review, the reader is referred to the September 2022 report. This section discusses criteria on alternatives relevant to G2 parties, and where information from the 2022 report is updated, these are noted.

In responding to paragraph 5 of Decision XXVIII/2, TEAP considered the relevant factors to determine the availability of refrigerant alternatives to G2 parties. There are some commonalities among G2 Parties but not unique enough to form a distinct requirement for this group. Some of the commonalities include:

- Most G2 parties had manufacturing enterprises producing RACHP units, with local or mixed ownership, and with varying capabilities for research and development;
- At least one G2 party, India, manufactures components that are used for building units such as compressors or motors;
- Manufactured units are mostly sold locally, but some parties have significant output made for export and needs to respond to the importing parties' requirements,
- All the G2 parties are in a geographical region with similar climatic conditions although one party, India, is not defined as a high ambient temperature (HAT) party as per the definition set by Decision XXVIII/2, paragraph 29;
- All G2 parties have Minimum Energy Performance Standards (MEPS) in place; however, the MEPS are not harmonised and use different temperature settings for the efficiency ratings with different minimum efficiency levels;
- G2 parties are at varying stages of HCFC phaseout with some more advanced than the Montreal Protocol control targets;
- Due to the HCFC phase-out, by 2024-the use of HCFC refrigerants in A5 parties has significantly decreased;
- All G2 parties import HFC-based units across most RACHP applications.

Based on the above commonalities, TEAP considered how to make the criteria listed in Decision XXVI/9 paragraph 1(a) relevant to RACHP equipment used by G2 parties. The following are some distinguishing factors to the criteria used in the TEAP 2022 alternatives report that are relevant to RACHP:

A. For the criterion of **commercial availability** which considers both availability and accessibility of refrigerants and RACHP products, TEAP recognises that some refrigerants that are commercially available globally are not necessarily accessible in all Article 5 parties. TEAP did not find a distinguishing factor for G2 parties in this criterion.

B. On the criterion of **technically proven**, TEAP considers that it is possible to produce a system using certain refrigerants that are accessible and technically proven in non-A5 parties whilst the local industries or consumers in G2 parties might have reservations in accepting the product. There can be many reasons including that the product is not tested for safety as per some international standards, lack of regulations, market push back, lack of spare parts, lack of adequate training, and flammability or toxicity issues.

   Another factor that was considered by TEAP is the applicability to HAT conditions. Even though India is not listed as a HAT party, yet still it has local regions that experience HAT conditions and require HAT compatible products. HAT compatibility is related to EE and cooling capacity, both of which degrade with the increase in ambient temperature, especially for air-cooled products.

C. For the criterion of **environmentally sound**, TEAP recognises that environmental soundness is a relative term and can depend on the geographical region. There are variations that are a factor of either policy and local legislation or of certain industry trends that are specific to some parties. G2 parties are in the mainstream of environmental stewardship particularly since the region's hosting of COP 28 and its breakthrough decisions. TEAP did not find a distinguishing factor for G2 parties in this criterion.

D. For the criterion of **economically viable and cost effective**, TEAP recognise that industrialised A5 parties might find some substances viable, or mandatory, for export but not for the local market[143]. TEAP did not find a distinguishing factor for G2 parties in this criterion.

E. The criterion of **safe to use in areas with high urban densities** addresses the fact that some of the A5 parties have still not adopted international standards, while in others even if the standard is accepted, it is not mandatory. The criterion also addresses the question of whether those parties have facilities for testing and the capabilities to test as per the standards. At higher ambient temperatures the capacity of air-conditioning equipment may need to be larger depending on the room size, which limits refrigerant charge with flammable refrigerants.

F. On the criterion of **ease to maintain or service**, TEAP recognise that all A5 parties may require training and mandatory certification procedures (e.g., prescribing a minimum set of tools required for servicing flammable refrigerants). The 2024 TEAP Decision XXXV/11 Lifecycle Refrigerant Management Task Force Report categorises leak minimisation techniques by groups of parties based on their consumption. G2 parties fall within three groups of higher consumption brackets and share common characteristics with the other parties in those brackets.

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[143] An example is India, which is a manufacturing hub for passenger vehicles by many global multinational companies. Those companies continue to use HFC-134a for vehicles manufactured for the local market even though their parent companies might have switched to HFO-1234yf. In India, the cost involved for refill with HFO-1234yf is now as much as 5-10 times more expensive than that of HFC-134a. India might also consider manufacturing passenger vehicles for export using HFO-1234yf; however, that may not enable India to switch all its production to that substance.

Another factor is related to the difficulties facing technicians operating at HAT conditions and their wellbeing. TEAP concluded that these conditions occur irrespective of the substance used and that flammability of the refrigerant does not pose a higher risk at those conditions. TEAP did not find a distinguishing factor for G2 parties in this criterion.

Having taken all the above criteria into consideration for G2 parties, the only distinguishing criterion for accessibility in G2 parties is whether refrigerants are technically proven. TEAP reviewed and reconstructed the tables from the September 2022 TEAP report for RACHP applications for all parties.

The tables were reconstructed by listing the applications for each category of products and addressing the alternatives that are technically proven and globally available. Then listing the accessibility of G2 parties to those alternatives in the third column. The third column describes the degree of accessibility in terms of limited use, growing use, or widespread use.

The 2022 TEAP report refers to the same eight RACHP product categories that were included in the RTOC 2022 Assessment Report.[144] As an example, for the factory-sealed refrigeration category, there are three applications: a) domestic refrigerators and freezers, b) commercial plug-ins, and c) heat pump tumble dryers.

TEAP listed the lower GWP alternatives in groups as follows:

- **Non-Montreal Protocol controlled substances**: These substances have very low to zero GWP and zero ODP and include ammonia (R-717), hydrocarbons (HCs), $CO_2$ (R-744), HFOs & HCFOs.
- **A2L refrigerants**: these are mildly flammable A2L (A2L refers to the safety class of refrigerants as defined in RTOC assessment report) and include HFC-32 and various HFC-HFO blends, with GWPs[145] between 140 and 1,100.
- **A1 refrigerant blends**: these are non-flammable (A1 safety class) HFC or HFC-HFO blends with GWP that can exceed 1,100.
- **Refrigerants currently "under consideration"** refers to refrigerants that are either under development, testing, or have not been commercialised yet globally. These refrigerants are consequently not accessible to G2 parties but are listed here for information and to complete the picture of the refrigerants that might be available at a point in the future.

[144] Details of the refrigerant characteristics, including GWP, are listed in the RTOC 2022 Quadrennial Assessment Report in Annex I to chapter 3 (tables 3.I.1 and 3.I.2).

[145] GWP values are those used in the Kigali Amendment of the Montreal Protocol.

**Table 8.1 Factory sealed domestic and commercial refrigeration appliances**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Domestic refrigerators and freezers | **Non-Montreal Protocol controlled substances, available**<br>HC-600a | Widespread use of HC-600a in most G2 parties |
| Commercial plug-in refrigeration | **Non-Montreal Protocol controlled substances, available**<br>HC-290<br>HC-600a<br>**A2L Refrigerant blends, some use, including.**<br>R-454C<br>R-455A | Growing use of HCs in some G2 parties |
| Heat Pump Tumble dryers | **Non-Montreal Protocol controlled substances**<br>Recent introduction of hydrocarbon HC-290<br>**A1 Refrigerant blends, available**<br>R-450A<br>R-513A | Little use of this application in G2 parties |

Note:

1. There are no substantial differences in terms of equipment design between geographical regions. In most cases the same refrigeration units are transported to and operated in different climates.

**Table 8.2 Food retail and food service refrigeration**

| Application | Global alternatives to high GWP HFCs | Accessibility in A5 G2 parties |
|---|---|---|
| Condensing Units | **Non-Montreal Protocol controlled substances, available**<br>R-744, HC-290 | Growing use of all these options in some G2 parties |
| | **A2L, Refrigerant blends – available, including:**<br>R-454C<br>R-455A | |
| | **A1 Refrigerant blends - available, including:**<br>R-448A<br>R-449A<br>R-450A<br>R-513A | |
| Distributed systems | **Non-Montreal Protocol controlled substances - available**<br>R-744 | Growing use of all these options in some G2 parties |
| | **A2L Refrigerant blends - available, including:**<br>R-454C<br>R-455A | |
| | **A1 Refrigerant blends - available, including:**<br>R-448A<br>R-449A<br>R-450A<br>R-513A | |
| | **Various refrigerants currently under consideration, including:**<br>R-457A<br>R-454A<br>R-449B<br>R-407H<br>HFO-1234yf<br>HFO-1234ze(E) | Not accessible in G2, or globally |
| Large Central Systems | **Non-Montreal Protocol controlled substances available:**<br>R-744<br>R-717 is only available with secondary systems. | Growing use of all these options in some G2 parties |
| | **A1 Refrigerant blends, available, including:**<br>R-448A<br>R-449A<br>R-450A<br>R-513A | |

**Table 8.3 Transport refrigeration**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
| --- | --- | --- |
| Truck, trailers, light commercial vehicles (vans) | **Non-Montreal Protocol controlled substances available:**<br>HFO-1234yf for light commercial vehicles only | Little or no current use in most G2 parties |
| | **A1, HFC-HFC Blends available:**<br>R-452A | Little or no current use in most G2 parties |
| | **Various refrigerants currently under consideration, including:**<br>R-744<br>HC-290 | Not accessible in G2, or globally |
| Marine containers | **Non-Montreal Protocol controlled substances, available:**<br>R-744 | Containers are used for international trade; hence the available options are used in G2 parties |
| | **A1 blends available, including:**<br>R-513A<br>R-452A | |
| | **Various refrigerants currently under consideration, including:**<br>R-473A for ultra-low temperature applications<br>HC-170 for ultra-low temperature applications | Not accessible in G2, or globally |
| Ships (refrigeration and comfort cooling) | **Non-Montreal Protocol controlled substances, available:**<br>R-717<br>R-744 | Many ships are used internationally; hence the available options are used in some G2 parties |
| | **A1, Refrigerant blends, available**<br>R-513A | |
| | **Various refrigerants currently under consideration, including:**<br>R-473A for ultra-low temperature applications | Not accessible in G2 parties, or globally |
| Rail air conditioning | **A1, Refrigerant blends, available**<br>R-513A | Little or no current use in most G2 parties |

Note: There are no substantial differences in terms of equipment design between regions. In many cases the same refrigeration units are transported to and operated in different climates. The main differences are related to regulations (i.e., GWP, diesel emissions) and lower-GWP refrigerant availability. Some of the low-GWP refrigerant options are not accessible in some A5 Group 1 and G2 parties.

**Table 8.4 Air-to-air air conditioners and heat pumps**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Small Self-Contained AC<br>Window units<br>Charge limitations apply | **Non-Montreal Protocol controlled substances available:**<br>HC-290 | Limited use in G2 parties |
| Small Split AC (<12 kW)<br>Non ducted split<br>Ducted split<br>Packaged ducted<br>Charge limitations apply | **Non-Montreal Protocol controlled substances available:**<br>HC-290<br>HC-1270<br>HFO-1234yf<br>HFO-1234ze(E) | Limited use in G2 parties |
| | **A2L, Refrigerants available:**<br>HFC-32<br>R-454B | Growing use of all these options in some G2 parties |
| | **Various refrigerants currently under consideration, including:**<br>HFC-161<br>HFC-152a<br>R-511A<br>R-457A<br>R-455A<br>R-459A<br>R-454A | Not accessible in G2, or globally |
| Larger Split and Packaged AC (>12 kW)<br>Non ducted split<br>Ducted split | **Non-Montreal Protocol controlled substances available:**<br>HFO1234yf<br>HFO-1234ze(E) | Accessible in most G2 parties, but extent of use is unknown |

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Multi split<br>VRF<br>Packaged ducted<br><br>Charge limitations apply | **A2L, Refrigerants available:**<br>HFC-32<br>R-454B | Growing use of all these options in some G2 parties |
| | **Various refrigerants currently under consideration, including:**<br>HFC-161<br>HFC-152a<br>R-511A<br>R-457A<br>R-455A<br>R-459A<br>R-454A | Not accessible in G2, or globally |

Note: Air-to-air conditioners, including reversible air heating heat pumps (generally defined as reversible air conditioners), range in size from 1 kW to 750 kW although the majority are less than 70 kW.

**Table 8.5 Applied building cooling systems**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Small chillers<br>Charge limitations apply | **A2L, Refrigerants**<br>HFC-32<br>R-454B<br>R-452B | Growing use of all these options in some G2 parties |
| Large chillers | **Non-Montreal Protocol controlled substances**<br>R-718 (water) very large chillers<br>R-717 (ammonia)<br>HCFO-1233zd(E) for large centrifugal chillers<br>HFO-1234ze(E) for screw and centrifugal chillers<br>R-514A for large centrifugal chillers<br>HFO-1224yd(Z) for centrifugal chillers | Growing use of all these options in some G2 parties |

Note: Even though HCFO-1233zd(E) is not a Montreal Protocol HFC controlled substance, it has a very small ODP.

**Table 8.6 Mobile AC/HP**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| All applications; passenger cars, buses and trucks | **Non-Montreal Protocol controlled substances**<br>HFO-1234yf<br>R-744 | Growing use of HFO-1234yf in imported cars in some G2 parties |
| | **Various refrigerants currently under consideration, including:**<br>HC-290<br>R-513A | Not accessible in G2, or globally |

**Notes:**

1. All the above refrigerants are applicable to passenger cars and buses. They require skilled personnel to service them.
2. The deployment of highly electrified vehicles (plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV)) in Europe, China, India, and North America will lead to the implementation of heat pump systems and of a new generation of thermal systems. Manufacturers are working on the improvement of this feature by using cycle variations such as economiser coupled with vapour injected compressors.
3. R-744 is increasingly applied in fully electrified vehicles due to its good performance when operating as a reversible heat pump. However, R-744 is less suitable in hot and humid climates where EE is somewhat lower than that of HFC-134a and HFO-1234yf systems.
4. All refrigerants can be used at HAT conditions. R-744-based systems could show lower efficiency.

**Table 8.7 Industrial refrigeration**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Small industrial chillers | **Non-Montreal Protocol controlled substances**<br>HC-600a<br>HC-290 | Growing use in G2 parties |
| | **A2L, Refrigerants, available**<br>HFC-32<br>R-454C<br>R-455A<br>R-454B<br>R-452B | Growing use in G2 parties |
| Small industrial distributed systems and heat pumps | **Non-Montreal Protocol controlled substances**<br>HC-290 | Growing use in G2 parties |
| | **A2L, Refrigerants, available**<br>HFC-32<br>R-454C<br>R-455A | Growing use in G2 parties |
| | **A1, Refrigerant blends - available**<br>R-448A<br>R-449A<br>R-450A<br>R-513A | Limited use in some G2 parties |
| Medium & large industrial chillers | **Non-Montreal Protocol controlled substances**<br>R-717<br>R-744<br>HFO-1234ze(E)<br>R-718 (water) has temperature limitations<br>HC-170 used in petroleum industries | R-717 Accessible and used in most G2 parties<br>R-744 Growing use in large and medium sized industrial applications. Special technology enables use in warm climates. |

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| | HC-1150 used for temperatures from -80 ºC to -110 °C<br>HC-1270 | |
| | **A2L, Refrigerants, available**<br>HFC-32<br>R-454C<br>R-455A | Growing use in most G2 parties |
| Medium and large industrial distributed systems and heat pumps | **Non-Montreal Protocol controlled substances**<br>R-717<br>R-744<br>HCFO-1233zd(E) – Has some ODP | Growing use in most G2 parties |
| | **A2L, Refrigerants, available**<br>HFC-32<br>R-454C<br>R-455A | Growing use in most G2 parties |
| | **Various refrigerants currently under consideration, including:**<br>HFO-1336mzz(Z) | Not accessible in G2, or globally |

Notes:

1. R-717 and R-744 are the dominant options for large industrial systems (e.g., in food and drink manufacturing and bulk cold storage), with hydrocarbons used in some large specialised applications (e.g., in the petrochemical industry).
2. ISO 5149 and EN 378 require skilled workers with certain competence to service large industrial systems; their competence is defined by ISO 22712. Additionally, technician certification according to national norms and regulations is needed. There are no such requirements for systems containing less than 3 kg charge.
3. It is noteworthy that safety aspects are yet to be applied in most A5 parties including those of G2.

**Table 8.8 Heating only heat pumps**

| Application | Global alternatives to high GWP HFCs | Accessibility in G2 parties |
|---|---|---|
| Monobloc heat pump | **Non-Montreal Protocol controlled substances**<br>HC-290 | Limited use of the application in G2 parties |
| Domestic water heating | **Non-Montreal Protocol controlled substances**<br>R-744 | Limited use of the application in G2 parties |
| Monoblock and split heat pump | **A2L, Refrigerants**<br>HFC-32<br>R-454B | Limited use of the application in G2 parties |

Notes:

1. Heating only heat pumps are air-to-water systems used for space heating and for domestic hot water.
2. Safety constraints restrict the use of HC-290 to monobloc units located outdoors, if charge is higher than 150 grams, or indoor systems with ventilated cabinets (charge up to 500 grams).

## 8.3 Information on alternatives for HFCs in the foams sector

This section focuses on the status of alternatives in the foams sector. The information remains essentially the same as that provided in the 2022 technical review, so the reader is referred to the 2022 report for further reference.

In the 2022 report, TEAP noted that HFC alternative foam blowing agents (FBAs) in the foams sector are already in use with most providing necessary technical benefits to the foams end-product. Some characteristics are specific to the FBA, including commercial availability; environmental soundness, or economic viability and cost effectiveness, and safe for use in areas with high urban densities (considering flammability and toxicity issues, including risk evaluation). However, the technical performance of FBAs is specific to the end-use. Some specific concerns are identified with safety of FBAs in certain situations with specific foam types. Historically, the transition from CFCs led to a significant fragmentation of the FBA market because no substitutes have the same technical properties and low cost of CFCs. Each sub-segment required a different FBA for optimal performance, with regional and national variations.

As in 2022, no single FBA will likely be optimal for all sub-segments of foam applications in the future, with an increasing variety of FBA choices available. The overwhelming majority of the foam in appliances utilises hydrocarbon FBAs, but some companies are using HFCs or HFOs or HCFOs to meet mandated EE levels. Several companies are also considering blends of HFCs or HFOs/HCFOs with HCs or methyl formate to optimise performance characteristics with cost. Finally, water content in FBA blends has increased in many situations to reduce costs and, in rare cases, enhance performance with at least one HFO/HCFO.

Updated information to that contained in the 2022 report is noted below, with potential impact for all parties including those in G2.

- HFC-365mfc has been reported as no longer commercially available with production ceasing in September 2023. Although there may be some HFC-365mfc available in supply chains, no reports of new manufacture are known, and this alternative will not be commercially available once stocks are exhausted.

## 8.4 Information on alternatives for HFCs in the fire suppression sector

This section focuses on the status of alternatives in the fire suppression sector. The information remains essentially the same as that provided to the parties in the 2022 technical review and the 2022 FSTOC Assessment Report, so the reader is referred to those reports for further reference.

In the 2022 reports, TEAP provided information where alternatives to HFCs are available for fire protection applications in the following sectors of use: civil aviation; military ground vehicles, naval, and aviation applications; oil and gas; general industrial fire protection, and merchant shipping. TEAP noted that the evolution of alternatives has proceeded along the path of selection of chemicals with the most similar characteristics to halons followed by research and development including testing, certification, toxicity and safety analyses, standards development, and commercialization. In that process, several HFCs were developed through to commercialisation (note: both the agent and hardware must successfully pass all testing and certifications). Following the commercialisation of HFCs, development of further alternatives continues, and other chemicals were developed including FK-5-1-12, 2-BTP, CF3I, and some combinations with inert gases, water mist, or solid particulates. This evolution has been fairly linear, in that the most likely candidates have become the most commercially viable due to the extensive cost of research and development.

The technical review shows that G2 parties face the same barriers to the use of lower GWP alternatives for fire suppression that also apply to Article 5 Group 1 parties.

Updated information to that contained in the 2022 report is noted below, with potential impact for all parties including those in G2.

- FK-5-1-12 may become affected by proposed PFAS regulations and definitions in the EU and other parties.
- Added clarification is needed for water mist which was described as “easy to service”. When the systems are provided in locations with easy access to a potable water source, water mist is easy to service. However, for remote locations, (e.g., oil and gas sector on remote platforms), the requirement to fully discharge the water mist system cylinders and then refill them can become cumbersome and potentially hazardous. Most manufacturers have all moved away from a large static storage tank and are now only offering cylinders even though the main manufacturer reports that tanks can be used.

## 8.5 Information on alternatives for HFCs in medical and chemical uses

In the 2022 report, TEAP provided information on alternatives for HFCs for the following medical and chemical uses: aerosols (consumer, technical, and medical), metered dose inhalers (MDIs), solvents, semiconductor and other electronics manufacturing, and magnesium production. The information on the status of alternatives in the medical and chemical sectors remains the same as that provided in the 2022 technical review, so the reader is referred to the 2022 report for reference.

For information on the most recent market developments for MDIs, the reader is referred to the 2024 TEAP Progress Report, which states:

*“Although the Kigali Amendment allows Article 5 parties longer to phase down HFCs, global legislation and corporate policies of major pharmaceutical companies may accelerate the introduction of lower GWP [pressurised MDIs (pMDIs)] in Article 5 parties well before their scheduled phase down timeline. Pharmaceutical companies may market their lower GWP pMDIs globally at the earliest opportunity, rather than latest. This could potentially mean lower GWP pMDIs are available in Article 5 parties from 2026 onwards. The reduction in use of HFCs in Europe/United States may lead to concerns over security of supply and commercial pricing for Article 5 parties, including India."*

The technical review shows that G2 parties face the same specific concerns on the use of lower GWP alternatives for medical and chemical uses that also apply to G1 parties.

## 8.6 Information on standards, technical regulations, and codes

International standards are developed under the International Organization for Standardization (ISO) and the International Electrotechnical Committee (IEC), as agreed upon by the World Trade Organization (WTO). These international standards are used to derive national standards under standards developing organisations (SDOs). Standards may be adopted with changes, known as national differences. Technical committees (TCs) are responsible for updating international and regional or national standards.

Industry standards, technical regulations (e.g., Global Harmonized System) and building codes have been updated to reflect industry research and mitigation for new refrigerants since 2016. Over the last 15 years, extensive research has confirmed the availability of lower GWP alternatives to HFCs in the different applications and the accessibility of parties to these alternatives. The updated standards have been adopted in several parties as noted below. As the industry moves from conventional high GWP products like R-410A toward lower GWP refrigerants like HFC-32 or R-454B, the safety classification of refrigerants are changing. (Note: ISO 817 safety classification for R-410A is A1 while HFC-32 and R-454B are A2L.) Lower GWP refrigerants typically have a higher level of flammability. Therefore, equipment and installation standards need to be updated to adequately incorporate these changes.

Standards serve many purposes. For example, standards can provide a minimum performance level or a minimum safety level. As applied in this section, standards will refer to those that set a minimum safety level. Generally, there are two types of standards. Standards that cover a broad range of products or applications are known as horizontal standards. ISO standards are examples of horizontal standards. Standards that focus on a specific product or application are known as vertical standards. IEC standards are examples of vertical standards and generally cover equipment design.

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS)[146] now differentiates between classes of flammable fluids based on lower flammability level or flame speed. GHS provides guidance for the handling, storage and shipping of refrigerants and other fluids. The upgraded GHS guidance has been incorporated into national and local mandates and building codes (e.g., national transportation requirements and local code requirements for refrigerant storage in warehouses).

The primary mitigation strategy employed by the equipment or installation standards for flammable refrigerants is to segregate flammable mixtures from “competent ignition sources”. ISO class A2L (lower toxicity, lower flammability refrigerants) flammable mixtures were tested with known ignition sources for other flammable mixtures.[147] The study concluded that the vast majority of common household ignition sources would not ignite A2L refrigerants and identified the few competent sources, including very high energy electrical energy, not found in any of the common household electrical appliances tested in the study.

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[146] The UN-managed GHS provides a single set of harmonised criteria for classifying chemicals according to their health and physical hazards and specifies hazard communication elements for labelling and safety data sheets. It aims at ensuring that information on physical hazards and toxicity from chemicals be available in order to enhance the protection of human health and the environment during the handling, transport and use of these chemicals. The GHS also provides a basis for harmonisation of rules and regulations on chemicals at national, regional and worldwide level, an important factor also for trade facilitation. See https://unece.org/about-ghs.

[147] Kim and Sunderland 2018 *“Viability of Various Ignition Sources to Ignite A2L Refrigerant Leaks”*

Standards also limit refrigerant charge sizes and set out requirements to mitigate releases (e.g., measures to reduce concentrations) to minimise the likelihood and duration of flammable mixtures based on research into characteristics of refrigerant leaks of both A2L and higher flammability, ISO A3 refrigerants.

Standards, regulations and building codes have been updated since 2016 incorporating learnings from company and industry sponsored research including upgrades to:

- Refrigerant safety classification: ISO 817
- Equipment design requirements (e.g., IEC 60335-2-24. IEC 60335-2-34, IEC 60335-2-40, IEC 60335-2-89, IEC 60335-2-104)
- Installation and applied system requirements (e.g., ISO 5149, ASHRAE 15)

Some examples of equipment and components covered by standards include the following:

- Compressors
- Commercial refrigerating appliances
- Heat pumps, AC units and dehumidifiers, including chillers
- Ice-cream appliances/ice makers
- Packaged AC systems
- Refrigerant recovery equipment

Examples of standards and more details can be found in Annex 2.

Several G2 parties participate in the Gulf Cooperation Council (GCC) Standards Organization (GSO) (Bahrain, Kuwait, Oman, Qatar, Saudia Arabia, and UAE). Equipment is tested by a nationally recognized testing laboratory (NRTL) to meet G mark certification[148] requirements and actively certify equipment to the IEC 60335-2-40 standard or a deviation of these standards. (https://www.intertek.com/product-certification-marks/gmark-electrical/). Some national standards (e.g., ASHRAE 15) have been adopted by G2 parties.

## 8.7 Information on relevant Multilateral Fund (MLF) activities related to the Kigali Amendment

Since 2016, a number of relevant technology conversion and demonstration projects were approved, implemented or under implementation by G2 parties under the MLF. Examples relevant to some projects of G2 parties funded by the MLF since 2016 are provided in Annex 3. Information is also provided on relevant, planned activities for G2 parties included in the Adjusted Consolidated Business Plan for the MLF 2024-2026.[149] This information is in Annex 4.

The TEAP Decision XXVIII/2, paragraph 5 WG co-chairs invited the MLF Secretariat (MLFS) to contribute with information that will enable parties to better understand the current situation of G2 parties with respect to MLF support and relevant technology conversion activities. Only A5 parties that ratify the Adjustments or Amendments of the Montreal Protocol are eligible to receive financial support from the MLF for phaseout or phase-down of related controlled substances. India and the

[148] The Gulf Mark (G Mark) for Low Voltage Electrical Products and Appliances https://www.intertek.com/product-certification-marks/gmark----electrical/

[149] Available at: http://www.multilateralfund.org/default.aspx

UAE are the only G2 parties to have ratified the Kigali Amendment (as of 19 April 2024). The UAE is not receiving assistance from the MLF. The invitation requested information on relevant projects approved and implemented since 2016 in G2 parties. These activities could include projects on alternatives to HFCs in the RACHP sector that may be used to convert high GWP HFCs to lower GWP, or not-in-kind technologies in demonstration projects or any other conversion projects that have used such alternatives in G2 parties.

The co-chairs requested information particularly on the following RACHP applications as relevant to G2 parties:

- Factory-sealed domestic and commercial refrigeration appliances
- Food retail and service refrigeration (larger systems)
- Transport refrigeration
- Applied building cooling systems
- Mobile air conditioning/heat pumps
- Industrial refrigeration
- Heating only heat pumps

For other sectors, as per paragraph 5 of the decision, the WG requested the MLFS to share information, if available.

The MLFS promptly provided the list of projects since 2016 for G2 parties and clarified that the information provided is from its inventory of projects and that the MLFS was unable to sub-divide the information as per the specific subsectors outlined in the WG request. Instead, subsectors used by MLFS were provided in the inventory.

Regarding the request for results of demonstration and conversion projects to lower GWP alternatives, that is, indication of project success if completed and any issue encountered in the conversion and technology uptake, the MLFS could not provide a clear assessment of the project's impact, or the challenges encountered during implementation but did provide remarks on the progress. The MLFS plans to collect more information, especially on issues encountered in the conversion and technology uptake.

The information received is in Annex 3. Examples of relevant HFC phasedown MLF demonstration and investment projects are listed, as of 2016.

G2 parties that requested implementing agencies to include potential activities in the Adjusted Consolidated Business Plan of the MLF 2024-2026 are: India, Oman, Pakistan, Iran, Qatar, and Iraq. Among all G2 parties receiving assistance from the MLF, only India has ratified the Kigali Amendment. UAE has also ratified but does not receive MLF assistance. A summary is provided in Annex 4.

### 8.8 HFC consumption data reported by some G2 parties

Some G2 parties have reported HFC consumption as in Table 8.9: India (for years 2021 and 2022); Oman (for 2019, 2020, 2021, and 2022); Pakistan (for 2019 and 2020). It is important to note that for G2 parties the HFC baseline period is 2024-2026.

**Table 8.9 Reporting for HFC consumption[150] by some G2 parties (metric tonnes $CO_2$ equivalent) (as of 4 March 2024)**

| Party | 2019 | 2020 | 2021 | 2022 | Ratification of Kigali Amendment |
|---|---|---|---|---|---|
| India | | | 41,787,290 | 57,219,531 | Yes |
| Oman | 1,988,072 | 1,821,602 | 2,185,789 | 2,089,387 | No |
| Pakistan | 7,435,247 | 9,456,060 | | | No |

[150] Available at: https://ozone.unep.org/countries/data-table?report_type=0&output_type=odp-CO2e-tonnes&party_grouping=individual&article5%5Bis_article5%5D=is_article5&group%5B%5D=10&period_start=1986&period_end=2023&ignore_zero=1&baseline=1&group_by=group&op=GENERATE+REPORT&form_id=ozone_country_data_form__report_table_form

# 9 TEAP Organisational and Other Matters

This section includes information on adherence to TEAP's Terms of Reference (TOR) related to nominations and appointments of experts to the TEAP, its TOCs and Temporary Subsidiary Bodies (TSBs) as well as organisational matters and ongoing planning considerations related to the Panel's work for parties.

## 9.1 Decision XXXI/8: TEAP Terms of Reference – procedures relevant to nominations

The role of TEAP and its TOCs continues to evolve in meeting the current needs of parties. The parties have placed significant importance on the TEAP's TOR and on the smooth operation of this body of experts towards achieving the parties' goals of the Montreal Protocol. TEAP is successfully implementing the TOR including: a review of membership and reappointment process throughout all the TOCs; developed guidelines for nominations to the TOCs; developed a standardised disclosure of interest/conflict of interest online forms guidance and enforcement; standardised the practice of reviewing TOR requirements with members at the opening of each TEAP, TOC and TSB meetings.

TEAP members have a broad experience of collective responsibility and of consensus building. Their collective know-how includes understanding the history of the Protocol, its decisions, its issues, and the way in which the technical outputs developed by the TOCs and the TEAP underpin the Protocol. This is in addition to the individual technical expertise each member brings to the Panel. TEAP and its TOCs continue to review membership and work to identify the needed expertise to meet current and new demands relevant to decisions, including HFC phase-down with the implementation of the Kigali Amendment. TEAP continues its efforts in achieving A5 and non-A5 balance, considering geographical and gender balance. TEAP looks to the continuing support of parties to identify experts based on its matrix of needed expertise and to ensure that those experts are able to fully participate in the activities and work of the TEAP and its TOCs for parties.

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 is continuously working to identify appropriate expertise and find qualified candidates who are interested and available to serve. TEAP takes into consideration its current and anticipated workload, its current pool of experts with the potential loss of expertise through attrition or lack of financial 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.

As reported in previous progress reports, to facilitate the submission of nominations by the parties, the terms of reference instruct the Panel and its TOCs to draw up guidelines for the nomination of experts. It is stipulated that "the TEAP/TOCs will publicize a matrix of expertise available, and the expertise needed in the TEAP/TOCs 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 5 of this report provides updated TOC membership lists, including the current terms of appointment for all members. Each TOC describes the expertise generally needed to support the work of the TOC. Annex 6 provides the matrix of needed expertise currently sought by TEAP and its TOCs.

The TOR specifies 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 MOP 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). The same requirements apply to Senior Experts, members of the Panel who provide "specific expertise not covered by the TEAP co-chairs or TOC co-chairs" (TOR 2.1.1).

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

### *9.1.1 Nominations and appointment decisions*

Ensuring relevant and sufficient technical expertise is the priority consideration for the Panel and its TOCs. The need to maintain a reasonable size and balance, to avoid the duplication of expertise and to ensure that gaps in expertise are filled, means that experts nominated by parties may sometimes be declined or that their consideration may be deferred by the TOC 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 standardized nomination form (Annex 7), that may include a curriculum vitae, and which is also available on the TEAP webpage on the Ozone Secretariat's website[151]. If information is not already included in the curriculum vitae of the nominee, the standardized form requests relevant information such as education and other qualifications, relevant employment history, publications, awards, memberships, and references.

It is helpful when there is prior consultation between the parties and the co-chairs of the Panel and/or the relevant TOC on potential nominations for the positions of co-chairs of the Panel or the TOCs. In

[151] Link to nomination form available on TEAP webpage at: https://ozone.unep.org/science/assessment/teap

the case of nominations or nominations for reappointment for the position of members in a TOC, the TOC co-chairs consult with the Panel co-chairs and the relevant national focal points.

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

As specified in section 2.3 of the TOR, upon nomination by the relevant party, parties appoint members of the panel (TEAP co-chairs, TOC co-chairs, and Senior Experts) 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."

### 9.2 Organisational matters

TEAP has continued to maintain or have access to the expertise, experience, and capacity to provide the parties with the technical and economic information they need to further the goals and objectives of the Montreal Protocol through reports, presentations, analyses, and recommendations as requested by parties. The expertise and structure of TEAP and its TOCs have changed during its history in order to address its workload at the time. For example, this has evolved significantly to meet the new issues related to the Kigali Amendment (for example HFC alternatives, EE, refrigerant lifecycle management). TEAP continues to review its organisation and structure to ensure that TEAP and its TOCS are structured in size and expertise to support future efforts of the parties to phase out ODS and phase down HFCs.

TEAP notes some of the challenges to its work over the past few years:

- The COVID pandemic required Montreal Protocol processes to adapt and many of those changes have become the norm (e.g., online shared report development, hybrid meetings), raising challenges for TEAP in achieving consensus and engagement on its work virtually.
- The overlap of the ODS phaseout and HFC phasedown regimes have significantly expanded the scope of discussions and decisions that need to be taken by parties under the Montreal Protocol; as a result, TEAP's workload has expanded substantially not only to respond to standing decisions but also to new decisions, all within the same timeframes required for OEWG and MOP documents.
- TEAP and TOC memberships showcase world-leading technical experts in their field, however there is concern with the limited availability and growing lack of financial support for experts that have key historical knowledge and experience under the Montreal Protocol to continue.
- Balancing the need for new experts while maintaining the same level of independent technical and economic expertise for our work for parties becomes challenging in ensuring new experts are educated in TEAP's TOR, annual disclosure and conflict of interest requirements, process for consensus, and processes for developing, reviewing, and presenting reports.

We are still seeing some longer-term impacts on TEAP/TOC activities stemming from the lack of face-to-face meetings during the COVID pandemic, especially to its consensus-based process in preparing its reports. Consensus requires mutual respect and trust – and it is hard to develop and maintain that culture without meeting face to face, especially for new members. TEAP/TOCs can function in part through a greater number of on-line meetings, but they are necessarily shorter to enable participation by members in different time-zones. Face to face or hybrid meetings remain an essential part of TEAP/TOC function and consensus.

The challenge for TEAP and for the parties, is both to maintain the needed expertise and to recruit new volunteers with needed technical expertise, ability to work independently, confidentially, and to reach consensus, and the necessary time, energy, and ability to write clearly. Some TOCs have experienced substantial attrition of key members, both through retirement, and especially because of lack of support for their participation, with increasing loss of expertise for those TOCs.

Some members have been unable to travel to face-to-face meetings for diverse administrative reasons, and visas with longer timelines/increasing geographical restrictions. Many non-A5 experts find it increasingly difficult to obtain funding support for travel from their organisations. Organisations that previously supported non-A5 meeting attendance have transitioned to using virtual meetings to conduct their business and find it increasingly difficult to justify travel to TOC meetings. Parties may wish to consider how to assist TEAP in ensuring the independence in its products and the full participation of TEAP/TOC members in its consensus-based process, i.e., providing travel support to members, where needed, irrespective of their A5/non-A5 status. This would not only support the full participation of current experts but could encourage new, needed volunteer experts to become TEAP/TOC members.

TEAP and its TOCs are making efforts to recruit active new members to meet gaps in expertise with some success. Several new members have been identified through their work on task forces. This has enabled the new experts to familiarise themselves with the process and allows TEAP to consider their capability and suitability for TEAP/TOC membership.

TEAP has concerns about its workload given a developing pattern of repeated requests for updates on topics recently covered in assessments or reports responding to previous decisions (on the same topics), seemingly as a mechanism to continue discussions until a consensus decision of parties can be reached. While the technical information may change very little on an annual basis, it still requires TEAP to work to provide reports, which entails bringing together relevant experts for consensus. The growing frequency of these update requests could lead to TEAP exceeding its capacity for its important workload over the course of a year. For example, during 2024, TEAP will have produced three major new reports, plus within its Progress Report, responses to five separate decisions requesting updates to recently provided information.

The workload of the TEAP and its TOCs for the period 2024-2026 is contained in Annex 8, based on decisions of parties to date. Considering the workload over a longer time period rather than annually may provide a more accurate representation of the pipeline of the preparatory and drafting workload for reports of TEAP. Parties are asked to consider TEAP’s current and future workload when considering the scope as well as timeline for any new requests to the TEAP.

#### *9.2.1 Decision XXXV/20 on options for organisation of TEAP/TOCs*

At the 35$^{th}$ MOP, parties adopted Decision XXXV/20, “Options for the organization of the Technology and Economic Assessment Panel and its technical options committees,” which states:

*Taking note of the 2023 progress report of the Technology and Economic Assessment Panel, including section 8 on the composition, balance and workload of the Panel and its technical options committees, in response to decision XXXIV/11,*

*To request that the Technology and Economic Assessment Panel, in its progress report prepared ahead of the forty-seventh meeting of the Open-ended Working Group of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, provide options on the organization of the*

*Panel and its technical options committees, considering the Panel's terms of reference established in decision XXIV/8, and informed by consultation with the technical options committees' co-chairs and members, and by their experiences with operating, on a trial basis, with new ways of organizing their work.*

TEAP discussed this decision at its annual meeting and is planning its response, to be submitted in 2025, to provide additional options to address the challenges and current and future workload of the TEAP and its TOCs.

### *9.2.2 Managing work related to replenishment*

TEAP would like to bring to the attention of parties the following observations on its work related to the replenishment of the Multilateral Fund for the Implementation of the Montreal Protocol (MLF). For replenishment of the MLF in the 2024-2026 triennium, as requested under Decision XXXIV/2, TEAP prepared a report in May 2023 and a supplemental report in September 2023. Parties agreed to Decision XXXV/1,

"*Replenishment of the Multilateral Fund for the Implementation of the Montreal Protocol for the triennium 2024–2026" and adopted a budget of US$ 965 million for this triennium. The parties also agreed in paragraph 3 of that decision that "the Executive Committee should take action to ensure, to the extent possible, that the entire budget for the triennium 2024–2026 is committed by the end of 2026, and that parties not operating under paragraph 1 of Article 5 of the Montreal Protocol should make timely payments in accordance with paragraph 7 of decision XI/6.*"

The replenishment of MLF at this historic level represents a significant milestone in assistance to A5 parties to comply with the terms of the Montreal Protocol and its amendments – for the first time, the MLF is funding the incremental costs of not just the phase-out of ODS but also the phase-down of HFCs. TEAP recognises that this new level of resources, which approximately doubles the historical level of previous replenishments, brings additional work and would require substantive efforts for the Executive Committee (ExCom) and all the institutions of the Montreal Protocol to ensure, to the extent possible, that the full budget of US$ 965 million is committed by the end of 2026.

TEAP's workload in 2023 to provide the estimated funding for the replenishment of the MLF for the 2024-2026 was substantial, given the funding considerations for both the continued ODS phaseout and the HFC phasedown during this period. TEAP is considering lessons learnt from its experience during the preparation of the 2024-2026 report on the MLF replenishment.

The study estimating the funding for the replenishment of the MLF is a standing request of parties to the TEAP every three years and has required intense activity over the year following the decision establishing the terms of reference. TEAP is now considering ongoing activities that could support this work in the intervening years to make the effort more consistent and manageable. TEAP is identifying ways to improve its internal processes related to this task (i.e., more regular database and modelling updates based on HFC consumption reporting and ExCom meeting funding approvals), its engagement to more fully understand emerging issues affecting MLF future funding decisions and identifying ongoing sources for information and support for its work. TEAP looks to the support of parties as TEAP works to improve its processes, manage its overall workload, and continue to deliver this important assessment to parties and better respond to future requests.

## Annex 1: Emissions of Halon 1301

As reported in the TEAP 2023 Progress Report, the unexplained temporary increases in emissions of halon 1301 derived from atmospheric measurements continue to concern the FSTOC. The FSTOC has tried, but has been unsuccessful, in linking these unexplained temporary increases in emissions to the fire suppression bank or use. If these additional emissions were from the bank, the cumulative total would make the resulting bank smaller, and the available bank much smaller. Additionally, if the bank was subsequently smaller, one would expect the emissions to also be smaller, which is not what the data show. The FSTOC therefore considers that these additional emissions are not from the fire suppression bank, but from another source.

Since it is known halon 1301 is produced as a feedstock for Fipronil and various pharmaceuticals (e.g., Mefloquin and a DPP-IV Inhibitor), the FSTOC is hypothesizing that these unexplained temporary increases in emissions in halon 1301 are somehow related to its feedstock production and use.

Recently the FSTOC has been made aware that production of halons (believed to be substantially or exclusively $CF_3Br$ or halon 1301) for feedstock has been published by the Ozone Secretariat under Article 7 reporting[152]. Table A1-1, extracted from the Ozone Secretariat report, lists the number of parties reporting production of halons for feedstock and the total amounts, on a yearly basis. Whilst these data are for all halons, the FSTOC believes that most, if not all of the halon produced for feedstock is halon 1301. Using halon 1301 as a feedstock will add a $-CF_3$ group to the target molecule, which is the desired outcome.

**Table A1-1 Production of Halons for Feedstock.**

| **Year** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
|---|---|---|---|---|---|---|---|---|
| **Number of Parties Reporting** | 2 | 3 | 3 | 3 | 4 | 4 | 3 | 3 |
| **All (Halons)/ Tonnes** | 855 | 1,202 | 758 | 900 | 1,270 | 1,471 | 2,163 | 1,342 |
| **Year** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | |
| **Number Parties Reporting** | 2 | 2 | 4 | 4 | 4 | 4 | 4 | |
| **All (Halons)/ Tonnes** | 871 | 753 | 1,360 | 1,805 | 1,306 | 1,486 | 1,796 | |

The FSTOC applied the range of emissions factors provided by the MCTOC (2.6% at the low end to 7.5% at the high end) to the reported feedstock production, as shown in Figure A1-1 and Figure A1-2 below. Even at the high end of the range, although the resultant emissions were much smaller than those derived from atmospheric concentrations (denoted as AGAGE in the charts), the pattern (the yearly rise and fall of emissions) looked similar. The FSTOC then applied successively higher

[152] Information provided by parties in accordance with Articles 7 and 9 of the Montreal Protocol on Substances that Deplete the Ozone Layer https://ozone.unep.org/system/files/documents/MOP-35-6_IMPCOM-71-2E.pdf.

emissions factors to the feedstock production and found that at 26%, the match was remarkable, as shown in Figure A1-3 and Figure A1-4 below.

**Figure A1-1 Emissions of halon 1301 including production for feedstock (Emission Factor 2.6% applied)**

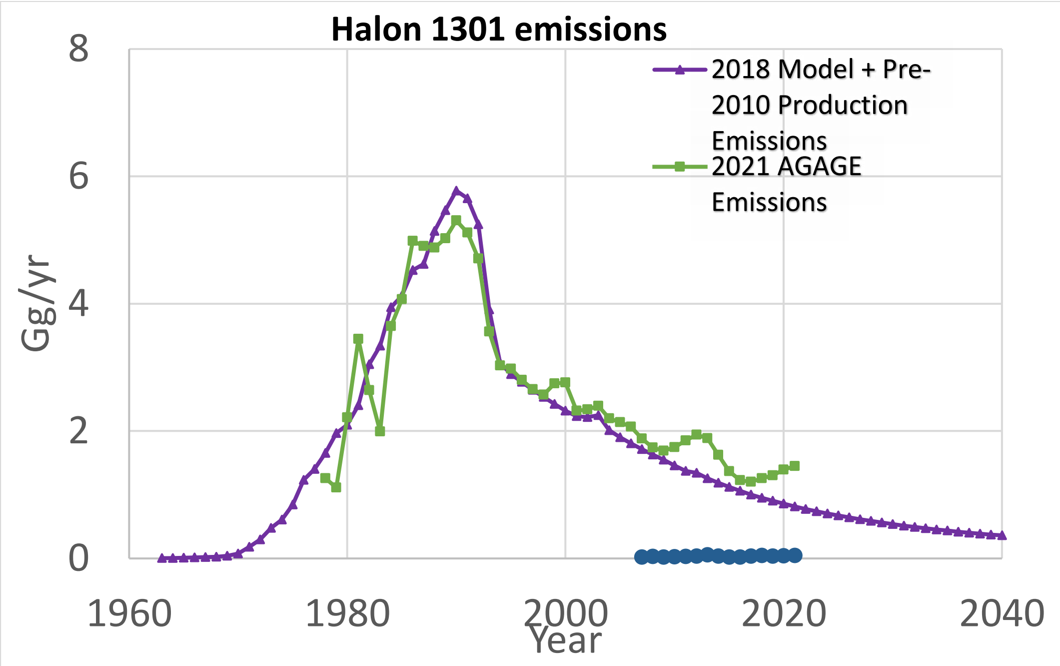



**Figure A1-2 Emissions of halon 1301 including production for feedstock (Emission Factor 7.5% applied)**

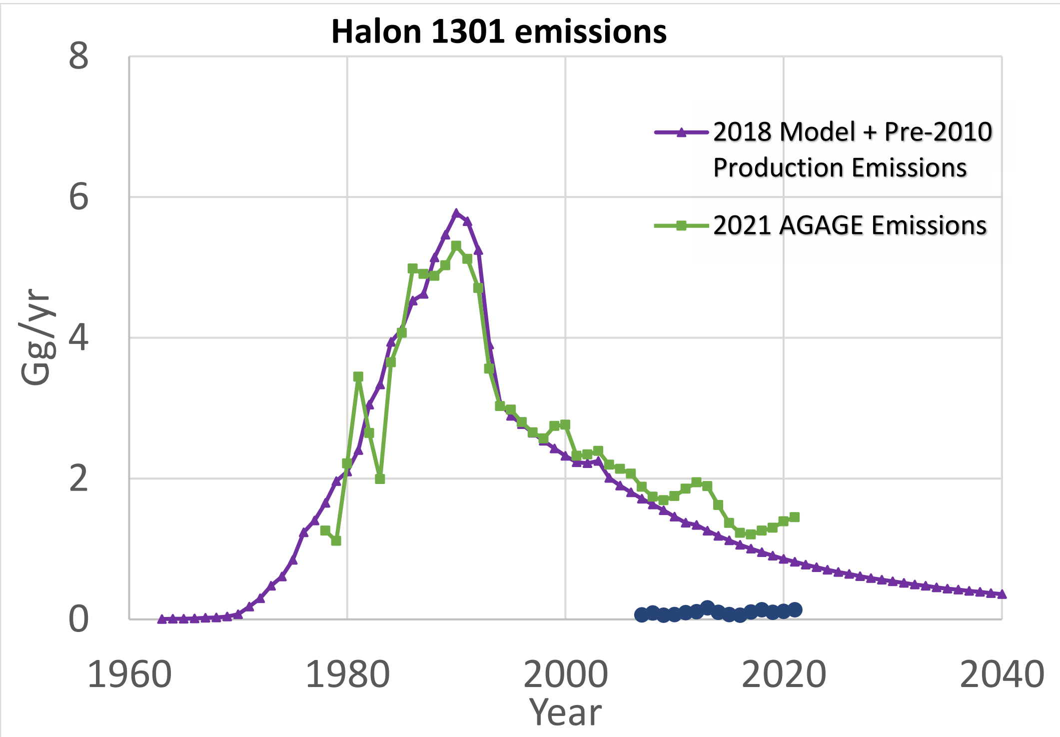


**Figure A1-3** **Emissions of halon 1301 including production for feedstock (Emission Factor 15% applied)**

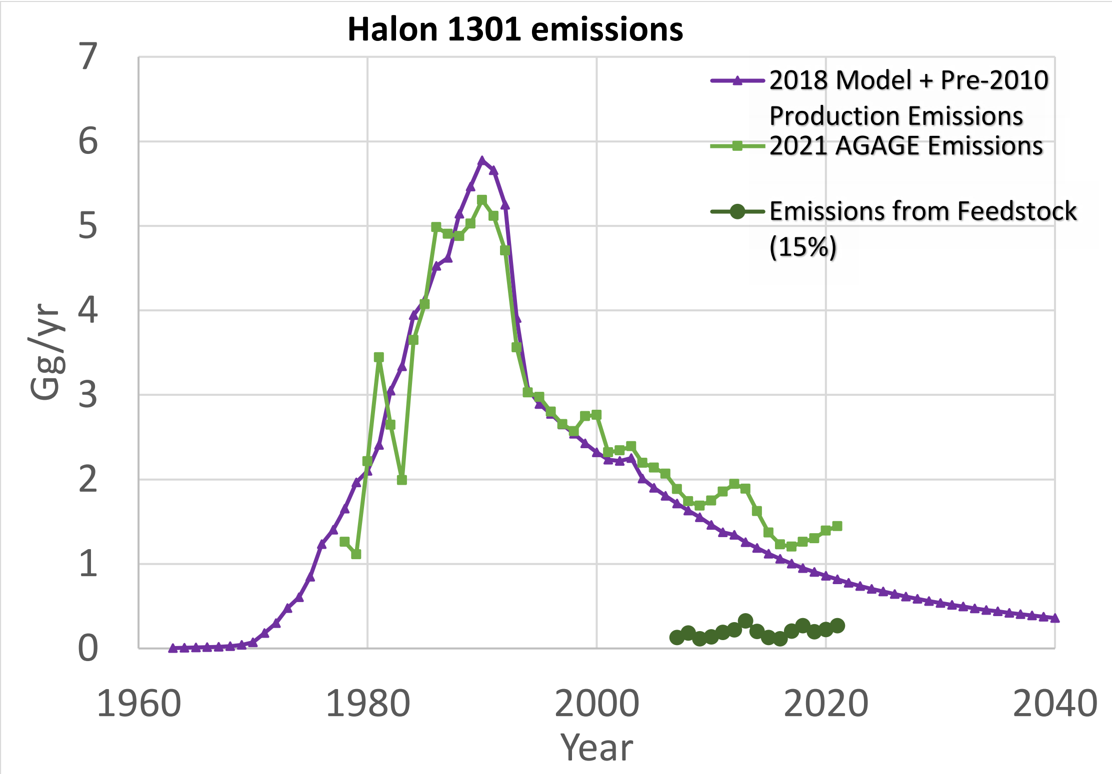
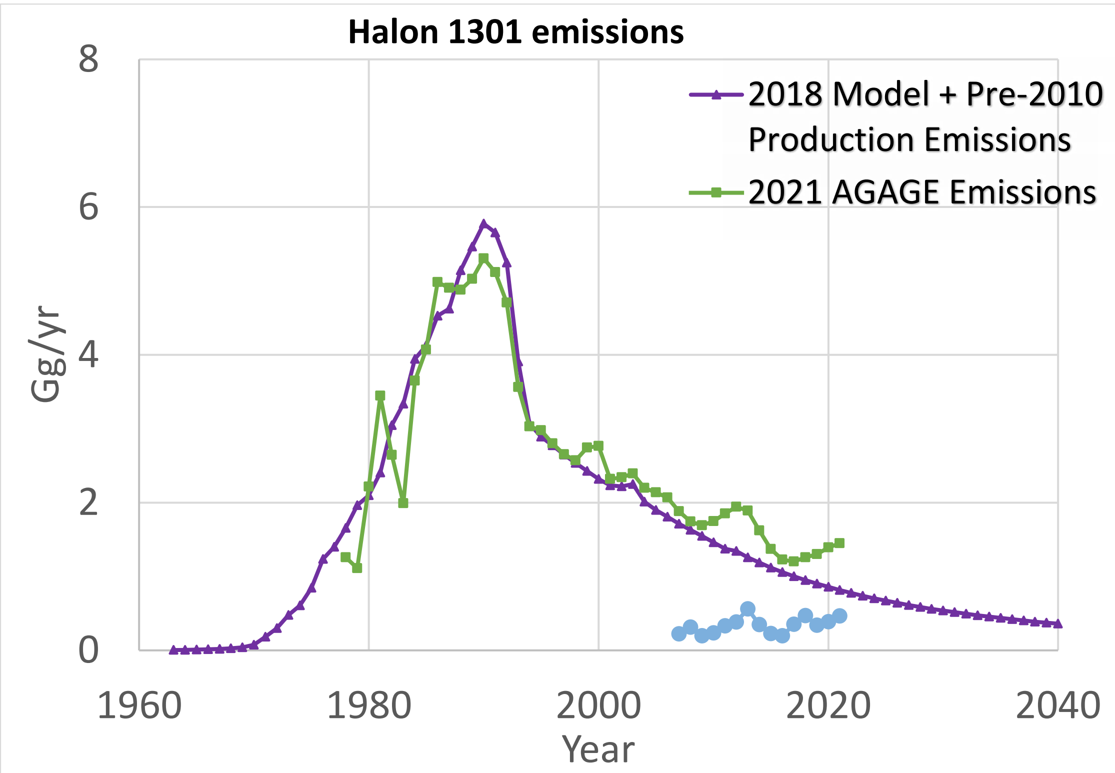
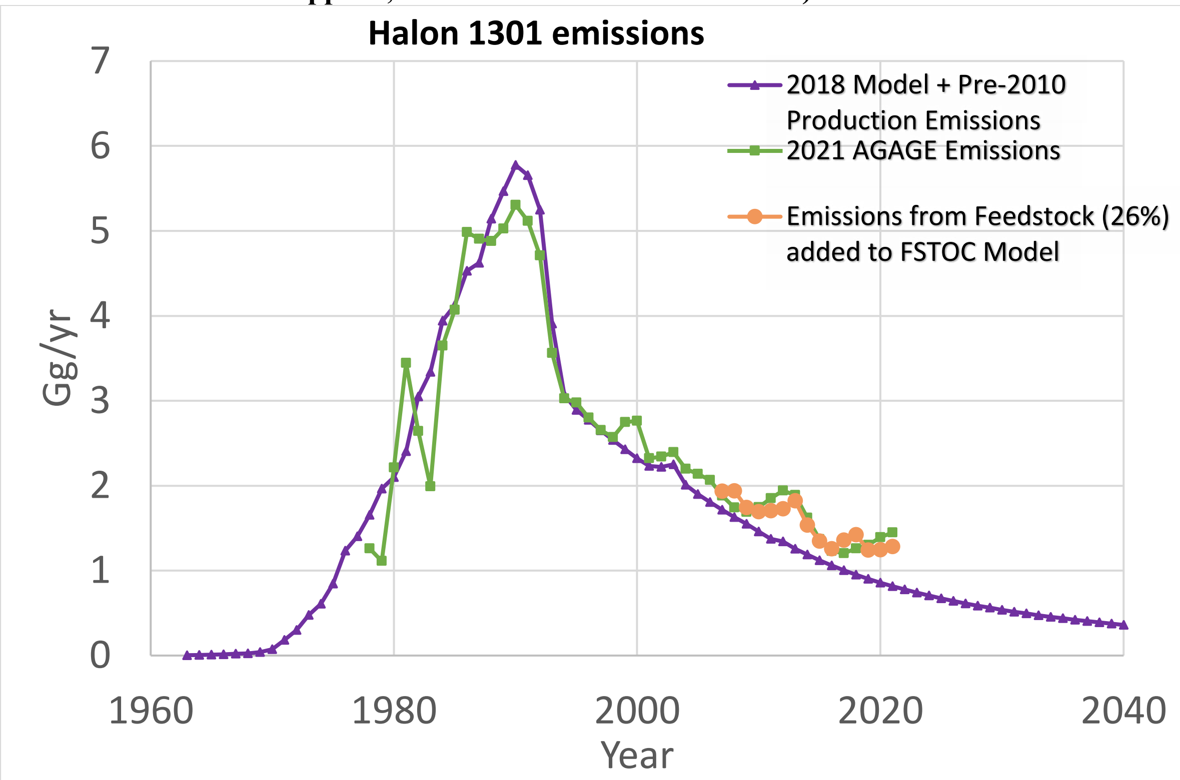



**Figure A1-4** **Emissions of halon 1301 including production for feedstock (Emission Factor 26% applied)**



Finally, the FSTOC added the emissions from feedstock production to the emissions from the FSTOC model, as shown in Figure A1-5 below.

**Figure A1-5 Emissions of halon 1301 including production for feedstock (Emission Factor 26% applied, and added to the FSTOC Model)**




The agreement between the emissions derived from atmospheric measurements and the FSTOC model, plus emissions from production for feedstock use is remarkable. The FSTOC notes that an emission factor of 26% is significantly higher than the MCTOC estimates, and offers the following thoughts:

- Emissions from very small production plants may be higher than those from larger production plants.
- The emissions reported to the Ozone Secretariat are those from production for feedstock use. They do not include any emissions that might occur during the use of the halon 1301 as a feedstock.

These are two areas where the FSTOC is requesting more information.

## Annex 2: Safety standards updated to enable lower GWP refrigerants

International standards are developed under the International Standards Organization (ISO) and the International Electrotechnical Committee (IEC), as agreed upon by the World Trade Organization (WTO). These international standards are used to derive national standards under standards developing organisations (SDOs). Standards may be adopted with changes, known as national differences. Technical committees (TCs) are responsible for updating international and regional or national standards.


Standards are modified or created nationally (e.g., to be more stringent) and can be adopted by multiple countries. Some examples of international and national standards, updated since the Kigali Amendment was ratified, are listed below. Some G2 parties have adopted these national and international standards.

**Table A2-1 International RACHP standards**

| Region | International Standards | Application Area | Title | Current Edition | Updates Since 2015 |
|---|---|---|---|---|---|
| **International** | ISO 817 | Provides refrigerant and refrigerant blend safety classification using alphanumeric guidance (A, B for toxicity; 1, 2L,2, 3 for flammability) | Refrigerants-Designation and Safety Classification | Edition 3 :2014 AMD1, AMD2; 4th Ed Expected 4Q'2024 | ISO 817 separated from ASHRAE 34 in 2018 with its own application process. The standard Includes more information on flammable refrigerants, including burning velocity at different test conditions; also requires auto-ignition testing (AIT) and optional hot surface ignition test (HSIT) data |
| **International** | ISO 5149 | General equipment installation standard. specifies the requirements for the safety of persons and property, provides guidance for the protection of the environment, and establishes procedures for the operation, maintenance, and repair of refrigerating systems and the recovery of refrigerants. | Part 1: Definitions, classification and selection criteria | Edition 1: 2014; 2nd Ed Expected 4Q'2025 | Covers equipment not under product standards such as IEC 60335-2-40, etc. Standard was updated to incorporate technical aspects of product standards which include mitigation strategies such as air circulation, safety shut-off valves, etc. In general, allows larger charge size for flammable refrigerants using mitigation strategies |
| | | | Part 2: Design, construction, testing, marking and documentation | Edition 1: 2014; 2nd Ed Expected 4Q'2025 | Covers equipment not under product standards such as IEC 60335-2-40, etc. Updated machinery room and emergency ventilation requirements |
| | | | Part 3: Installation site | Edition 1: 2014; 2nd Ed Expected 4Q'2025 | Covers equipment not under product standards such as IEC 60335-2-40, etc. Standard updated regarding installation categories, personnel occupancy and mitigation level required for flammable refrigerants |

| Region | International Standards | Application Area | Title | Current Edition | Updates Since 2015 |
|---|---|---|---|---|---|
| | | | Part 4: Operation, maintenance, repair and recovery | Edition 2: 2022 | Covers equipment not under product standards such as IEC 60335-2-40, etc. Addition of guidelines for repair of equipment using flammable refrigerants (see Annex E) |
| **International** | IEC 60335-2-24 | Ice-cream appliances/ice makers | Particular requirements for refrigerating appliances, ice-cream appliances and ice makers | Edition 8: 2020 | Updates made regarding material encasing and in contact with thermal insulation; other updates made regarding motor-compressors, compatibility and testing. |
| **International** | IEC 60335-2-34 | compressors | Particular requirements for motor-compressors | Edition 6: 2021 | Updates made regarding application categories, motor compressor compatibility testing |
| **International** | IEC 60335-2-40 | heat pumps, AC and dehumidifiers, includes chillers | Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers | Edition 7: 2022; Working on 8th edition. Expect to publish 2025 | Updates since 2015: Overall larger charge for flammable refrigerants. Strategies used in standard: prevent refrigerant ignition by: limiting/removing ignition sources; refrigerant room/volume charge limitations, mitigation/ventilation strategies including safety shut-off valves and releasable charge. |
| **International** | IEC 60335-2-89 | commercial refrigerating appliances | Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor | Edition 3: 2019; Working on 4th edition. Expect to publish Q4'2024 | Since 2015: Overall larger charge sizes for flammable refrigerants using strategies such as air flow and specific design features (Annex C). |
| **International** | IEC 60335-2-104 | recovery equipment | Particular requirements for appliances to recover and/or recycle refrigerant from air conditioning and refrigeration equipment | Edition 2: 2021; Working on 3rd Ed. Expect to publish 1Q'2025 | Standard was updated specifically to incorporate flammable refrigerant recovery |

**Table A2-2 Examples of regional RACHP standards**

| Region | Standards | Application Area | Title |
|---|---|---|---|
| Europe | EN 378 | Part 1: Installation standard- definitions | Basic requirements, definitions, classification, and selection criteria |
| | | Part 2: Installation standard-design/construction | Design, construction, testing, marking, and documentation |
| | | Part 3: Installation standard-site and personnel | Installation site and personal protection |
| | | Part 4: Installation standard-operation, maintenance, repair, recovery | Operation, maintenance, repair and recovery |
| | | Part 5 | Refrigerant Properties |
| Europe | EN 60335-2-24 | | Particular requirements for refrigerating appliances, ice-cream appliances and ice makers |
| Europe | EN 60335-2-34 | | Particular requirements for motor-compressors |
| Europe | EN 60335-2-40 | | Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers |
| Europe | EN 60335-2-89 | | Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor |
| Japan | JIS B8240 | Specifies the materials, design and construction of pressure vessels (e.g. storage tanks) for equipment that uses vapor-compression or evaporative cooling. | Particular requirements for appliances to recover and/or recycle refrigerant from air conditioning and refrigeration equipment |

| Region | Standards | Application Area | Title |
| --- | --- | --- | --- |
| Japan | JIS B8616 | (Packaged Air Conditioners) specifies the materials, design, and testing procedure of packaged AC systems intended to provide comfort to building occupants. | |
| | | Refers to JIS B8620 (Safety Code for Small Refrigeration Equipment) for its refrigerant leakage testing procedure. | |
| United States | ASHRAE 34 | Refrigerant Classification and Safety Guidance | |
| United States | ASHRAE 15 | Standard provides maximum charge allowed for various occupancies | |
| United States | ASRHAE 15.2 | Standard provides maximum charge allowed for various occupancies | |
| United States | IIAR | provide informative documents on the safety, design, components, and start-up of mechanical refrigeration systems based on ammonia | |
| United States | UL 60335-2-24 | Ice-cream appliances/ice makers | Particular requirements for refrigerating appliances, ice-cream appliances and ice makers |
| United States | UL 60335-2-34 | compressors | Particular requirements for motor-compressors |
| United States | UL 60335-2-40 | heat pumps, AC and dehumidifiers, includes chillers | Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers |
| United States | UL 60335-2-89 | commercial refrigerating appliances | Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor |

## Annex 3: Examples of relevant demonstration and investment projects for G2 parties since 2016 [153] [154]

| COUNTRY | CODE | STATUS | TYPE | SUB-SECTOR | PROJECT TITLE | ODS REPLACEMENT | DATE APPROVAL |
|---|---|---|---|---|---|---|---|
| **India** | IND/EEF/93/DEM/507 | NEW | DEM | Air conditioning | Design and development of a pilot scale energy-efficient rotary compressor along with microchannel heat exchanger compatible with R-290 technology at Godrej & Boyce Mfg. Ltd., for use in manufacturing of room air conditioners (decision 91/65) | R-290 | Dec-23 |
| **India** | IND/EEF/93/DEM/510 | NEW | DEM | Commercial | Conversion of the manufacturing of commercial refrigeration appliances at Rockwell Industries Limited from HFC-134a to propane (R-290) (technical assistance to enhance the energy efficiency of the converted equipment) (decision 91/65) | R-290 | Dec-23 |
| **Saudi Arabia** | SAU/FOA/76/DEM/27 | FIN | DEM | Rigid | Demonstration project for the phase-out of HCFCs by using HFO as foam blowing agent in the spray foam applications in high ambient temperatures | HFO | May-16 |
| **Saudi Arabia** | SAU/REF/76/DEM/29 | FIN | DEM | Air conditioning | Demonstration project at air-conditioning manufacturers to develop window and packaged air-conditioners using low-global warming potential refrigerants | HFC-32 | May-16 |
| **Saudi Arabia** | SAU/REF/76/DEM/28 | ONG | DEM | Air conditioning | Demonstration project on promoting HFO-based low-global warming potential refrigerants for air-conditioning sector in high ambient temperatures | HFO | May-16 |

[153] Information provided by MLF Secretariat, TEAP extracted relevant examples and shortened entries, removing financial figures to facilitate reading.

[154] DEM: Demonstration project; FIN: Financially closed project; COM: completed project activities but not financially closed; ONG: Ongoing project: INV: Investment project

| COUNTRY | CODE | STATUS | TYPE | SUB-SECTOR | PROJECT TITLE | ODS REPLACEMENT | DATE APPROVAL |
|---|---|---|---|---|---|---|---|
| **Bahrain** | BAH/PHA/88/INV/43 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (commercial refrigeration foam and spray foam sector - umbrella project) | Water/carbon dioxide | Nov-21 |
| **India** | IND/PHA/86/INV/479 | COM | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (air-conditioning manufacturing sector plan) | HFC-32 | Dec-20 |
| **India** | IND/PHA/77/INV/468 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (polyurethane foam sector plan) | Cyclopentane | Dec-16 |
| **India** | IND/PHA/77/INV/469 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (air-conditioning manufacturing sector plan) | HFC-32 | Dec-16 |
| **India** | IND/PHA/82/INV/473 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (air-conditioning manufacturing sector plan) | HFC-32 | Dec-18 |
| **India** | IND/PHA/91/INV/494 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage III, first tranche) (refrigeration manufacturing sector) | R-600a/R-290 and HFC-32 for process chiller | Dec-22 |
| **India** | IND/PHA/91/INV/495 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage III, first tranche) (air-conditioning manufacturing sector) | HFC-32 | Dec-22 |
| **India** | IND/PHA/86/INV/480 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (polyurethane foam sector plan) | Cyclopentane | Dec-20 |
| **Iran** | IRA/PHA/84/INV/235 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (foam sector) | Cyclopentane | Dec-19 |
| **Iran** | IRA/PHA/77/INV/225 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (foam sector) | Cyclopentane | Dec-16 |
| **Iran** | IRA/PHA/77/INV/226 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (foam sector) | Cyclopentane | Dec-16 |
| **Iran** | IRA/PHA/84/INV/238 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (commercial refrigeration sector) | R-290 | Dec-19 |

| COUNTRY | CODE | STATUS | TYPE | SUB-SECTOR | PROJECT TITLE | ODS REPLACEMENT | DATE APPROVAL |
|---|---|---|---|---|---|---|---|
| **Iran** | IRA/PHA/84/INV/242 | FIN | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (foam sector) | Water/carbon dioxide | Dec-19 |
| **Iran** | IRA/PHA/84/INV/236 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (refrigeration servicing sector) | R-290 | Dec-19 |
| **Iran** | IRA/PHA/77/INV/224 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (foam sector) | Cyclopentane | Dec-16 |
| **Iran** | IRA/PHA/77/INV/228 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (foam sector) | Cyclopentane | Dec-16 |
| **Iran** | IRA/PHA/84/INV/237 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (foam sector) | Cyclopentane | Dec-19 |
| **Iran** | IRA/PHA/84/INV/239 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (foam sector) | Cyclopentane | Dec-19 |
| **Iran** | IRA/PHA/86/INV/243 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (commercial refrigeration sector) | HFC-32 | Dec-20 |
| **Iran** | IRA/PHA/86/INV/244 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (foam sector) | Cyclopentane | Dec-20 |
| **Iran** | IRA/PHA/86/INV/245 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (foam sector) | Cyclopentane | Dec-20 |
| **Iran** | IRA/PHA/86/INV/246 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (foam sector) | Cyclopentane | Dec-20 |
| **Iran** | IRA/PHA/86/INV/250 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (commercial refrigeration sector) | HFC-32 | Dec-20 |
| **Iran** | IRA/PHA/90/INV/258 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, fourth tranche) (commercial refrigeration sector) | R-290 | Jun-22 |
| **Iran** | IRA/PHA/90/INV/260 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, fourth tranche) (foam sector) | Water blown | Jun-22 |
| **Iran** | IRA/PHA/90/INV/261 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, fourth tranche) (foam sector) | Cyclopentane | Jun-22 |

| COUNTRY | CODE | STATUS | TYPE | SUB-SECTOR | PROJECT TITLE | ODS REPLACEMENT | DATE APPROVAL |
|---|---|---|---|---|---|---|---|
| **Iran** | IRA/PHA/92/INV/264 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, second tranche) (refrigeration servicing sector) | R-290 | Jun-23 |
| **Iran** | IRA/PHA/92/INV/265 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, third tranche) (commercial refrigeration sector) | HFC-32 | Jun-23 |
| **Iran** | IRA/PHA/92/INV/267 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, fourth tranche) (foam sector) | Water blown | Jun-23 |
| **Kuwait** | KUW/PHA/88/INV/45 | COM | INV | HCFC phase out plan | HCFC phase-out management plan (stage I, fourth tranche) (extruded polystyrene foam sector phase-out) | Water/carbon dioxide | Nov-21 |
| **Pakistan** | PAK/FOA/84/INV/103 | ONG | INV | Polystyrene/ polyethylene | Phase-out of HCFC-142b/HCFC-22 from the manufacturing of extruded polystyrene at Symobl Industries, Lahore | Carbon dioxide | Dec-19 |
| **Pakistan** | PAK/PHA/76/INV/94 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, first tranche) (polyurethane foam sector) | Cyclopentane | May-16 |
| **Pakistan** | PAK/PHA/90/INV/110 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage II, fourth tranche) (domestic air-conditioner manufacturing sector) | HFC-32 | Jun-22 |
| **Pakistan** | PAK/PHA/90/INV/111 | ONG | INV | HCFC phase out plan | HCFC phase-out management plan (stage III, first tranche) (foam sector) | Cyclopentane | Jun-22 |
| **Saudi Arabia** | SAU/PHA/77/INV/31 | COM | INV | HCFC phase out plan | HCFC phase-out management plan (stage I, fourth tranche) (polyurethane foam sector plan) | Cyclopentane | Dec-16 |

## Annex 4: Planned activities in Adjusted Consolidated Business Plan of the MLF 2024-2026 for G2 parties

| Country | Agency | Type[155] | Title | Required by Model | A-Appr. P-Plan'd | Remarks |
|---|---|---|---|---|---|---|
| India | UNDP | INV | Control and phase out HFC-23 by-product emissions | HFC-23 | P | PRP requested in 2023. |
| India | UNDP | KIP | HFC phase-down plan | KIP Stage I | P | UNDP lead agency. |
| India | UNDP | INV | Demonstration Project for the conversion of HFC-134a in MAC for R-290 cascade system in SUBROS | KIP Stage I - Investment | P | PRP requested in 2023. |
| India | UNDP | PRP | PRP for HFC phase-down plan | KIP Stage I Preparation | P | **Country ratified Kigali.** UNDP is the lead agency. |
| India | UNEP | PRP | India HFC Phase down plan preparation | KIP Stage I Preparation | P | UNDP is a lead agency. |
| India | Germany | DEM | Design and development of a pilot scale energy-efficient rotary compressor along with microchannel heat exchanger compatible with R-290 technology at Godrej & Boyce Mfg. Ltd., for use in manufacturing of room air conditioners (decision 91/65) | Pilot Project for Energy Efficiency - Investment | P | |
| Iran (Islamic Republic of) | UNDP | PRP | PRP for HFC phase-down plan | KIP Stage I Preparation | P | **Country has not ratified Kigali.** UNDP is the lead agency. |
| Iran (Islamic Republic of) | UNIDO | PRP | HFC phase-down National Implementation plan (Preparation) | KIP Stage I Preparation | P | UNDP lead; UNIDO and UNEP cooperating implementing agencies |
| Iraq | UNEP | PRP | Iraq HFC Phase down plan preparation | KIP Stage I Preparation | P | UNEP is a sole agency. From BP 2023-2025. **KA has not been ratified yet** |

[155] INV: Investment project; KIP: Kigali Implementation Plan; PRP: Project preparation; DEM: Demonstration project

| **Country** | **Agency** | **Type**[155] | **Title** | **Required by Model** | **A-Appr. P-Plan'd** | **Remarks** |
|---|---|---|---|---|---|---|
| Iraq | UNIDO | PRP | HFC phase-down National Implementation plan (Preparation) | KIP Stage I Preparation | P | UNEP lead; UNIDO cooperating implementing agency |
| Oman | UNEP | PRP | Oman HFC Phase down plan preparation | KIP Stage I Preparation | P | UNIDO is a lead agency. **KA has not yet. been ratified** |
| Oman | UNIDO | PRP | HFC phase-down National Implementation plan (Preparation) | KIP Stage I Preparation | P | UNIDO lead; UNEP cooperating implementing agency |
| Pakistan | UNEP | PRP | Pakistan HFC Phase down plan preparation | KIP Stage I Preparation | P | UNIDO is a lead agency. **KA has not been ratified yet.** |
| Pakistan | UNIDO | PRP | HFC phase-down National Implementation plan (Preparation) | KIP Stage I Preparation | P | UNIDO lead; UNEP cooperating implementing agency |
| Qatar | UNEP | PRP | Qatar HFC Phase down plan preparation | KIP Stage I Preparation | P | UNIDO is a lead agency. From BP 2023-2025. **KA has not been ratified yet** |
| Qatar | UNIDO | PRP | HFC phase-down National Implementation plan (Preparation) | KIP Stage I Preparation | P | UNIDO lead; UNEP cooperating implementing agency |

Source: Information collected from MLF web site (April 2024), News and Announcements/ MLF Consolidated Business Plan 2024-2026. http://www.multilateralfund.org/default.aspx.

# Annex 5: 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.

### A5.1 Technology and Economic Assessment Panel (TEAP) 2024

TEAP is presently composed of three co-chairs, the co-chairs of the Technical Options Committees and five senior experts as indicated in Table A5.1 below.

**Table A5-1 TEAP Membership at May 2024**

| | **Co-chairs** | **Affiliation** | **Country** | **Appointed through** |
|---|---|---|---|---|
| 1 | Bella Maranion | U.S. Environmental Protection Agency | USA | 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 | 2024* |
| 5 | Ray Gluckman | Gluckman Consulting | UK | 2024* |
| 6 | Marco Gonzalez | Independent Expert | Costa Rica | 2024* |
| 7 | Shiqiu Zhang | College of Environmental Sci. & Eng., Peking University | China | 2024* |
| 8 | Sukumar Devotta | Independent Expert | India | 2024* |
| | **TOC Chairs** | **Affiliation** | **Country** | **Appointed through** |
| 9 | Omar Abdelaziz | The American University in Cairo | Egypt | 2027 |
| 10 | Paulo Altoé | Independent Expert | Brazil | 2024* |
| 11 | Adam Chattaway | Collins Aerospace | UK | 2024* |
| 12 | Takeshi Eriguchi | AGC Inc. | Japan | 2027 |
| 13 | Sergey Kopylov | Russian Res. Institute for Fire Protection | Russian Fed. | 2025 |
| 14 | Roberto Peixoto | Maua Institute (IMT), Sao Paulo | Brazil | 2027 |
| 15 | Fabio Polonara | Universitá Politecnica delle Marche | Italy | 2026 |
| 16 | Ian Porter | La Trobe University | Australia | 2025 |
| 17 | Natarajan Rajendran | Five Rivers Research & Consulting LLC | USA | 2027 |
| 18 | Helen Tope | Planet Futures | Australia | 2025 |
| 19 | Daniel P. Verdonik | Jensen Hughes Inc | USA | 2024* |
| 20 | Helen Walter-Terrinoni | Trane Technologies | USA | 2025 |
| 21 | Jianjun Zhang | Zhejiang Chemical Industry Research Institute | China | 2027 |

** Indicates members whose terms expire at the end of 2024. See comments under TOC for consistency.*

### A5.2 Flexible and Rigid Foams Technical Options Committee (FTOC)

FTOC members currently have expertise in: producing and handling foam blowing agents; foam formulations; 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 A5-2 FTOC Membership at May 2024**

| | **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 | 2025 |
| 4 | Roy Chowdhury | Foam Supplies | Australia | 2025 |
| 5 | Joseph Costa | Arkema | US | 2026 |
| 6 | Gwyn Davis | Kingspan Group | UK | 2024* |
| 7 | Ilhan Karaağaç | Kingspan Group | Turkey | 2028 |
| 8 | Shpresa Kotaji | Huntsman Corporation | Belgium | 2027 |
| 9 | Simon Lee | Independent Expert | US | 2025 |
| 10 | Yehia Lotfi | Techno Cam | Egypt | 2027 |
| 11 | Jorge Lemus | Eiffel | Mexico | 2028 |
| 12 | Lisa Massaro | DuPont | US | 2027 |
| 13 | Smita Mohanty | LARM CIPET Bhubaneswar | India | 2028 |
| 14 | Sascha Rulhoff | H-C-S Group | Germany | 2026 |
| 15 | Enshan Sheng | Huntsman Corporation | China | 2026 |
| 16 | Hendro Utama | PT. Intimas Chemindo | Indonesia | 2028 |
| 17 | Koichi Wada | Japan Urethane Industry Institute | Japan | 2026 |
| 18 | Dave Williams | Independent Expert | US | 2026 |
| 19 | Ernest Wysong | Natural Polymers LLC | US | 2028 |

* *Indicates members whose terms expire at the end of the current year (2024).*

### A5.3 Fire Suppression Technical Options Committee (FSTOC)

Generally speaking, 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, 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 standards for both new and recycled agents, and destruction issues;
4. issues impacting current and future use (also referred to as enduring uses), e.g., continued reliance on halons for existing uses in military, oil and gas, merchant shipping, etc., and for existing/new installations in civil aviation, and phase-down requirements of fire suppression uses of high-GWP HFCs; this includes modelling of remaining quantities and emissions of halons, and growth of HCFCs and high-GWP HFCs;
5. 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 (also referred to as enduring 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.

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 Japan). As noted in the matrix of expertise needed, the FSTOC is continuing to look for additional experts to promote A5/non-A5 and regional balance while also being mindful of gender balance.

**Table A5-3 FSTOC Membership at May 2024**

| | Co-chairs | Affiliation | Country | Appointed through |
|---|---|---|---|---|
| 1 | Adam Chattaway | Collins Aerospace | UK | 2024* |
| 2 | Sergey N. Kopylov | Russian Res. Institute for Fire Protection | Russian Federation | 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 | 2027 |
| 7 | Youri Auroque | European Aviation Safety Agency | France | 2027 |
| 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 | Consultant, part time, for the World Bank | Denmark | 2024* |
| 14 | Inderpal Singh Kanwal | CFEES, DRDO | India | 2024* |
| 15 | R.P. Singh | IDST | India | 2024* |
| 16 | Sidney de Brito Teixeira | Embraer | Brazil | 2026 |
| 17 | Mitsuru Yagi | Nohmi Bosai Ltd & Fire and Environment Prot. Network | Japan | 2024* |
| 18 | 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 | 2024* |
| 2 | Carl Chapell | Hilcorp Alaska LLC | USA | 2024* |
| 3 | Alan Elder | Johnson Controls | UK | 2024* |
| 4 | Joshua R. Fritsch | United States Army | USA | 2024* |
| 5 | Matsuo Ishiyama | Nohmi Bosai Ltd & Fire and Environment Prot. Network | Japan | 2024* |
| 6 | Nikolai Kopylov | Russian Res. Institute for Fire Protection | Russian Fed. | 2024* |
| 7 | Steve McCormick | Huntington Ingalls Industries | USA | 2024* |
| 8 | John G. Owens | Independent Consultant | USA | 2024* |
| 9 | John J. O’Sullivan | Bureau Veritas | UK | 2024* |
| 10 | Mark L. Robin | Chemours | USA | 2024* |
| 11 | Joseph A. Senecal | FireMetrics LLC | USA | 2024* |

** Indicates members whose terms expire at the end of 2024*

### A5.4 Methyl Bromide Technical Options Committee (MBTOC)

The MBTOC brings together expertise on controlled and exempted (QPS) uses of MB 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 MB 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 A5-4 MBTOC Membership at May 2024**

| | 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 Agric. Sciences | China | 2026 |
| 7 | Guillermo Castellá | Independent Expert | Uruguay | 2024* |
| 8 | Kang Fenfen | Plant and Foodstuffs Insp. Centre Tiajin Customs District | China | 2026 |
| 9 | Ayze Ozdem | Plant Protection Central Res. Inst. | Turkey | 2026 |
| 10 | Ken Glassey | MAFF – NZ | New Zealand | 2026 |
| 11 | Eduardo Gonzalez | Fumigator | Philippines | 2026 |
| 12 | Takashi Misumi | MAFF – Japan | Japan | 2026 |
| 13 | Christoph Reichmuth | Honorary Professor – Humboldt Univ | Germany | 2026 |
| 14 | Jordi Riudavets | IRTA – Department of Plant Prot. | Spain | 2024* |
| 15 | Akio Tateya | Technical Adviser, Syngenta | Japan | 2024* |
| 16 | Alejandro Valeiro | Nat. Institute for Ag. Technology | Argentina | 2026 |
| 17 | Nick Vink | University of Stellenbosch | South Africa | 2026 |
| 18 | Tim Widmer | USDA | USA | 2025 |

** Indicates members whose terms expire at the end of the 2024.*

### A5.5 Medical and Chemicals Technical Options Committee (MCTOC)

The MCTOC 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 A5-5 MCTOC Membership as of May 2024**

| | Co-chairs | Affiliation | Country | Appointed through |
|---|---|---|---|---|
| 1 | Takeshi Eriguchi | AGC Inc. | Japan | 2027 |
| 2 | Helen Tope | Independent Consultant, Planet Futures | Australia | 2025 |
| 3 | Jianjun Zhang | Zhejiang Chemical Industry Research Institute | China | 2027 |
| | **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 | Stephanie Bogle | U.S. Environmental Protection Agency | USA | 2025 |
| 9 | Steve Burns | AstraZeneca | UK | 2025 |
| 10 | Nick Campbell | Independent Expert | UK | 2026 |
| 11 | Andrea Casazza | Chiesi Farmaceutici | Italy | 2024* |
| 12 | Nee Sun (Robert) Choong Kwet Yive | University of Mauritius | Mauritius | 2026 |
| 13 | Rick Cooke | Man-West Environmental Group Ltd. | Canada | 2025 |
| 14 | Maureen George | Columbia University School of Nursing | USA | 2025 |
| 15 | Jianxin Hu | College of Environmental Sciences & Engineering, Peking University | China | 2026 |
| 16 | Ryan Hulse | Honeywell | USA | 2024* |
| 17 | Fang Jin | Guangzhou Medical University | China | 2024* |
| 18 | Rabinder Kaul | SRF Limited | India | 2027 |
| 19 | Javaid Khan | The Aga Khan University | Pakistan | 2026 |
| 20 | Andrew Lindley | Independent consultant to Koura and European Fluorocarbon Technical Committee (EFCTC) | UK | 2024* |
| 21 | Timothy J. Noakes | Koura | UK | 2026 |
| 22 | John G. Owens | Independent Consultant | USA | 2024* |
| 23 | John Pritchard | Independent Consultant, Inspiring Strategies | UK | 2026 |
| 24 | Rabbur Reza | Beximco Pharmaceuticals | Bangladesh | 2026 |
| 25 | Christian Sekomo Birame | National Industrial and Research Agency (NIRDA) | Rwanda | 2027 |
| 26 | David Sherry | Nolan Sherry & Associates Ltd. | UK | 2027 |
| 27 | Peter Sleigh | Independent Consultant | UK | 2027 |
| 28 | Jørgen Vestbo | Manchester University NHS Foundation Trust and Allergi- og Lungeklinikken, Vanløse | Denmark | 2025 |
| 29 | Kristine Whorlow | Non-Executive Director | Australia | 2026 |

| | | | | |
|---|---|---|---|---|
| 30 | Alex Wilkinson | East and North Hertfordshire NHS Trust | UK | 2025 |
| 31 | Gerallt Williams | Aptar Pharma | UK | 2024* |
| 32 | Ashley Woodcock | Manchester University NHS Foundation Trust | UK | 2027 |
| 33 | Arzu Yorgancıoğlu | Celal Bayar University Medical Faculty | Turkey | 2025 |
| 34 | Lifei Zhang | National Research Center for Environmental Analysis and Measurement | China | 2026 |

** Indicates members whose terms expire at the end of 2024.*

### A5.6 Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC)

The RTOC brings together expertise in RACHP sectors. Members are experts in the areas of: refrigerants, domestic refrigeration, commercial refrigeration, industrial refrigeration and heat pump systems, transport refrigeration, aAir-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 temperature applications, and modelling of RACHP Systems. Members have research, industry activities, regulatory and commercial experience.

**Table A5-6 RTOC Membership as of May 2024**

| | Co-chairs | Affiliation | Party | Appointed through |
|---|---|---|---|---|
| 1 | Omar Abdelaziz | The American University in Cairo | Egypt | 2027 |
| 2 | Roberto Peixoto | Maua Institute (IMT) | Brazil | 2027 |
| 3 | Fabio Polonara | Università Politecnica delle Marche | Italy | 2026 |
| 4 | Natarajan Rajendran | Five Rivers Research & Consulting LLC | USA | 2027 |
| | **Members** | **Affiliation** | **Party** | **Appointed through** |
| 5 | Ghina Annan | Stantec | Lebanon | 2024* |
| 6 | Jitendra Bhambure | Independent Expert | India | 2024* |
| 7 | Maria C. Britto Bacellar | Johnson Controls, JCI | Brazil | 2024* |
| 8 | Feng Cao | Xi'an Jiaotong University | China | 2024* |
| 9 | Ana Maria Carreño | CLASP | Colombia | 2024* |
| 10 | Radim Čermák | Thermo King | Czech Republic | 2024* |
| 11 | Yu Chen | TRANSICOLD | USA | 2024* |
| 12 | Daniel Colbourne | Re-Phridge Ltd. | UK | 2024* |
| 13 | Sukumar Devotta | Independent Expert | India | 2024* |
| 14 | Hilde Dhont | Daikin Europe | Belgium | 2024* |
| 15 | Gabrielle Dreyfus | IGSD | USA | 2024* |
| 16 | Bassam Elassaad | Independent Expert | Lebanon | 2024* |
| 17 | Kylie Farrelley | Refrigerant Reclaim Australia | Australia | 2024* |
| 18 | Qiang Gao | Sanhua Group | China | 2024* |
| 19 | Ray Gluckman | Gluckman Consulting Ltd | UK | 2024* |
| 20 | Samir Hamed | Petra Industries | Jordan | 2024* |
| 21 | Herlin Herlianika | Independent Expert | Indonesia | 2024* |
| 22 | Yuki Kamioka | Daikin Japan | Japan | 2024* |
| 23 | Michael Kauffeld | Karlsruhe Univ. of A.S. | Germany | 2024* |
| 24 | Mary Koban | Chemours | USA | 2024* |
| 25 | Juergen Kohler | University of Braunscheig | Germany | 2024* |
| 26 | Steve Kujak | TRANE | USA | 2024* |
| 27 | Lambert Kuijpers | A/gent b.v. Environmental Consultant | Netherlands | 2024* |
| 28 | Richard Lawton | Cambridge CRT | UK | 2024* |
| 29 | Tingxun Li | Guangzhou Sun Yat Sen U. | China | 2024* |
| 30 | Carloandrea Malvicino | Stellantis | Italy | 2024* |
| 31 | Mary Najjuma | Independent Expert | Uganda | 2024* |
| 32 | Petter Nekså | SINTEF Energy Research | Norway | 2024* |
| 33 | M. Alaa Olama | Olama Consultants | Egypt | 2024* |
| 34 | Tetsuji Okada | JRAIA | Japan | 2024* |

| | | | | |
|---|---|---|---|---|
| 35 | Pallav Purohit | International Institute for Applied System Analysis | India | 2024* |
| 36 | Madi Sakande | New Cold System | Burkina Faso | 2024* |
| 37 | Tao Ren | Qingdao Haier Air Con. Electronics | China | 2024* |
| 38 | Giorgio Rusignuolo | Carrier | USA | 2024* |
| 39 | Leyla Sayin | Centre for Sustainable Cooling, University of Birmingham | Turkey | 2024* |
| 40 | Nihar Shah | Lawrence Berkeley National Laboratory | India | 2024* |
| 41 | Andrea Voigt | Danfoss | Germany | 2024* |
| 42 | Asbjørn L. Vonsild | Vonsild Consulting | Denmark | 2024* |
| 43 | Christian M. Wisniewski | US Environmental Protection Agency | USA | 2024* |
| 44 | Samuel Yana Motta | Oak Ridge National Laboratory | Peru | 2024* |

** Indicates members whose terms expire at the end of 2024.*

# Annex 6: 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 2024.

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, non-governmental organisations (NGOs) or other organisations."

TEAP has identified its current needed expertise for Senior Experts in the matrix provided below.

**Table A6.1 TEAP Matrix of needed expertise**

| 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.<br><br>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 |
| **FTOC** | 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 |
| **FSTOC** | Use of HFCs and Alternatives | South America, Middle East and Africa (2) |
| | Use of halons and alternatives in merchant shipping and recovery from shipbreaking | India, Pakistan |
| | Nuclear power plants | A5 and non-A5 |
| | Civil Aviation, (esp. Maintenance, Repair and Overhaul activities) | A5 and non-A5 |
| | Halon and HFC recycling | A5 and non-A5 |
| | Halon 1301 feedstock use and emissions | A5 and non-A5 |
| **MBTOC** | 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 |
| **MCTOC** | Aerosols manufacturing | China, Indonesia, Latin America |
| | CTC and VSLS global manufacturing and use | A5 or non-A5 |
| | Semiconductor and other electronics manufacturing | East Asia, non-A5 |
| | End-of-life management and destruction technologies | A5 and non-A5 |
| | Metered dose inhalers | A5 and non-A5 |
| **RTOC** | Experts with extensive experience on Industrial Refrigeration, both for the food and pharma cold-chain and for other industrial applications. | A5 and non-A5 |

Currently, TEAP has five Senior Experts whose terms end in 2024. 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 7: Nomination form

| TEAP: Nomination Form |
|---|

**For reference the link to the standard nomination form is available on the TEAP webpage at: https://ozone.unep.org/science/assessment/teap**

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'

**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 or No**

*Has TEAP been consulted on this nomination?*

**Yes or 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 (i.e., funding for their time). Members from A5 parties may be funded for their travel (flight) and per diem (United Nations Daily Subsistence Allowance) 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. TEAP members, including TOC co-chairs, 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.

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

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

Once appointed, members of TEAP, TOCs or TSBs provide a "Declaration of Interest" (DOI) at least once a year and prior to the relevant group's first meeting or beginning of the group's substantive work for the year (i.e., review of first-order draft reports). Members provide updated DOIs within 30 days of any material changes. The DOIs are posted on the Ozone Secretariat website.

# Annex 8: TEAP planned reports 2024-2026

| *Year* | *Issue* | *Request by parties to TEAP* | *Reports to be produced* |
|---|---|---|---|
| **2024** | **Progress update** | | |
| | Technical progress update by TEAP and its TOCs | **Decision IV/13** – Report annually to OEWG on technical progress in reducing the use and emissions of controlled substances and assess the use of alternatives, particularly their direct and indirect global-warming effects | May 2024 progress report |
| | | **Decision XI/17** – Report on any important new developments | |
| | Procedures relevant to nominations to the TEAP and its TOCs | **Decision XXXI/8** – 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 | May 2024 progress report |
| | **Thematic** | | |
| | Critical-use nominations | **Decision IX/6** – Review nominations for critical use exemption of methyl bromide and make recommendations based on the criteria established in the decision (and other relevant decisions) | May 2024 interim report<br><br>Planned September 2024 final report |
| | Essential-use nominations | **Decision IV/25** – Review any submitted nominations and make recommendations in accordance with the criteria established in the decision | 2024 progress report *(only upon submission of nominations)* |
| | Review related to the Kigali Amendment to the Montreal Protocol | **Decision XXVIII/2, paragraph 5** – Conduct a technology review four or five years before 2028 to consider a compliance deferral of two years from the freeze date of 2028 for Article 5, group 2, parties to address growth above a certain threshold in several sectors[a] | May 2024 progress report |

| *Year* | *Issue* | *Request by parties to TEAP* | *Reports to be produced* |
|---|---|---|---|
| | HFC-23 emission | **Decision XXXV/7, paragraph 2** – Prepare a report for the 36th MOP containing information regarding; (a) The quantity of HFC-23 being consumed, by country and by sector; (b) Provide updated estimates on the amounts of HFC-23 generated at and emissions from HCFC-22 production facilities including methodology with respect to such emissions. In preparing this information, the Technology and Economic Assessment Panel should take into account information reported under paragraph 3 ter of Article 7 by all parties that manufacture Annex C, Group I and/or Annex F substances as well as information from other sources | Planned September 2024 report |
| | Feedstock uses | **Decision XXXV/8** – Provide, in cooperation with the SAP as appropriate, an update on the emissions from feedstock production, as by-product and from feedstock use of controlled substances including the following: (a) Sources of such emissions, including percentage increases with respect to increased production of controlled substances to be used for feedstock applications; (b) A comparison of estimates of annual global emissions of controlled substances by species based on bottom-up calculations and estimates made by the Scientific Assessment Panel on the basis of atmospheric observations; (c) Methodology adopted for estimating the emissions; (d) Updated information on alternatives, including information on technical feasibility, economic viability, safety and sustainability; (e) Information on best practices and technologies for minimising emissions. | May 2024 progress report |
| | Carbon tetrachloride emissions | **Decision XXXV/9** – Provide, in consultation with the SAP, an update on the emissions of carbon tetrachloride including the following: (a) Emissions by source categories, including emissions as a percentage of total production of carbon tetrachloride with a description of the methodology used by the Panel; (b) Updated information on alternatives for carbon tetrachloride use as feedstock applications including information on technical feasibility, economic viability, safety, and sustainability; (c) Updated information on best practices and technologies, for minimising carbon tetrachloride emissions. | May 2024 progress report |
| | Energy efficiency | **Decision XXXV/10** – Provide updates on the information identified in paragraph 1 (a) of Decision XXXIV/3, taking into account discussions at the 35th MOP.<br><br>**Decision XXXIV/3, paragraph 1(b)** - 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. | May 2024 progress report |

| *Year* | *Issue* | *Request by parties to TEAP* | *Reports to be produced* |
|---|---|---|---|
| | Very short-lived substances | **Decision XXXV/6** – Provide, in cooperation with SAP, for consideration by the 46th OEWG: (a) updated information on very short-lived substances, including their ozone-depleting potential and the impact of each of the very short-lived substances on the stratospheric ozone layer in quantifiable terms, (b) Information on alternatives to very short-lived substances in the main applications for which they are currently used, including on availability, technical feasibility, economic viability, safety and sustainability. | May 2024 progress report |
| | Life-cycle refrigerant management | **Decision XXXV/11, paragraph 1** – Prepare a report to be presented at the 46th OEWG on: (a) Available technologies for the leakage prevention, recovery, recycling, reclamation and destruction of refrigerants, and their accessibility in parties operating under paragraph 1 of Article 5 of the Montreal Protocol, including regionally specific approaches; (b)The obstacles and challenges associated with the effective leakage prevention, recovery, recycling, reclamation and destruction of refrigerants; (c)The costs and climate and ozone benefits associated with the leakage prevention, recovery, recycling, reclamation and disposal of refrigerants, taking into account the experience under the Multilateral Fund for the Implementation of the Montreal Protocol; (d) Policies, incentive schemes, such as producer's responsibility schemes, good practices and lessons learned related to ensuring the effective leakage prevention, recovery, recycling, reclamation and disposal of refrigerants. | May 2024 Task Force report |
| | Laboratory and analytical uses of controlled substances | **Decision XXXI/5** – Report in the TEAP quadrennial report on any progress made by parties in reducing their production and consumption of ozone depleting substances for laboratory and analytical uses, on any new alternatives to those uses, and on laboratory standards that can be performed without such substances, on the understanding that, should new compelling information become available, including opportunities for significant reductions in production and consumption, that information should be reported in its annual progress report | May 2024 progress report |
| | Process agents | **Decision XXXI/6** – Report in the TEAP quadrennial reports on any progress made by parties in reducing their use and emissions of controlled substances as process agents and on any new alternatives to such uses, including new production processes and emissions-reduction techniques, on the understanding that should new compelling information become available, that information should be reported in its annual progress report | May 2024 progress report |
| | Process agents; destruction technologies; laboratory and analytical uses; n-propyl bromide; possible new substances[b] | Review only if the specific conditions set out in decision XXX/15 are met[c] | |
| | | Number of reports to be produced in 2024: | 5 |

| *Year* | *Issue* | *Request by parties to TEAP* | *Report anticipated to be produced* |
|---|---|---|---|
| **2025** | **Progress update** | | |
| | Technical progress update by TEAP and its TOCs | **Decision IV/13** – Report annually to OEWG on technical progress in reducing the use and emissions of controlled substances and assess the use of alternatives, particularly their direct and indirect global-warming effects | 2025 progress report |
| | | **Decision XI/17** – Report on any important new developments | |
| | Procedures relevant to nominations to the TEAP and its TOCs | **Decision XXXI/8** – 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 | 2025 progress report |
| | **Thematic** | | |
| | Critical-use nominations | **Decision IX/6** – Review nominations for critical use exemption of methyl bromide and make recommendations based on the criteria established in the decision (and other relevant decisions) | 2025 interim report *(only upon submission of nominations)*<br><br>2025 final report *(only upon submission of nominations)* |
| | Essential-use nominations | **Decision IV/25** – Review any submitted nominations and make recommendations in accordance with the criteria established in the decision | 2025 progress report *(only upon submission of nominations)* |
| | Energy efficiency | **Decision XXXIV/3, paragraph 1(b)** - 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. | 2025 progress report |

| *Year* | *Issue* | *Request by parties to TEAP* | *Report anticipated to be produced* |
|---|---|---|---|
| | Laboratory and analytical uses of controlled substances | **Decision XXXI/5** – Report in the TEAP quadrennial report on any progress made by parties in reducing their production and consumption of ozone depleting substances for laboratory and analytical uses, on any new alternatives to those uses, and on laboratory standards that can be performed without such substances, on the understanding that, should new compelling information become available, including opportunities for significant reductions in production and consumption, that information should be reported in its annual progress report | 2025 progress report *(only if new compelling information becomes available)* |
| | Process agents | **Decision XXXI/6** – Report in the TEAP quadrennial reports on any progress made by parties in reducing their use and emissions of controlled substances as process agents and on any new alternatives to such uses, including new production processes and emissions-reduction techniques, on the understanding that should new compelling information become available, that information should be reported in its annual progress report | 2025 progress report *(only if new compelling information becomes available)* |
| | Process agents; destruction technologies; laboratory and analytical uses; n-propyl bromide; possible new substances[b] | Review only if the specific conditions set out in decision XXX/15 are met[c] | |
| | | Indicative number of expected reports in 2025: | 1-3* |

* NOTE: While 2025 indicates a potentially lower number of expected reports from standing decisions, TEAP anticipates a significant part of its workload in 2025 will be to plan for and begin development of the substantial number of reports due in 2026, including the quadrennial assessment and study on replenishment of the MLF.

| *Year* | *Issue* | *Request by parties to TEAP* | *Report produced* |
|---|---|---|---|
| **2026** | **Progress update** | | |
| | Technical progress update by TEAP and its TOCs | **Decision IV/13** – Report annually to OEWG on technical progress in reducing the use and emissions of controlled substances and assess the use of alternatives, particularly their direct and indirect global-warming effects | 2026 progress report |
| | | **Decision XI/17** – Report on any important new developments | |
| | Procedures relevant to nominations to the TEAP and its TOCs | **Decision XXXI/8** – 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 | 2026 progress report |
| | **Thematic** | | |
| | Critical-use nominations | **Decision IX/6** – Review nominations for critical use exemption of methyl bromide and make recommendations based on the criteria established in the decision (and other relevant decisions) | 2026 interim report *(only upon submission of nominations)*<br><br>2026 final report *(only upon submission of nominations)* |
| | Essential-use nominations | **Decision IV/25** – Review any submitted nominations and make recommendations in accordance with the criteria established in the decision | 2026 progress report *(only upon submission of nominations)* |
| | Energy efficiency | **Decision XXXIV/3, paragraph 1(b)** - 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. | 2026 progress report |
| | Laboratory and analytical uses | **Decision XXXI/5** – Report in the TEAP quadrennial report on any progress made by parties in reducing their production and consumption of ozone depleting substances for laboratory and analytical uses, on any new alternatives to those uses, and on laboratory standards that | TEAP 2026 quadrennial assessment report *(6)* |

| | | | |
|---|---|---|---|
| | | can be performed without such substances, on the understanding that, should new compelling information become available, including opportunities for significant reductions in production and consumption, that information should be reported in its annual progress report | |
| | Process agents | **Decision XXXI/6** – Report in the TEAP quadrennial reports on any progress made by parties in reducing their use and emissions of controlled substances as process agents and on any new alternatives to such uses, including new production processes and emissions-reduction techniques, on the understanding that should new compelling information become available, that information should be reported in its annual progress report | TEAP 2026 quadrennial assessment report *(6)* |
| | Process agents; destruction technologies; laboratory and analytical uses; n-propyl bromide; possible new substances[b] | Review only if the specific conditions set out in **decision XXX/15** are met[c] | |
| | **Periodic assessment** | | |
| | Replenishment study for 2027-2029 | Expected decision at the 37th MOP, in 2025, and potential additional guidance by OEWG (48th meeting) in 2026 – Prepare a report on the appropriate level of the 2027–2029 replenishment of the Multilateral Fund | Replenishment task force report *(2027–2029)*<br><br>Supplement to the replenishment task force report |
| | Quadrennial assessment | **Decision XXX/3** - Prepare the TEAP 2026 quadrennial assessment<br><br>**Decision XXXIV/3, paragraph 1(b)** - 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. | TEAP 2026 quadrennial assessment report *(6)* |
| | HFCs not listed in Annex F of the Montreal Protocol | **Decision XXIX/12** – Provide in the quadrennial reports of the assessment panels to be presented to the 35th MOP, in 2023, and every four years thereafter, information on the consumption and production of HFCs not listed in Annex F of the Protocol that have global | TEAP 2026 quadrennial assessment report *(6)* |

| | | | |
|---|---|---|---|
| | | warming potential no less than the lowest global warming potential of the HFCs listed in Annex F | |
| | HCFC availability | **Decision XXX/2** – Provide in its quadrennial reports to be presented to the 35th MOP, in 2023, and to the 39th MOP, in 2027, information on the availability of Annex C, group I, substances, including amounts available from recovery, recycling and reclamation, and best available information on country-level and total known stocks, as well as the availability of alternative options for the applications described in Article 2F, paragraphs 6 (a) and 6 (b) | TEAP 2026 quadrennial assessment report *(6)* |
| | | Indicative number of expected reports in 2026: | 9-11 |

[a] In case the review in response to decision XXVIII/2, para. 5, is conducted four years before 2028.

[b] The provisions of decision XXX/15 regarding process agents and laboratory and analytical uses are superceded by decisions XXXI/6 and XXXI/5, respectively. The process of dealing with possible new substances is set out in decision IX/24.

[c] Reports to be produced on the listed issues are not indicated herein given that the time at which the respective conditions set out in decision XXX/15 will be met is not known.